Connected Vehicle Pilot Deployment Program Phase 2

Updated Performance Measurement and Evaluation Support Plan – Wyoming

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Notice

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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 and roadside alerts to parking notifications, amongst others. 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 1 includes the planning for the CV pilot including the concept of operations development. Phase 2 is the design, development, and testing phase. Phase 3 includes a real-world demonstration of the applications developed as part of this pilot.

This document presents the Phase 2 updated 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.

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1 Introduction

1.1 Project Scope

Wyoming is one of the first wave of 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 leverage dedicated short-range communications (DSRC) for vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and infrastructure-to-vehicle (I2V) communication 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. I-80 is a major corridor for east/west freight in the northwest part of the country, supporting the movement of over 32 million tons of freight per year (at 16 tons per truck). Truck volume ranges from 30 to 55% of the total traffic stream on an annual basis, with seasonal rises that can make up as much as 70% of the traffic stream. Furthermore, its elevation is all above 6,000 feet, with the highest point reaching 8,640 feet (2,633 m) above sea level at Sherman Summit.

For the pilot project, WYDOT concluded Phase 1 (planning) in September 2016 and then initiated Phase 2 (deployment) which is scheduled to conclude in August 2018. This will be followed by an 18-month demonstration period in the third phase. Systems and applications developed in the pilot will enable drivers of connected vehicles to have improved awareness of potential hazards and of situations they cannot see. At a very high level, the pilot scope includes the following implementation elements:

- **Deploy 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 are planned to be heavy trucks. All vehicles are expected to be regular users of I-80. Several types of OBUs 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 I2V applications** that will enable communication to drivers of 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 ingesting more location specific mobile road weather information

system (RWIS) data, using Pikalert®[1] to provide for more accurate and road segment specific conditions to define better variable speed limits (VSLs), and improving road condition dissemination via 511, Dynamic Message Signs (DMS) and other WYDOT sources.

Please refer to other Wyoming CV Pilot Deployment documents identified in Section 3 for additional pertinent information about the system design, data collection, and pre-deployment condition analyses.

1.2 Purpose of this Performance Measurement and Evaluation Plan

The WYDOT CV Pilot team will measure the system performance and impacts to the commercial vehicle operators and other travelers of I-80. Additionally, these activities will provide essential input to WYDOT to improve the system and determine future enhancements beyond the Pilot. During Phase 1, the Wyoming team developed a Performance Measurement and Evaluation Support (PMES) Plan to define the measures, evaluation designs and data needs. During Phase 2, the Wyoming CV Pilot has been designed, built and tested. This effort has provided significant insight into data availability and evaluation design approaches to support performance measurement. This document is an update to the Phase 1 PMES Plan. Although the performance measures have not changed, important details regarding how we plan to conduct analyses for each performance measure is provided herein.

In addition to the Wyoming CV Pilot team's performance measurement activities, the FHWA has established an Independent Evaluation (IE) team who 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 with the IE team 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, identified by the IE, where available.

1.3 Document Overview

This document is an update of the Phase 1 Performance Measurement and Evaluation Support Plan. As such, it identifies and describes the updated 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.

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

- Section 2 provides information on the references used to develop this document.

[1] Pikalert is a trademark of the University Corporation for Atmospheric Research.

- Section 3 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 4 identifies the project confounding factors and mitigation approaches that will affect the approaches used to conduct the evaluations.
- Section 5 defines the system performance and impact evaluation designs for each of the measures described in Section 3.
- Section 6 describes our approaches to performance management, including data collection and management, support to the Independent Evaluator, and system performance reporting.
- Section 7 explains the roles and responsibilities of the project partners.
- Section 8 provides the schedule for performance measure and evaluation support activities.
- Section 9 provides a summary of our conclusions.

This document is considered the final PMES Plan that will be used by the Wyoming CV Pilot team to measure the system performance and impacts during Phase 3 – Pilot Demonstration.

2 References

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

Table 2-1. References.

#	Documents, Sources Referenced
1	Deepak Gopalakrishna, et al. (2015a). *Connected Vehicle Pilot Deployment Program Phase 1, Concept of Operations (ConOps), ICF/Wyoming*. U.S. Department of Transportation.
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11	Tony English, et al., (2017) *Connected Vehicle Pilot Deployment Program Phase 2 Data Management Plan – Wyoming (FHWA-JPO-17-470).* U.S. Department of Transportation.

12 Fred Kitchener, et al., (2016) *Connected Vehicle Pilot Deployment Program Phase 1, Performance Measurement and Evaluation Support Plan v2 – ICF/Wyoming (FHWA-JPO-16-290).* U.S. Department of Transportation.

13 Tony English, et al., (March 16, 2018) *Connected Vehicle Pilot Deployment Program Phase 1 System Requirements Specification (SyRS), Version 8 – WYDOT (FHWA-JPO-16-291).* U.S. Department of Transportation.

14 Tony English, et al., (March 16, 2018) *Connected Vehicle Pilot Deployment Program Phase 2 System Design Document (SDD) – Wyoming CV Pilot (FHWA-JPO-17-468).* U.S. Department of Transportation.

15 Tony English, et al., (March 16, 2018) *Connected Vehicle Pilot Deployment Program Phase 2 Interface Control Document (ICD) – WYDOT CV Pilot (FHWA-JPO-17-468).* U.S. Department of Transportation.

3 Critical Performance Measures and Targets

3.1 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 on-board and traffic management applications that will be developed as part of the Wyoming CV Pilot. Table 3-1 links the general benefits to the application and beneficiaries, namely the agencies and users of the system.

Table 3-1. Agency and User Benefits.

Application	Agency			User			
	WYDOT	Fleet Management	Other	Maintenance Vehicle	Integrated Truck	Retrofit Vehicle	Highway Patrol
1. Forward Collision Warning	-	-	-	Improved safety through real-time warning of an impending front-end collision with a connected vehicle ahead.			
2. I2V Situational Awareness	-	-	-	Improved safety through (near) real-time wide area alerts of conditions in the downstream roadway or planned route.			
3. Distress Notification	-	-	-	Improved safety through automated and/or manual incident involvement notification or relay of information.	Improved safety through automated and/or manual incident involvement notification or relay of information.	-	Improved safety through manual incident involvement notification or relay of information.
4. Work Zone Warnings	-	-	-	Improved safety through (near) real-time notification of unsafe work zones at specific points on the downstream roadway.			
5. Spot Weather Impact Warning	-	-	-	Improved safety through (near) real-time notification of unsafe conditions or road closure at specific points on the downstream roadway.			
6. Other Traffic Mgmt. and Traveler Information Applications	Increased coverage of road condition reports and improved dissemination capability of more accurate information, including more efficient VSL and Traveler Information strategies.	Near real-time notification of implemented road weather management strategies and conditions for optimized scheduling and route planning.	Improved notifications of implemented road weather management strategies and conditions.	-	-	-	-

3.2 Performance Measures and Targets

The WYDOT CV Pilot Team has identified 21 potential improvements in efficiency, safety, and mobility performance offered by this Pilot Deployment. These 21 performance measures are organized in eight (8) performance categories as shown in Figure 3-1. These eight performance categories focus represent the primary activities and outcomes of the Wyoming CV Pilot system, including data collection, information dissemination, alerts, and advisories shared between vehicles and roadside, improved speed adherence and reduced crash rates. 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.

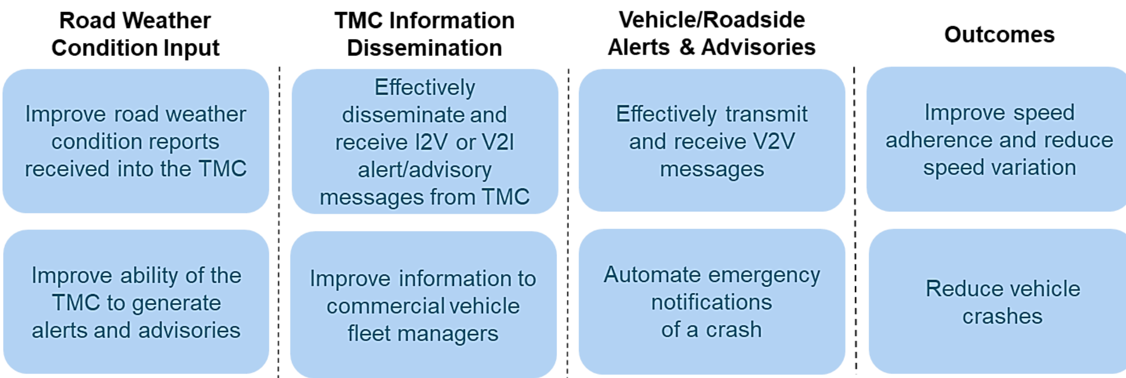

Figure 3-1. WYDOT CV Pilot Performance Measurement Categories (Source: WYDOT).

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 performance measures and associated targets have been reviewed during Phase 2 and only slight changes made. Table 3-2 summarizes the proposed performance measures and targets which will guide the evaluation of the Wyoming CV Pilot project. In addition to these specific performance measures, lessons learned will be documented and reported in the Phase 3 reports.

Table 3-2. 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 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 rejected by TMC operators as inaccurate	<10% rejected
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 traditional methods)	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 posted speed (compare before and after CV Pilot)	20% improvement over baseline of total vehicles traveling within +/- 10 mph of the posted speed during CV Pilot. Baseline will determine what percent is traveling within +/-

		10 mph of posted 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
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

3.3 Relationship of Performance Measures to System Applications

The Wyoming CV Pilot is focusing on six system applications. 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 3-3 illustrates the mapping of performance categories and measures to system applications.

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

Performance Measures		System Applications					
Category	**Measures**	**Forward Collision Warning**	**I2V Situational Awareness**	**Distress Notification**	**Work Zone Warnings**	**Spot Weather Impact Warning**	**Traffic Mgmt. and TI Applications**
Improve road weather conditions reports received into TMC.	1, 2, 3						X
Improve ability of the TMC to generate alerts and advisories.	4		X			X	X
Effectively disseminate and receive I2V and V2I	5, 6, 7		X	X	X	X	X

[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).

alert/advisory messages from TMC.							
Improve information to commercial vehicle fleet managers.	8, 9, 10						X
Effectively transmit and receive V2V messages.	11, 12	X		X			
Automated emergency notifications of a crash.	13			X			X
Improve speed adherence and reduce speed variation.	14, 15, 16		X		X		X
Reduced vehicle crashes.	17, 18, 19, 20, 21	X	X	X	X	X	X

3.4 Pre-Deployment (Baseline) Conditions Established

Extensive efforts were conducted during Phase 2 to establish our Pre-Deployment (baseline) conditions. The results of these efforts are documented in our *Final System Performance Report, Baseline Conditions*. The following performance measures established baseline conditions.

- PM 1-3 – Road weather condition reports (quantity, coverage, and latency)
- PM 8-9 – Commercial vehicle managers' satisfaction with TMC provided information and use of that information in terms of operational changes made (survey)
- PM 10 – Commercial vehicle driver understanding and use of CV technologies (survey)
- PM 14-15 – Vehicle speed adherence (truck and car)
- PM 18-21 – I-80 crashes and rates (truck and car), separating critical crashes (fatal or incapacitating)

The baseline data collection period was one of the most severe on record, especially the number and intensity of strong wind events in the corridor. Fifty-six (56) separate significant winter weather events were documented between December 2016 and November 2017. These weather events resulted in extensive use of variable speed limit systems and dynamic message signs, constant updates of the Wyoming traveler information system and the commercial vehicle operator portal, and numerous road closures. Of the crashes in this period, over 17% were blown over trucks due to extreme strong winds. Additionally, there were 7 fatalities. Indeed, this was a very impactful baseline winter season on the traveling public and commercial vehicle operators.

The primary focus of the Wyoming Connected Vehicle Pilot is to improve safety in the I-80 corridor. The analysis of historical and current speed adherence and crash data presented herein provides some early insight into how connected vehicle technology may achieve this goal of improved safety. For instance:

- During this baseline data collection period for all weather conditions, about 14.2% of vehicles are currently traveling 5 mph above the post speed (speed adherence is good) and a 29.6% of the vehicles are traveling outside a +/- 10 mph buffer (speed variation is moderate). For certain severe storm conditions, like ice and high winds (storm category 6), the compliance rate drops to 53.4% and the speed buffer to 45%. These conditions can translate or contribute to the number of crashes and crash severity. We anticipate an improvement in these values through CV-technologies to improve Situational Awareness (TIM messages) regarding posted speeds, especially in variable speed limit (VSL) areas. Additionally, the VSL systems and dynamic message signs (DMS) will have more accurate and timely information based on improved and expanded data collection and enhanced analysis from Pikalert.

- 1,310 crashes were recorded from October 2016 through May 2017. Weather conditions existing during the crashes included clear (48%) and snowing (21%). Road conditions existing during the crashes included ice/frost (39%), dry (36%) and snow (15%). We believe CV-enabled technologies can help to reduce the number of crashes during all conditions. Forward Collision Warning can help avoid a crash in any condition. Spot Weather Impact Warnings can alert a driver to poor weather or road conditions resulting in an avoided crash. Improved driver Situational Awareness through TIM messages can also result in an avoided crash, especially during inclement weather and hazardous road conditions.
- Historically, about 30% of crashes on I-80 are multi-vehicle crashes, which include some events with tens of vehicles involved. Our goal is to reduce the number of secondary crashes by using CV technologies to alert drivers of a crash ahead so they can stop earlier or otherwise avoid becoming a crash victim. Further, these crashes can be the reason a section of I-80 need to be closed. During the data collection period from October 2016 through May 2017, a cumulative total of 3,632 hours of closures on 52 road closure segments were issued. We anticipate that implementation of CV applications such as Forward Collision Warning, Distress Notification, Work Zone Warnings, and in-vehicle TIM messages have the potential to reduce the number of vehicles in a crash by warning the driver of a crash just ahead.
- Since 2010, 553 critical injury crashes have resulted from crashes on I-80. Of those, 132 fatal crashes occurred. Through implementation of CV technologies mentioned above, we believe we have the potential to significantly reduce these numbers either by drivers avoiding a crash all together or speeds being reduced during a crash.

4 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

4.1 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. The field data will first be used to calibrate the micro-simulation model; then, various CV technology penetration rates will be coded into the micro-simulation model to simulate and evaluate the system performance under various CV penetration rate scenarios.

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), 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.

4.2 Freight and Passenger Vehicle Demand

The corridor is heavily used by commercial freight trucks, making system performance highly dependent on freight demand. Impacts include 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.

Mitigation Approaches

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.

4.3 CV Technology Adoption

New technology involving a change in the way people conduct operations 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.

Mitigation Approaches

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.

4.4 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]. Use of weather variables and weather storm categories is dependent on the type of evaluation being performed and the level of aggregation necessary for the analyses. Descriptions of these methods can be found in the relevant performance measure description in Section 5.3 of this report.

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 1I*. Wyoming Department of Transportation, FHWA-WY-13/03F. Cheyenne, WY.

4.5 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 that the Wyoming Pilot system design includes messages that are simple to understand and underwent human factors testing prior to final design. The University of Wyoming's driver simulator was used to evaluate 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 a non-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 included 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.).

4.6 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.).

4.7 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 8, indicates that the CV Pilot Demonstration will begin in May 2018 and continue through October 2019. This will allow for only one winter season of data collection, analysis, and reporting.

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 Wyoming team will ensure that the required data collection will be tested and ready to begin in October 2018 so all available data is actually collected.

Additionally, the evaluation designs will be scalable so that, if desired, Wyoming DOT can continue data collection and evaluation activities beyond the Phase 3 project schedule limits.

4.8 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 and to determine if the speed adherence impacts are sustained past the location where the speed signs are posted.

Mitigation Approaches

The location of the speed sensors was pre-determined before the CV Pilot project and were not subject to change with this project. Identification of the sensors relative to the nearest static or variable speed limit sign was all that could be done. The CV Pilot Demonstration will know the speed and location of every connected vehicle on either a 10 HZ or 30 second interval depending on the location (near and RSU or not) and the time since a TIM has been received. This data provides insight into continuous speed behavior of connected vehicles.

4.9 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

The Wyoming system design team selected equipment whose specs can accommodate these harsh environments. During the performance measurement evaluation, analysis will be conducted to determine the actual mean time between failure (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.

5 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 3.

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.

5.1 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 Security Management Operating Concept (SMOC) (Gopalakrishna, D. et al., 2015b).

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 seven evaluation design types are anticipated for use during the evaluation activities (Phase 3). 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.

5.1.1 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. Our baseline conditions were established during Phase 2 (2016-2017 winter season) and will define the benchmarks from which future conditions with CV Pilot project elements in place can be compared. The complete baseline conditions are described in the Wyoming *Final System Performance Report, Baseline Conditions*.

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, speed and crash data, and commercial vehicle managers and drivers current use of road weather condition information and technology. Values for these types 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. Ideally, the before-after performance assessment should compare data during similar weather conditions and the aforementioned system parameters. In terms of simulation modeling analysis, variables will be 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.

5.1.2 With-Without

This technique quantitatively compares data from conditions where CV Pilot project elements are in place and used with conditions where CV Pilot project elements are not present. 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).

5.1.3 System Performance Evaluation

This evaluation will quantitatively assess how well the system worked to provide traveler information messages, 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 and messages sent and number that were actually received, including V2I and V2V applications.

5.1.4 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 exiting 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.

5.1.5 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, commercial vehicle drivers, etc. The qualitative information collected will be used to supplement other pilot outcome data to perhaps better understand why certain things occurred.

5.1.6 Safety Modeling Analysis

Safety modeling analysis of the crash data will be performed to account for weather, geometric, traffic volumes, and other confounding factors. Safety modeling aims to calibrate jurisdiction-specific Safety Performance Functions that are accurate to predict number of crashes over a time period while accounting for various confounding factors. The first step in safety modeling will be the preparation of roadway segmentation, geometric, traffic flow, weather, and crash data. Then, the available roadway, traffic and weather conditions factors will be used to calibrate full Safety Performance Functions for the 402-mile I-80 freeway corridor in Wyoming.

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 the 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 allow 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. Statistical analysis techniques, such as the Negative Binomial models, the Bayesian models, as well as non-parametric techniques

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

will be employed for estimating crash frequencies under different confounding factors such as changes in weather as well as the interactions between weather, traffic, and geometric characteristics.

This evaluation design will support the analysis of PMs 18-21.

5.1.7 Simulation Modeling

In addition to safety modeling analysis of crash data, 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 purpose of simulation modeling is to determine safety and mobility effects of CV Pilot Deployments by controlling for the impacts of confounding factors, and to identify confounding factors and potential strategies for managing them. The draft simulation modeling tasks include: 1) a preliminary review of the literature to summarize the state-of-the-art regarding the performance evaluation of CV technology and applications via microsimulation, 2) steps and data requirements for microsimulation modeling for CV performance evaluation, and software and tools, and 3) plan for Wyoming to identify data availability, and data collection planning to fill any gaps.

A VISSIM and SSAM simulation framework for a representative freeway corridor will be built to determine the suitability of adopting a microscopic simulation approach for providing insight into the safety effectiveness of CV technology under various scenarios. 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 by the end of Phase 2 but it is expected to utilize time to conflict measures as well as number of lane changes and speed variation measures.

The baseline condition simulation model will be calibrated using real-world traffic performance data collected from the selected freeway corridor. Cluster analysis will be employed to identify the required data for modeling calibration; detailed traffic flow data under both normal winter weather condition and adverse weather conditions, as well as summer work zone condition will be collected. The research team will employ the traffic flow and speed data collected by WYDOT's two Wavetronix speed sensors installed at specific I-80 locations for model calibration. Specifically, we will select 2-hour traffic data from one day under normal winter weather condition and other days under two levels of snowy and severe weather conditions. We will first extract the cumulative speed distribution profiles at the selected WYDOT speed sensors, then, manually adjust the speed distribution profiles in VISSIM to match the field observed profiles. After that, we will adjust driver behavior parameters in the VISSIM simulation model. Three micro-simulation models will be calibrated; normal weather condition, snow weather condition, and severe weather condition, respectively. The simulated traffic flow and speed profiles will be compared against field collect data; statistical tests, including the GEH test and Mean Absolute Percent Error (MAPE) will be employed to verify the differences between simulation results and field data; it is expected that GEH value should be less than 5 and MAPE value less than 5%. For model calibration under connected vehicle environment, since at this stage there are no available traffic flow and safety performance data from the field, the VISSIM model calibration will be based on driver behavior data generated from the CV Pilot Deployment Program – Participant Training and Education, which is expected to be performed at the Driving Simulator Lab, University of Wyoming (WYOSIM) during Phase 2 and 3. The calibration of SSAM will also be based on the simulated safety performance data from WYOSIM's high fidelity driving simulator.

This evaluation design will support the analysis of PMs 18-21.

5.2 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 and messages 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, RSU, 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.

5.3 Performance Measurement Details

The performance measurement details will be presented using the organization in Table 3-2. 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.

This updated PMES Plan reflects the revisions to analytical methods developed during the pre-deployment conditions preparation. The evaluation design descriptions below highlight the most current methods being proposed to analyze the performance measures. Additional details of analysis methods to be implemented (where a pre-deployment condition was established) can be found in our *Final System Performance Report, Baseline Conditions*.

The evaluation design descriptions below have also been updated where needed to better explain the methods proposed for performance measures focused on CV-data to be analyzed post-deployment.

5.3.1 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 using CV technologies. This information forms the basis of better messages, 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 section/day (quantity).
2. Number of road sections with at least one reported road condition per hour (coverage).
3. Average refresh time of road condition reporting in each section (latency).

The data collected for these three PMs will be analyzed as a whole and grouped by different weather events. Careful review of the pre-deployment data collected resulted in the following weather event types (see the *Final System Performance Report, Baseline Conditions* for additional details).

- Strong winds only
- Fog, low visibility
- Poor pavement conditions, no strong winds reported
- Poor pavement conditions with strong winds
- Extreme weather conditions with numerous high impact conditions

Comparisons will be made pre- and post- deployment to gain insight into possibly varying results during different weather event types.

5.3.1.1 PM #1: Number of road weather condition reports per road section/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. The target is for a 30% 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 WYDOT snowplow road weather condition reports submitted (baseline and post deployment)

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 calculation will be made by first dividing the total number of reports during a given weather event by the number of unique road reporting sections. Then, dividing that value by the fractional number of days (hours of the weather event divided by 24). The data identified above will be used to make these comparisons and a percent change in road condition reports will be calculated. Data will be analyzed for different weather event types.

5.3.1.2 PM #2: The number of road sections 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 maintenance sections 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. The target is for a 25% increase in the number of road sections 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 WYDOT snowplow road weather condition reports submitted (baseline and post deployment)

Evaluation Design: The before-after evaluation approach will be used to measure the number of road sections with at least one road condition report per hour compared with similar data representing the baseline conditions. The total value per weather event will be calculated by averaging the total number of road sections reported per hour within a given weather event. The data identified above will be mapped to the corridor and against the maintenance operational sections and used to calculate a percent increase in the number of road sections of I-80 with at least one road condition report per hour. Data will be analyzed for different weather event types.

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

Description: Wyoming DOT's goal is for road condition reports in each section to be updated (refreshed) when conditions change. Currently, this is accomplished by DOT maintenance personnel as they are plowing and treating the roadways. During the CV Pilot those data will be enhanced with better equipped snow plows with road reporting tablets. 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 WYDOT snowplow road weather condition reports submitted (baseline and post deployment)

Evaluation Design: The before-after evaluation approach will be used to measure the road condition reporting refresh time in each section compared to the baseline conditions. The value will be calculated by taking an average of all the individual weather event values. The baseline will be established using current TMC logs which document the road condition reports by section. The refresh rate for the baseline and post-deployment cases and comparisons made to calculate the percent change in the refresh rate. Data will be analyzed for different weather event types.

5.3.2 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 motorist alert warnings that reflect current conditions. The following performance measure will be described in greater detail below:

4. Percent of Pikalert generated motorist alert warnings (MAWs) that were rejected by TMC operators as inaccurate.

5.3.2.1 PM #4: Pikalert generated motorist alert warnings (MAWs) that were rejected by TMC operators as inaccurate.

Description: The Pikalert system will generate motorist alert warnings after processing input from several sources. These MAWs 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 MAWs that were rejected by TMC operators because they were deemed inaccurate. The TMC operators will have the ability on their consoles to click a box that reads "inaccurate" next to a MAW presented to them so the data will be available to measure this PM. This performance measure will determine the percent of Pikalert system recommended MAWs that were rejected by TMC operators – with a target of <10% rejected as inaccurate.

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

- Pikalert system logs of recommended MAWs
- TMC logs of those Pikalert system recommendations being rejected by TMC operators

Evaluation Design: The system performance evaluation approach will be used to measure the rejection of Pikalert system generated MAWs by TMC operators. A percent of rejected MAWs will be calculated and reported. The Pikalert MAWs will be contained in a specific database table. Tracking the MAWs rejection by TMC operators will be accomplished in TMC logs. If rejected, an indicator will be appended in a new column in the Pikalert MAW database. The percent of MAW rejection will be calculated from these results. Figure 5-1 illustrates the process and special data query details.

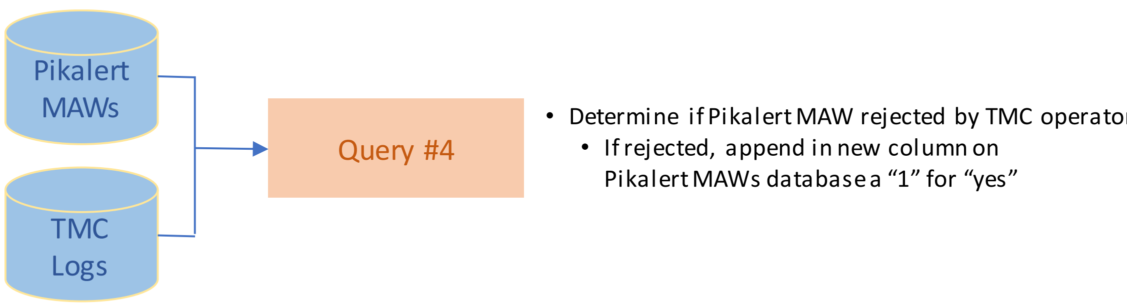

Figure 5-1. CV Data Query Flow to Support PM 4 (Source: WYDOT)

5.3.3 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 three performance measures are contained in this performance category and will be described in greater detail below:

5. Number of messages sent from the TMC that were received by the 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).
7. Connected vehicles that likely took action following receipt of an alert.

5.3.3.1 PM #5: Number of messages 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 messages sent to the RSUs from the TMC. This performance measure will determine the percent of messages that were sent from the TMC that were actually received by the RSUs. This is extremely important to a successful CV system. This evaluation will assess the performance of the system to 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 messages sent by the TMC 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 messages that are received by RSUs. Analysis of the logs identified above will allow the evaluators to follow the messages through the various systems and links to not only determine the percent that reach the intended RSU, but also determine which system operated as designed and which system may have had difficulties in passing along the information properly. In order to make this assessment, data from TMC logs and RSU logs will need to be accessed (queried from the database) and analyzed. Those analyses will track unique message IDs between the TMC and RSU and determine messages that were sent, were also received. Figure 5-2 graphically illustrates the process flow of the activity. It is assumed that specialized data queries will make the calculation of percent that were sent from the TMC were received by the correct RSU and display the success rates in a results table.

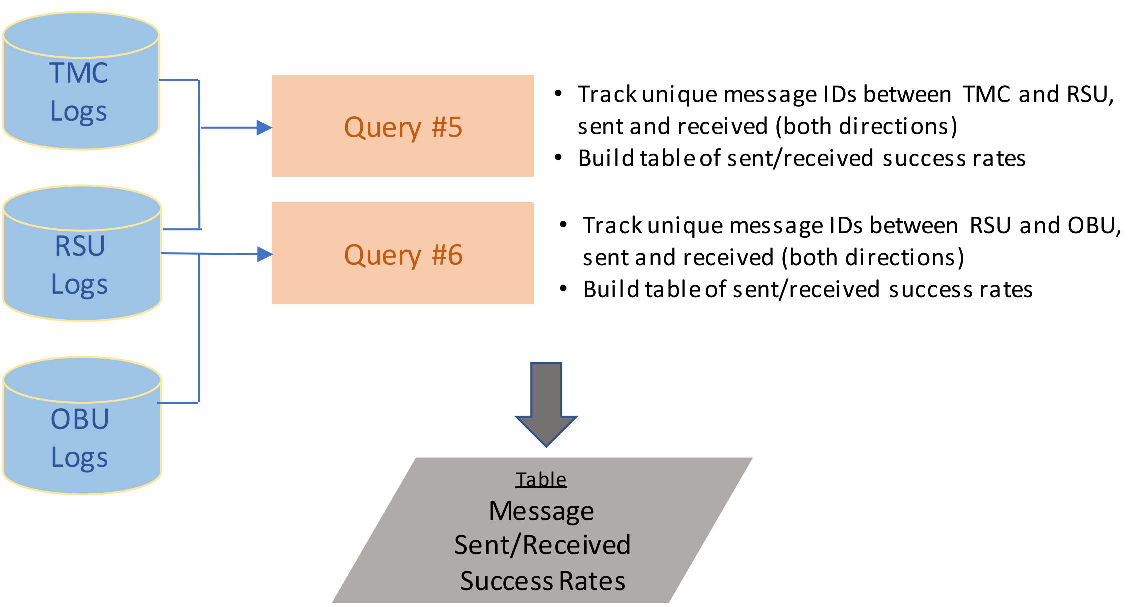

Figure 5-2. CV Data Query Process Flow to Support PMs 5 and 6 (Source: WYDOT)

This process, shown in Figure 5-2, also illustrates the process for PM 6 that follows the calculation of success rates between the RSU and the CV-vehicle OBU.

5.3.3.2 PM #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)

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 messages that were sent from the RSUs were actually received by their designated recipients (WYDOT fleet 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 messages 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
- OBU logs

Evaluation Design: The system performance evaluation approach will be used to measure the percent of sent messages 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. Figure 5-2 above illustrates the CV data query process flow that will support this analysis. This analysis will track unique message IDs between the TMC and RSU and determine messages that were sent, were also received. It is assumed that specialized data queries will make the calculation of percent that were sent from the RSU were received by the designated OBUs and display the success rates in a results table.

5.3.3.3 PM #7: Connected vehicles that likely took action following receipt of an alert

These actions include:

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

Description: 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 a vehicle that exited I-80 related 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 alerts received.

Data Needs: 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

Evaluation Design: The behavior assessment design approach will be used to measure the percent of connected vehicle drivers that likely 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.

To determine the action that a driver took after receiving a TIM requires analysis of the vehicle basic safety messages immediately before and after the alert was revived. The challenge is that some actions are immediately taken such as reducing speed or pulling to the side of the road, while others take much longer to execute such as exiting the roadway or finding parking at the closest parking area. It was determined by the PM team that the best way to determine the actions taken was to create a data “dashboard” where team members could visualize the TIM message and the vehicle dynamics before and after the alert and determine the action(s) taken by the driver on a case-by-case basis. This solution may be used on an interim basis and could be programmed after review of initial cases such that there is data available to “train” an automated system.

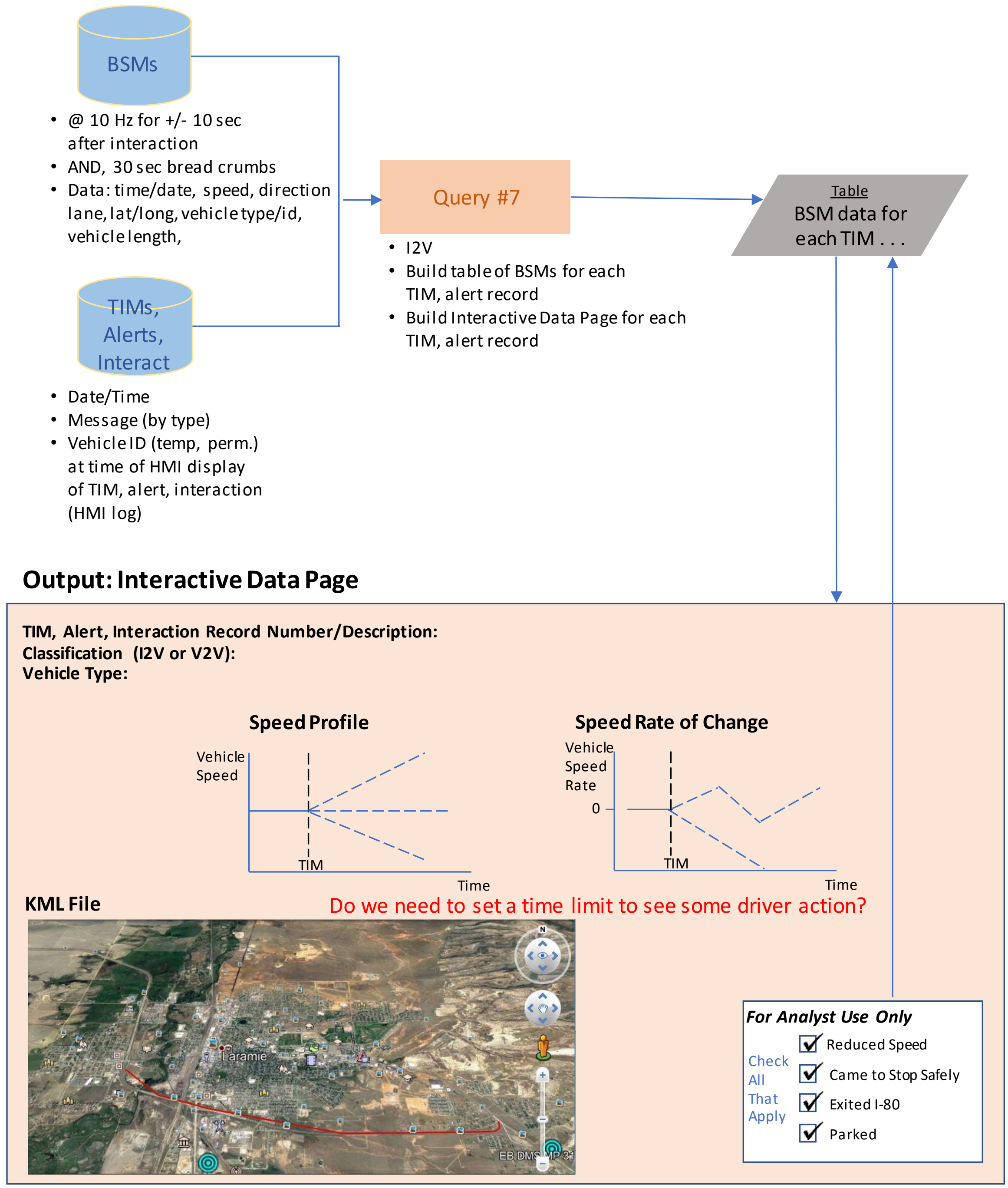

Figure 5-3 illustrates the data flow for the dashboard system. The query to support PM #7 will review the log of TIM's and alerts to create an "event" whenever the logs indicate that an alert or TIM was displayed on a vehicle's HMI. For each of these events, the vehicle BSMs will be pulled for the 10 seconds before the event to a period after the event of 1 hour or until a new alert was displayed on the vehicle HMI, whichever period is shorter. From the table created by this query, an interactive data page or dashboard will be generated for each event. The dashboard will display graphs of the vehicle speed and acceleration/deceleration for the event along with a map view of the vehicle path, which would be used to determine if the vehicle parked or exited the interstate.

After reviewing the information, the analyst would select as many of the driver reactions that are applicable and these results would be stored in the Query #7 event table.

PM #7 is similar to PM #12 except for the events in the PM #12 query event table would be for TIMs that were received from other vehicles as opposed to receiving them from RSUs.

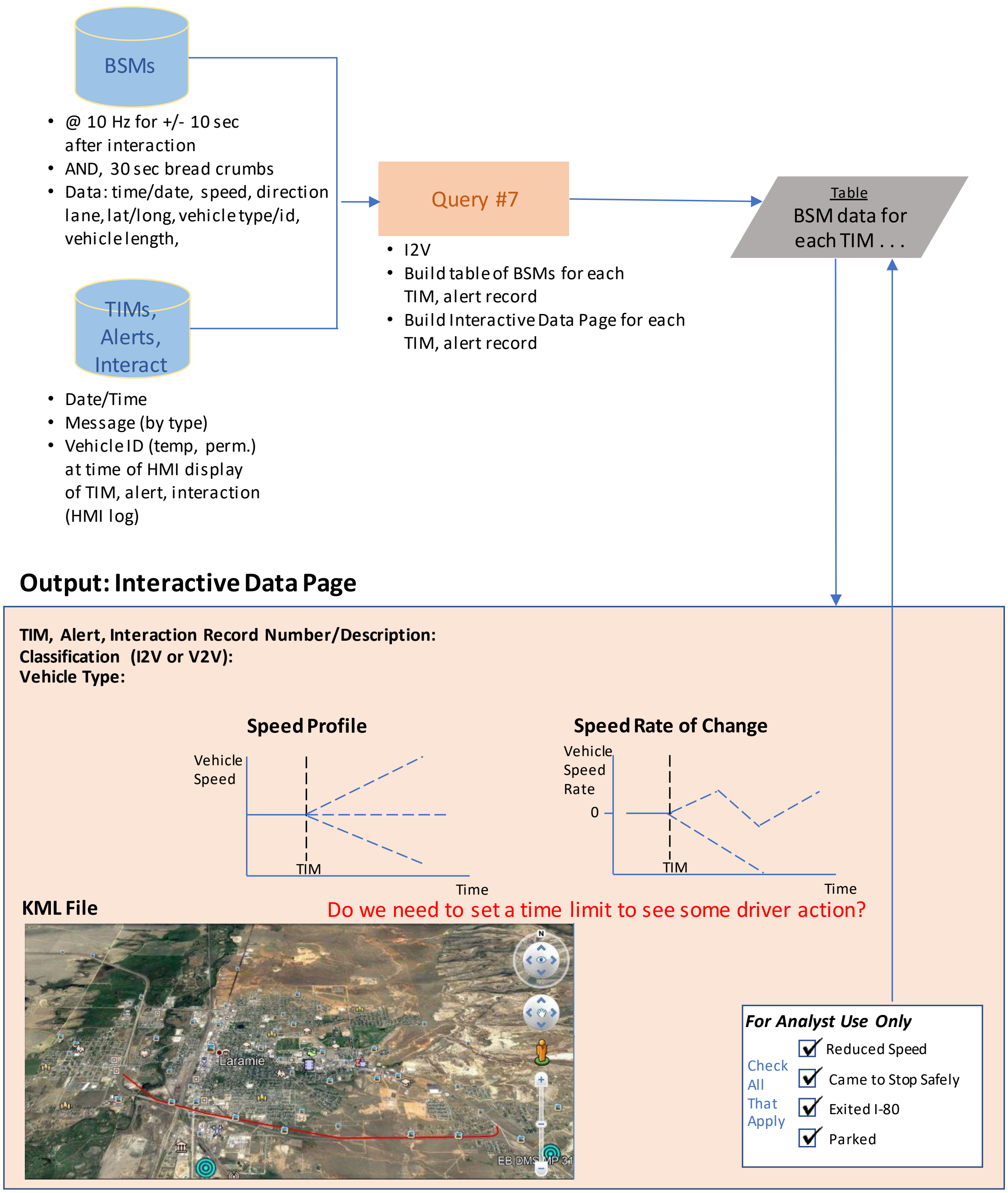

Figure 5-3: Query Tool and Interactive Data Page for PM #7 (Source: WYDOT)

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.

5.3.4 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:

8. Number of operational changes made by fleet managers due to information from the TMC (compare before and after CV Pilot)
9. Commercial vehicle managers are satisfied with information provided by the TMC (compare before and after the CV Pilot)
10. Commercial vehicle drivers experience benefits due to CV technology during major incidents and events on I-80

5.3.4.1 PM #8: Number of operational changes made due to information from TMC (compare before and after the 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
- Survey of fleet managers (from CVOP subscriptions) asking what operational changes were made (type and timing) during major events 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. A description of the baseline data collected to support this PM can be found in our *Final System Performance Report, Baseline Conditions*.

5.3.4.2 PM #9: Commercial vehicle managers are satisfied with information provided by the TMC (compare before and after 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 PM 8 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:

- Surveys received from 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. Baseline surveys will be implemented for use in comparing with the post-deployment surveys. An electronic survey will be developed and available to all CVOP-subscribed commercial vehicle fleet managers in order to learn their impressions and level of satisfaction with the new information. The survey will also focus on what improvements they would suggest in the information to assist them in effectively managing their fleet. A description of the baseline data collected to support this PM can be found in our *Final System Performance Report, Baseline Conditions*.

5.3.4.3 PM #10: Commercial vehicle drivers experienced benefits due to CV technology during major incidents and events on I-80

Description: It will be important to learn about the experiences of the commercial vehicle drivers using the CV technologies during the Pilot. This measure will attempt to survey a subset of drivers to understand how the technologies may have benefited them and what could be improved in the future. For instance, did the CV technologies allow a driver to avoid an incident or safely drive during a major weather event? The participation in the survey will be voluntary and drivers will be recruited through contact with CVOP-subscribed commercial vehicle operators.

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

- Surveys received from the commercial vehicle drivers.

Evaluation Design: The qualitative assessment evaluation approach will be used to understand the benefits and suggested improvements in the CV technologies from commercial vehicle drivers. A baseline survey will be implemented to help establish the conditions of drivers related to basic and CV technology prior to deployment. This baseline survey will be administered to drivers during their CV-system training. An electronic survey will be developed and available to a limited number of commercial vehicle drivers in order to learn their impressions with the new technology. The survey will also focus on what improvements they would suggest in the technology to safely drive their routes. Question topics may include:

- Experience driving a commercial vehicle on I-80
- Familiarization and understanding of technological tools to support safe driving within the I-80 corridor, including connected vehicle technologies

- How traveler information is acquired and used to ensure safe and efficient driving within the I-80 corridor
- Impressions of safety and use of technology, including with and without CV technologies
- Responses to various severe weather conditions when driving within the I-80 corridor
- Benefits of CV technologies

5.3.5 Effectively transmitted and received V2V messages

Section 6.3.3 addressed the effectiveness of 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:

11. V2V messages properly received in surrounding vehicles from sending vehicle (WYDOT fleet vehicles in vicinity of each other)
12. Percent of connected vehicles that likely took action following receipt of a V2V alert

5.3.5.1 PM #11: V2V messages properly received in surrounding vehicles from sending vehicle (WYDOT fleet vehicles in vicinity of each other)

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 (WYDOT vehicles only). 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
- 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 WYDOT fleet connected vehicle) were received by other WYDOT fleet 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. This analysis will track unique message IDs between the RSUs and OBUs and determine messages that were sent, were also received. These calculations will be made by a specialized data query and a results table will be generated to be reviewed by the performance measurement analysts (similar to the process used to analyze PMs 5 and 6). Figure 5-4 illustrates the process proposed.

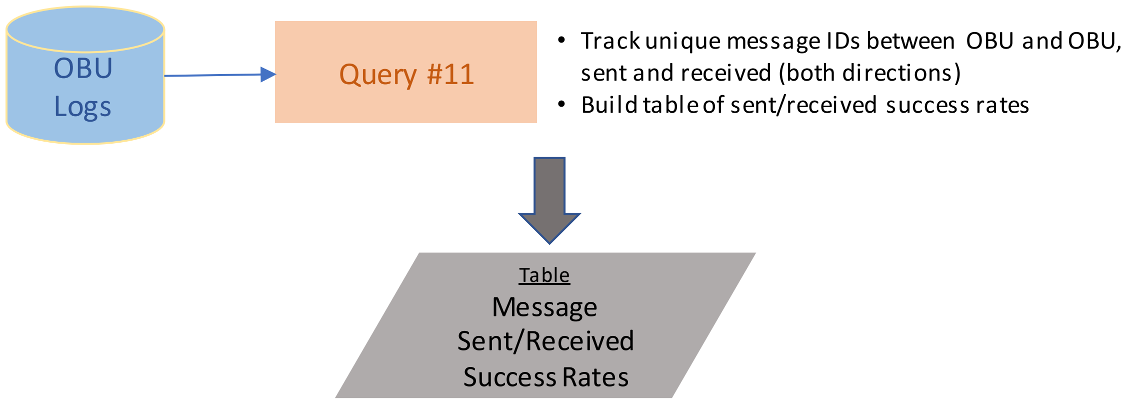

Figure 5-4. CV Data Query Process Flow to Support PM 11 (Source: WYDOT)

5.3.5.2 PM #12: Percent of connected vehicles that likely took action following receipt of a V2V alert

These actions include:

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

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 #7 regarding actions taken from messages 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

Evaluation Design: The behavior assessment design approach will be used to measure the percent of connected vehicle that likely 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.

To determine the action that a driver took after receiving a TIM requires analysis of the vehicle basic safety messages immediately before and after the alert was revived. The challenge is that some actions are immediately taken such as reducing speed or pulling to the side of the road, while others take much longer to execute such as exiting the roadway or finding parking at the closest parking area. It was determined by the PM team that the best way to determine the actions taken was to create a data “dashboard” where team members could visualize the TIM message and the vehicle dynamics before and after the alert and determine the action(s) taken by the driver on a case-by-case basis. This solution may be used on an interim basis and could be programmed after review of initial cases such that there is data available to “train” an automated system.

Figure 5-5 illustrates the data flow for the dashboard system. The query to support PM #12 will review the log of TIM’s and alerts to create an “event” whenever the logs indicate that an alert or TIM was displayed on a vehicle’s HMI. For each of these events, the vehicle BSMs will be pulled for the 10 seconds before the event to a period after the event of 1 hour or until a new alert was displayed on the vehicle HMI, whichever period is shorter. From the table created by this query, an interactive data page or dashboard will be generated for each event. The dashboard will display graphs of the vehicle speed and acceleration/deceleration for the event along with a map view of the vehicle path, which would be used to determine if the vehicle parked or exited the interstate. After reviewing the information, the analyst would select as many of the driver reactions that are applicable and these results would be stored in the Query #12 event table.

PM #12 is similar to PM #7 except for the events in the PM #7 query event table would be for TIMs that were received from RSUs as opposed to receiving them from other vehicles.

In addition to analyzing equipped vehicle logs, the evaluation of this performance measure will utilize the driver simulator lab at the University of Wyoming as described above in Section 5.3.3.3.

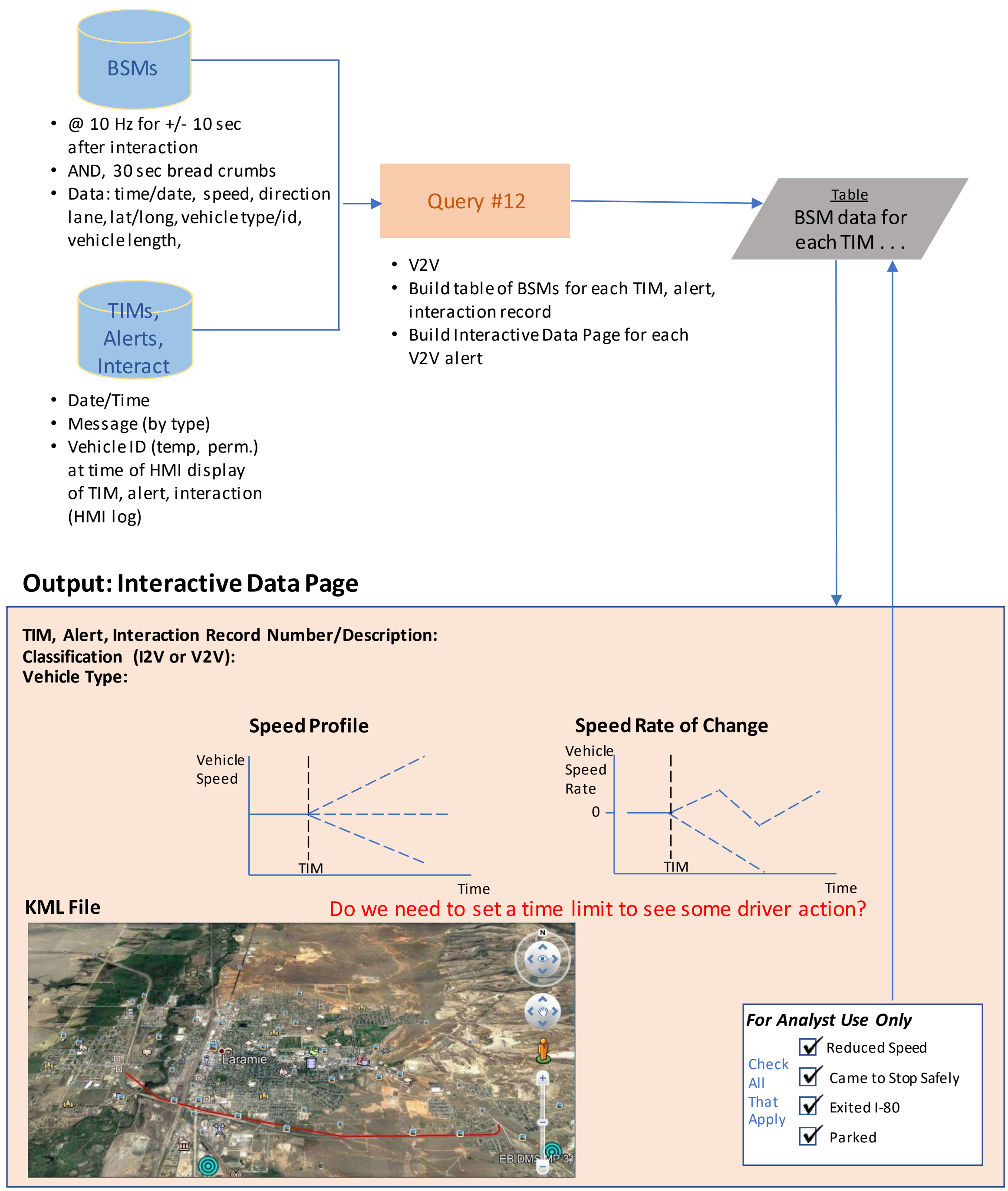

Figure 5-5: Query Tool and Interactive Data Page for PM #12 (Source: WYDOT)

5.3.6 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:

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

5.3.6.1 PM #13: Number of emergency notifications that are first received in the TMC from connected vehicles (compared to traditional methods).

Description: This performance measure focuses on the number of emergency notifications received in the TMC from connected vehicles (called distress notifications) versus other means of notification. Emergency notifications can come from several sources including the driver or passenger of the 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 distress notifications will be logged during the Pilot Demonstration, as well as total emergency notifications from other sources. It should be noted that we expect very few data points where this analysis can be performed. However, we have included this PM so we capture what data might be available – since it is such an important potential benefit of CV technology.

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, timing, and location of emergency notifications from connected vehicles. These data will be compared to the total emergency notifications from all sources. To measure the number of emergency notifications first received from connected vehicles, TMC logs of distress notifications and Wyoming Highway Patrol (WHP) logs will be required. Depending on the location of the 911 caller, the call could be received by any number of 911 centers along the I-80 corridor. This direct 911 data will not be available for analysis. However, the WHP will be notified by the 911 center if the incident is on I-80 and those logs will be available. A specific data query will be developed to match up the events, calculate the time difference between the two notification types, and prepare a table of matched events and their times and differences. Each notification type will need to have date/time, location, incident type, etc. in order to be sure the two notifications can be matched properly. A table will be generated the displays the matched distress notifications and WHP emergency events with supporting data to evaluate this performance measure. Figure 5-6 illustrates the data query process proposed.

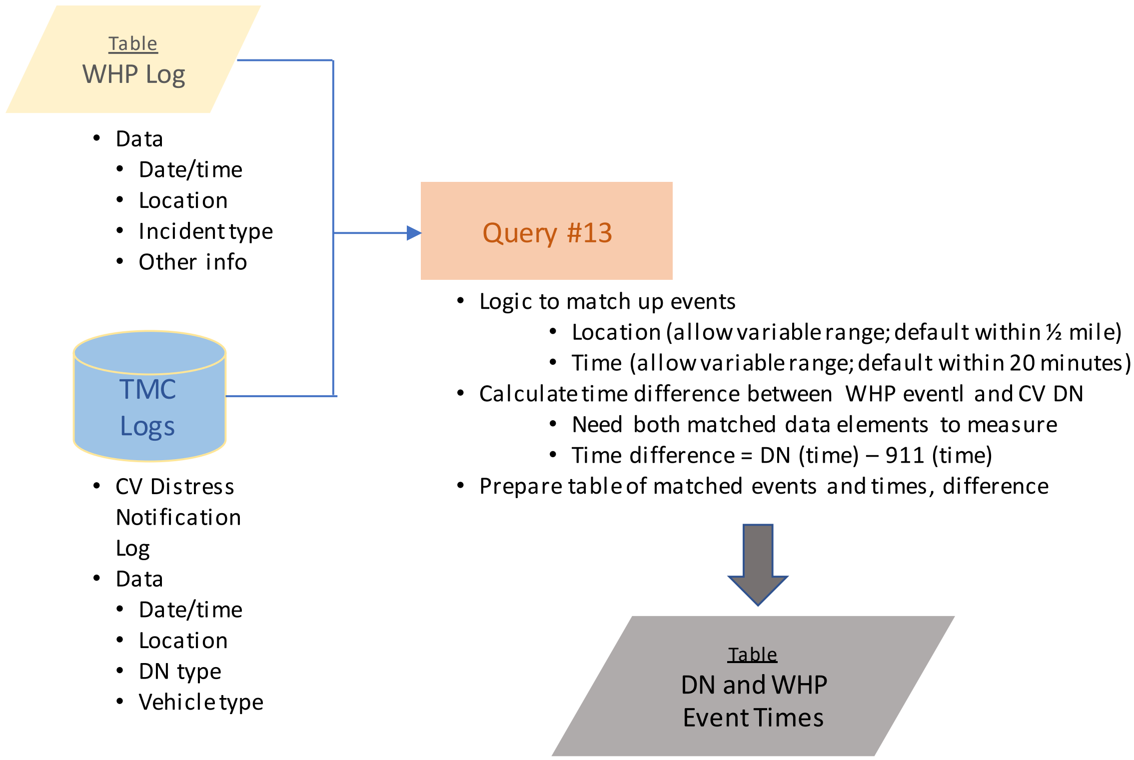

Figure 5-6. CV Data Query Process to Support PM 13 (Source: WYDOT)

5.3.7 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 and, in limited instances, at non-VSL locations. 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 RSU 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:

14. Vehicles traveling at no more than 5 mph over the posted speed (compare before and after CV Pilot)
15. Vehicles traveling within +/- 10 mph of posted speed (compare before and after CV Pilot)
16. 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. Connected vehicle snowplows and Highway Patrol vehicles are two vehicle types that will be excluded from the analyses given their non-typical speed behavior.

5.3.7.1 PM #14: 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 by “priority speed sensors” with speed compliance defined as vehicles traveling at no more than 5 mph above current posted speeds. The Priority sensors are mostly located in the variable speed limit corridors with a few sensors in non-VSL corridors. Speed adherence measurement will focus primarily on the VSL corridors since those are the high-risk areas on the corridor. The selection of the 33 priority sensors (out of 76 sensors where data was available) is based on the limited impacts of geometric features (horizontal curvature and vertical grade), data availability in the baseline winter season, quality of data each sensor was providing, and representation of each of the VSL corridors. PM #14 will be reported as an aggregate of all priority sensors and also at the individual speed sensor level.

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
- Weather data from Road Weather Information Systems (RWIS) near speed sensors
- 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. 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.

Speed observations will be split by direction (eastbound or westbound) and associated with the closest upstream static or variable speed limit sign. Static speed limit signs will be given a sign ID associated with the speed limit posted on the static sign (75 or 80 mph). VSL signs have their own unique ID and the VSL event records will be merged into the speed observations based on minimizing the non-negative time differences between the VSL event and the speed observation.

Data associated with the regulatory speed limit, sign ID, and time of speed limit change will be appended to the processed speed observation record.

Speed behavior is highly dependent on the weather conditions under which the speed behavior is observed. To account for weather, each speed sensor will be associated with a nearby RWIS and weather data appended to each speed observation.

Previous research on the project corridor found five weather variables (relative humidity, surface temperature, surface condition, visibility, and wind speed) to be significantly related to speed choice (Young et al, 2004). This earlier research also determined threshold values for each of these variables, allowing them to be turned into categorical variables. For example, wind speeds below 30 mph were not seen to have a significant impact on speeds while speeds between 30 and 45 mph had an impact and wind speeds above 45 had an even greater impact. Using these thresholds, the wind speeds will be converted to a value 1 for speeds below 30 mph, 2 for speeds between 30 and 45, and 3 for speeds above 45. Similarly, the other four variables will also be converted into categorical values with the category 1 always representing ideal conditions. Relative humidity only has two threshold values (1 for below 92% and 2 for values above 92%). Road surface condition has four categories (1 for dry, 2 for wet, 3 for snow, and 4 for ice). There are 216 unique combinations of the five weather categorical variables and each combination is assigned a unique storm number from 1 to 216.

Speed observations from January to May 2017 along with the appended categorical weather variables and storm numbers are used in a hierarchical clustering analysis using an agglomerative method where every observation is first assigned a single cluster and with each iteration the algorithm merges the closest pair of clusters until the stated number of clusters is reached. Many of the 216 storm numbers were not observed during this period, which was expected since the unique combinations of weather variables were not pre-screened to remove meteorological impossible or unlikely combinations. Five, seven, nine, and 25 cluster levels were analyzed to determine the appropriate number of clusters that would adequately account for weather yet be a small enough number that the results would be meaningful. Nine clusters were chosen to be a stable cluster set and one of the clusters were manually split into three based on differences in reported weather even though the observed speed behavior was analytically similar. The final result is 11 storm categories and each of the storm number was matched to a storm category. Category 0 are storm numbers that were not observed during the training period. The original storm numbers are retained in case it becomes necessary to retrain the storm categories.

Table 5-1 details the storm categories for speed performance measures.

Every speed observation will be mapped to a storm category and the speed compliance variable set to 1 if the observed speed is no more than 5 mph above posted speed. Otherwise, the speed compliance variable is set to 0.

A data quality variable will also be set based on the observed and posted speeds. If either of those speeds are either missing or equal to zero, then the Data Quality variable will be set to 0. A value of 1 will represent observations that will be included in the evaluation of the performance measure.

PM #14 will be reported for all observations linked to each of the 11 storm categories and for observations from individual speed sensors for a select number of priority sensors. Reporting by individual speed sensors isolates some of the geometric effects on speed behavior and may provide additional insight by removing some of the variation found across multiple sensor locations.

Table 5-1: Storm Categories for Speed Performance Measures

Storm Category	Description	Storm Numbers Assigned to Category
0	No category assigned	14, 15, 17, 18, 19, 20, 21, 22, 23, 24, 26, 27, 29, 30, 31, 32, 33, 35, 36, 38, 39, 41, 42, 44, 45, 47, 48, 50, 51, 53, 54, 66, 69, 72, 74, 75, 78, 81, 83, 84, 86, 87, 89, 90, 91, 92, 93, 96, 99, 101, 102, 105,108, 114, 116, 117, 120, 122, 123, 125, 126, 128, 129, 130, 131, 132, 133, 134, 135, 137, 138, 140, 141, 142, 143, 144, 146, 147, 148, 149, 150, 151, 152, 153, 155, 156, 158, 159, 160, 161, 162, 165, 168, 171, 173, 174, 177, 179, 180, 182, 183, 186,189, 191, 192, 194, 195, 197, 198, 199, 200,201, 204, 207, 209, 210, 213,215, 216
1	Ideal	1, 2, 3, 10, 11, 55, 56, 64, 65, 82
2	Wind Event	4, 5, 7, 9, 13, 16, 34, 40, 52
3	Snow or Ice Surface Condition	109, 110, 113, 118, 127, 145, 163, 164, 172, 190, 208
4	Low Visibility	37
5	Wet pavement, moderate wind	60
6	Ice, high wind	170
7	Ice, low visibility or moderate wind	211, 212
8	High wind, high RH, wet roads	71, 88, 107
9	Mixed Conditions	8, 12, 25, 62, 76, 79, 85, 94, 97, 98, 103, 106, 169, 175, 187, 188, 193, 196, 205
10	Wind Events with Cold Surface Temps	6, 63, 77, 95, 176, 185, 203, 206
11	Mixed Conditions 2	28, 43, 46, 49, 57, 58, 59, 61, , 67, 68, 70, 73, 80, 100,111, 112, 115, 119, 121, 124, 136, 139, 154, 157, 166, 167, 178, 181, 184, 202, 214

5.3.7.2 PM #15: Vehicles traveling within +/- 10 mph of posted speed

Description: This measure focuses on speed variation of vehicles traveling the VSL corridors and at limited non-VSL location as measured as the percent of vehicles traveling within 10 mph of the posted speed. Speed variation is an important indicator of safety as previous studies have shown that reductions in speed variation are correlated with increased safety[6]. 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

[6] Garber, N J and Gadirau, R. *Speed Variance and its Influence on Accidents*. AAA Foundation for Traffic Safety. Washington, D.C., HS-040 559.

percent of vehicles traveling within 10 mph of the posted 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 this performance measure is for 20% improvement over baseline in percent of vehicles in the VSL corridors traveling within +/- 10 mph of 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
- Weather data from Road Weather Information Systems (RWIS) near speed sensors
- 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 posted speed for all vehicles traveling the VSL corridors and a few non-VSL locations 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[7]. New baseline data will be collected during Phase 2 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%

[7] Young, Rhonda, Vijay Sabawat, Promothes Saha, and Yanfei Sui. (2013) *Rural Variable Speed Limits: Phase 1I*. Wyoming Department of Transportation, FHWA-WY-13/03F. Cheyenne, WY.

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

Speed observations will be split by direction (eastbound or westbound) and associated with the closest upstream static or variable speed limit sign. Static speed limit signs will be given a sign ID associated with the speed limit posted on the static sign (65, 75, or 80 mph). VSL signs have their own unique ID and the VSL event records will be merged into the speed observations based on minimizing the non-negative time differences between the VSL event and the speed observation. Data associated with the regulatory speed limit, sign ID, and time of speed limit change will be appended to the processed speed observation record.

Speed behavior is highly dependent on the weather conditions under which the speed behavior was observed. To account for weather, each speed sensor is associated with a nearby RWIS and weather data will be appended to each speed observation. Speed observations for PM #15 will be categorized by weather using the same approach as PM #14. See previous section for more detail on this methodology.

Every speed observation will be mapped to a storm category and the speed buffer variable set to 1 if the observed speed is within 10 mph of the posted speed. The speed buffer variable will beset to 0 otherwise.

A data quality variable will also be set based on the observed and posted speeds. If either of those speeds are missing or equal to zero, then the Data Quality variable will be set to 0. A value of 1 represents observations that will be included in the evaluation of the performance measure.

PM #15 will be reported for all observations linked to each of the 11 storm categories and for observations from individual speed sensors for a select number of priority sensors. Reporting by individual speed sensors isolates some of the geometric effects on speed behavior and may provide additional insight by removing some of the variation found across multiple sensor locations.

5.3.7.3 PM #16: 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 and a few non-VSL locations 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
- Weather data from Road Weather Information Systems (RWIS) near speed sensors
- 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 at priority speed sensor locations 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.

Pulling the speed information from the CV Basic Safety Messages (BSMs) requires a relatively complete query of the BSM database. This query tool is being developed within the CVPEP/SDC environment—Figure 5-7 illustrates the general process.

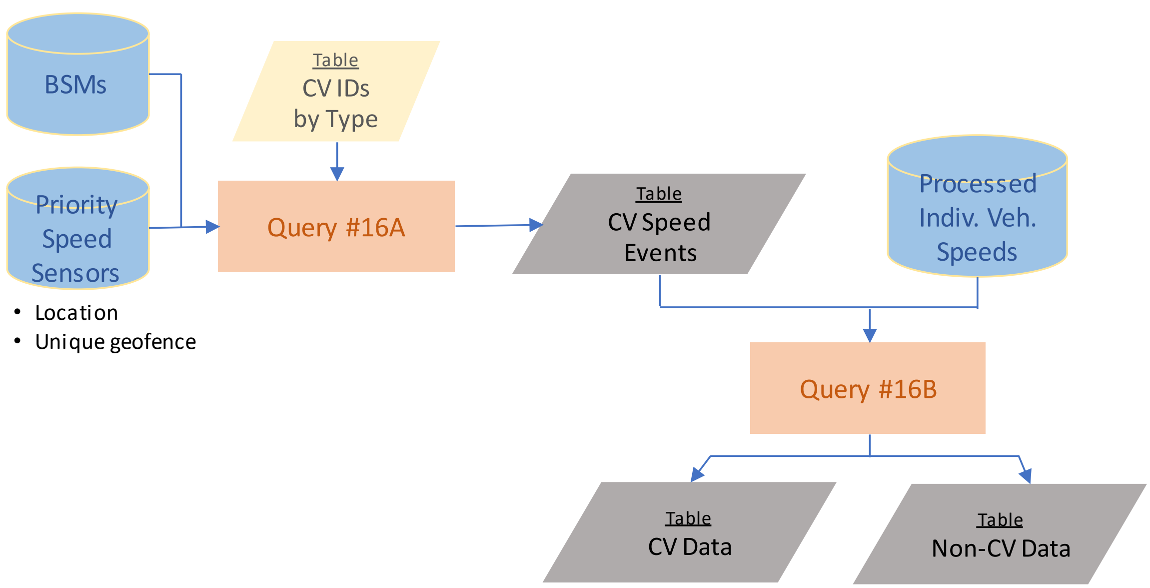

Figure 5-7. CV Data Query to Support PM #16 (Source: WYDOT)

The **processed speed data** table provides the foundation for all of the speed performance measures (PM 14-16). The query uses the individual speed observations from the priority roadside speed radar sensors along the I-80 corridor. This query first splits the speed observations into groups depending on the side of the road that the speed sensor is installed on and assigns a Sensor_Loc variable based on the speed sensor ID value. Next, three variables are appended to the speed observation data for the closest RWIS and Speed sensors (RWIS, EB_VSL and

WB_VSL). Observations in the static speed zones are assigned a speed sensor number associated with the static speed (65, 75, or 80 mph zones). From these new variables, categorized RWIS data is appended to the base speed data using the RWIS ID and the weather observation nearest in time to the speed observation. Depending on the values of the five weather variables, a storm number and storm category value are also assigned (StormNum and StormCat). The speed data is divided into EB and WB observations depending on lane number and sensor location and the VSL speed and date/time is appended to the observation by finding the closest VSL event that occurs after the speed observation.

The **Basic Safety Message Data** from CV-equipped vehicles contains the date, time, location (lat/long), vehicle ID (either static or non-static ID), length (if entered by driver), direction of travel, and speed.

<u>Query #16A:</u> Since the non-CV data is limited to locations where roadside speed radar sensors are located, the CV data query limits the CV BSM data to locations “near” these sensors. Other speed PMs use a subset of the I-80 sensors called “priority sensors” that provide good coverage of the corridor, have limited impacts due to horizontal and vertical road geometric features, and are sensors with good data quality statistics from the baseline analysis. To compare CV data with the non-CV data, the query focuses on these priority speed sensor locations.

A geofence is created around each priority speed sensor location to query the CV BSMs. An upper end speed of 85 mph and a maximum period of 30 seconds between retained CV BSMs was assumed. For speed sensors not near an RSU, this results in a geofence of approximately 3,740 feet, centered at the speed sensor location. For speed sensors near an RSU, the geofence would be much smaller since the RSU would be logging the BSM data from passing CV-equipped vehicles at the rate of 10 HZ. The geofence is constructed to exclude observations from any nearby frontage roads and interchange ramps. If the vehicle were traveling slower than the assumed 85 mph or was logging more BSMs due to a recent TIM message, more than one BSM could be associated with each speed sensor passing so the BSM data for the observation closest to the speed sensor should be the only one retained. It may be necessary to exclude observations on the outer limits of this geofence as the data is analyzed, so the distance between the observation and the speed sensor should be calculated.

Speed behavior of snow plows and highway patrol vehicles are not typical of freight and passenger cars so the PM limits the speed observations to “applicable” vehicles. Because of this, vehicles need to be identified as either being from the snow plow, highway patrol, or freight partner fleets. Additionally, the size of the vehicle greatly impacts speed behavior, so length and/or vehicle classification data from the BSM is important to retain. This allows comparison of passenger and truck speed statistics between CV and non-CV data.

The output of Query 16A would be a **CV Speed Event** table where each event in the table would represent a single vehicle passing a priority speed sensor. The frequency on running the query would need to be such to limit the number of records that would need to be searched to keep processing times reasonable.

<u>Query #16B:</u> This query combines the CV Speed Event table with the Processed Individual Speed database, which contains observed individual vehicle speeds, weather, and regulatory speeds. For each CV speed event, the individual processed speed database needs to be searched for the “best” match. Some data must be an exact match (sensor ID, direction of travel) while other data (date/time, lane, length, speed) needs to be based on logic to minimize differences. Each match will populate a variable in the processed speed data with the CV speed event ID. Unmatched processed speed events will have a null value in the field.

After matching, two tables will be created, one called the **CV Speed Data** of all matched CV speed events containing the merged fields from both the CV speed event table and the matched processed individual speed table. The other table, called the Non-CV Speed Data will contain all non-matched CV speed events within 10 minutes of a matched CV speed observation. Duplications of non-CV speed data will not be allowed in cases where more than one CV speed event occurs during this time window.

PM processing: The CV Data table will be analyzed to create a speed distribution (based on radar speeds) of the CV vehicles for each storm category and sensor ID. Similarly, the non-CV Data will be analyzed to create a speed distribution of non-CV data for each storm category. These two distributions will then be statistically compared to determine differences between the two vehicle populations.

5.3.8 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[8]. The following five performance measures are contained in this performance category and will be described in greater detail below:

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

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 2 of the pilot. Input for the calibration of the microsimulation models will come from existing roadside speed and gap observations, CV equipped vehicles, traffic

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

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. Crash data will be requested every two weeks from the safety program and uploaded to the CVPEP/SDC manually.

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

5.3.8.1 PM #17: 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 and enhanced notification of roadway hazards. 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:

- Self-reported 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. Data about crashes will be self-reported and is required under the freight partner Memorandum of Understanding (MOU).

5.3.8.2 PM #18: 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.
- Work zone information from WYDOT Construction Console
- Data from CV equipped vehicle operators 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. Crash reporting of larger, multi-vehicle crashes can make it difficult to identify secondary crashes due to multiple responding emergency personnel collecting on-site crash reports. During Phase 2 of the project it was determined to use a definition of secondary crashes where crashes were related if they occurred within 1-mile and 75 minutes of another crash. While this definition is much broader than the traditional secondary crashes found in the literature, it was determined to be suitable for the spot-weather types of crashes common to the corridor where crashes may not be related due to backups but are related due to similar weather conditions. Identified secondary crashes have a crash identification number of the primary crash in the Secondary Crash variable field. From this, the total number of vehicles in each crash can be aggregated.

Safety Modeling Analysis and Simulation Modeling will be used to support the evaluation of this PM. Refer to sections 5.1.6 and 5.1.7 for a description of our approach.

5.3.8.3 PM #19: 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.
- Location and Duration of Work Zones in Project Corridor from the WYDOT Construction Console database starting January 2013 to beginning of CV demonstration period.
- Data from CV equipped vehicle operators 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. Work zone related data within the crash database is limited to crashes where work zone equipment was involved as opposed to crashes that just happen to occur with a work zone area. Because of this, work zone information external to the crash database will be required. WYDOT uses a Construction Console to log construction activities along its roadways and includes information such as the duration, type, and location of the construction activities. Some projects related to minor maintenance (such as roadside mowing) list the entire corridor and a duration of several months so these projects needed to be excluded from the analysis. Crashes that occur with the milepost and date range of work zones in the construction console will be given a value of 1 for the Work Zone variable. Because most work zones on the project corridor require median crossovers, it was determined that crashes in either direction would be counted as a work zone regardless of the direction where the construction activities were occurring.

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.

Safety Modeling Analysis and Simulation Modeling will be used to support the evaluation of this PM. Refer to sections 5.1.6 and 5.1.7 for a description of our approach.

5.3.8.4 PM #20: 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.
- National Oceanic and Atmospheric Administration (NOAA)covering same time period as crash data
- Data from CV equipped vehicle operators 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.

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.

Safety Modeling Analysis and Simulation Modeling will be used to support the evaluation of this PM. Refer to sections 5.1.6 and 5.1.7 for a description of our approach.

5.3.8.5 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.
- Data from CV equipped vehicle operators 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.

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.

Safety Modeling Analysis and Simulation Modeling will be used to support the evaluation of this PM. Refer to sections 5.1.6 and 5.1.7 for a description of our approach.

5.4 Summary of Evaluation Approach

Table 5-2 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 6.3 for additional details and frequency of data collection and sharing.

Table 5-2. 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 WYDOT snowplow road weather condition reports submitted (baseline and post deployment)
2	X					• Number of WYDOT snowplow road weather condition reports submitted (baseline and post deployment)
3	X					• Number of WYDOT snowplow road weather condition reports submitted (baseline and 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)
Effectively Disseminated and Received I2V and V2I Alert/Advisory Messages from the TMC						
5			X			• TMC logs (post deployment) • RSU logs (post deployment)
6			X			• RSU logs (post deployment) • OBU logs (post deployment)
7				X		• TMC logs (post deployment) • OBU logs (post deployment) • Temporal and spatial data of all connected vehicles (post deployment)
Improved Information to Commercial Vehicle Fleet Managers						
8	X					• TMC logs indicating information provided to commercial vehicle fleet managers (baseline and post deployment) • Fleet manager survey responses of operational changes made (type and timing) based on input from the TMC (before and after CV Pilot)
9					X	• Commercial vehicle fleet manager survey responses of satisfaction levels with TMC information (before and after CV Pilot)
10					X	• Commercial vehicle driver survey responses
Effectively Transmitted and Received V2V Messages						

PM No.	Evaluation Approach: Before-After	With-Without	System Performance	Behavior Assessment	Qualitative Assessment	Data Need
11			X			• OBU logs recording sent and received V2V messages from other connected vehicles (post deployment) • RSU logs that recorded V2V messages being transmitted to other connected vehicles (post deployment)
12				X		• OBU logs regarding sent and received V2V messages (post deployment) • Temporal and spatial data of all connected vehicles (post deployment)
Automated Emergency Notifications of a Crash						
13			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						
14	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)
15	X					
16		X				
Reduced Vehicle Crashes						
17			X			• Data from CV equipped vehicle operators regarding involvement in crashes on project corridor (post deployment)
18	X					• Crash data from WYDOT-maintained crash database for the project corridor starting 5-years prior to and continuing through CV demonstration period. • Traffic volume data from existing roadside traffic monitoring equipment (before and after deployment) • Data from CV equipped vehicle operators regarding involvement in crashes on project corridor (before and after deployment)

PM No.	Evaluation Approach					Data Need
	Before-After	With-Without	System Performance	Behavior Assessment	Qualitative Assessment	
19	X					• Crash data from WYDOT-maintained crash database for the project corridor starting 5-years prior to and continuing through CV demonstration period. • Traffic volume data from existing roadside traffic monitoring equipment (before and after deployment) • Location and Duration of Work Zones in Project Corridor starting January, 2013 to beginning of CV demonstration period (before and after deployment) • Data from CV equipped vehicles regarding involvements in crashes on project corridor (post 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. demonstration period (before and after deployment) • Traffic volume data from existing roadside traffic monitoring equipment (before and after deployment) • Data from CV equipped vehicle operators regarding involvement in crashes on project corridor (before and after 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. • Traffic volume data from existing roadside traffic monitoring equipment. • Data from CV equipped vehicle operators regarding involvements in crashes on project corridor.

6 Performance Management

Performance management consists of data collection and management, support to independent evaluation, and system performance reporting. Each of these areas are described below.

6.1 Data Collection and Management

Performance measurement data will be collected in the following categories (see Data Management Plan and *Final System Performance Report, Baseline Conditions* for additional details).

- 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.

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. The frequency of data collection and availability will depend of the data type. The goal will be to share the data when it is available. For instance, it is envisioned that BSM data and Traveler Information Messages (TIMs) will be available in real time, while other data will be shared on a less frequent basis - such as speed data bi-weekly, and crashes monthly.

Data will be shared through the WYDOT Operational Data Environment (ODE) for near real-time data, working in coordination with the Wyoming Data Warehouse. Wyoming CV Pilot data will be shared with three separate USDOT databases (under development):

- Connected Vehicle Pilot Evaluation Platform (CV-PEP)/Secure Data Commons (SDC) – This database will accept and make available Wyoming CV Pilot data (and data from the other CV Pilot sites) to TTI and Volpe for evaluation purposes. It will have the ability to securely store Personally Identifiable Information (PII) data. Much of the data will be shared through an interface with ODE; however, it will be capable of accepting other uploaded data. In addition to data, the system will house evaluation tools to facilitate analysis being conducted within the platform. Wyoming intends to perform some of their analysis within the CV-PEP/SDC platform. Data, once uploaded, cannot be downloaded by any users. Users will be carefully managed, and a comprehensive permissions-set will be established. In the WYDOT CV Pilots Interface Control Document (ICD) section 5.36 the ODE to CV-PEP/SDC interface details are defined (WYDOT, 2017). Section 5.37 defines the Data Warehouse to CV-PEP/SDC interface details. The data are defined in section 7.14.2 of the ICD.

- Situational Data Warehouse (SDW) – Wyoming plans to share traveler information messages (TIM) with the SDW as the portal to provide TIMs to Sirius/XM. The TIMs will be communicated to connected vehicles capable of receiving satellite-based data. In the ICD section 5.22 the ODE to SDW interface details are defined.
- Research Data Exchange (RDE) – This USDOT database will be structured to share CV Pilot sanitized data with researchers and other interested parties. Wyoming will establish an interface with the ODE to facilitate an efficient flow of data. No PII data will be shared with this database. In the ICD section 5.38 the ODE to RDE interface details are defined. The data are defined in section 7.14.3 of the ICD.

6.2 Support to Independent Evaluation

The USDOT has sponsored an independent evaluation of the CVPDs to help assess whether the pilots were effective in achieving their goals of transformational safety, mobility, public agency efficiency, and environmental improvements; what lessons can be used to improve the design of future projects; and how resources should be applied in the future. In parallel, the independent evaluation will help the sites in identifying the impacts of their pilot deployments by complementing the sites' performance measurement effort; determining if their actions achieved desired objectives; and, ultimately, extracting lessons that can be used to improve the continued operation of their deployments.

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

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

To help define and clarify the IE's independent evaluation activities, they prepared an Evaluation Plan. The key objectives of the independent evaluation are as follows:

1. Assess the extent to which deploying CV technologies improved mobility, travel reliability and throughput in the I-80 corridor during adverse weather conditions.
2. Estimate the extent to which reductions in crash frequency and severities contributed to improvements in mobility and travel reliability along the I-80 corridor as a result of equipping commercial fleet vehicles and WYDOT maintenance vehicles with CV technologies.
3. Estimate the extent to which deploying CV technologies improved travel and freight reliability for commercial fleet vehicles equipped with CV technologies.
4. Quantify the extent to which CV technologies helped improve emergency management on the I-80 corridor through early identification of conditions and improved messaging and communication.

5. Assess the extent to which improved traveler information on road weather conditions and construction activities in the corridor improved freight drivers' ability to better plan and adjust their trips (e.g., locate truck parking locations along the corridor).
6. Assess the extent to which deploying CV technologies in the I-80 corridor help public agencies official to better manage operations and deploy traffic management strategies.
7. Estimate the extent to which improved mobility for connected trucks and for all traffic will reduce negative environmental impacts along I-80 during adverse weather.
8. Estimate that extent to which the life-cycle mobility, environmental and public agency efficiencies benefits as market penetration and background traffic changes over the seven years after deployment.
9. Conduct a benefit-cost assessment associated with equipping commercial fleet vehicles with CV technologies in the I-80 corridor.

Directly from the IE Evaluation Plan, Table 6-1 identifies the IE's evaluation hypotheses, performance measures and data sources.

The Wyoming Performance Measure Team will support the IE's activities through the following activities:

- Provide the data identified in Table 6-1 to support the IE's efforts to support their evaluation activities, where available.
- Maintain a stakeholder registry to support the IE's planned efforts to interview, survey, and conduct a workshop involving a vast array of project stakeholders.
- Coordinate evaluation efforts where it makes sense. Possible areas include stakeholder outreach and simulation modeling.

Table 6-1. Independent Evaluator's Hypothesis, Performance Measure, and Data Sources

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
1.	The pilot deployment will improve mobility for both equipped and non-equipped vehicles in the deployment corridor during inclement weather events.	• Change in Average Travel Time • Change in Average Delay • Change in Average Speed • Change in Vehicle Throughput • Change in the Temporal Extent of Congestion • Change in the Spatial Extent of Congestion	• WYDOT Radar-based Speed Sensors • BSM Part 1 • NPMRDS • WYDOT RWIS Weather Station	• Before/After using Observed data
2.	By reducing the number of trucks that are stranded, must backtrack, or otherwise waste time and fuel resulting from road closures or a lack of appropriate parking availability, the pilot deployment will result in improved travel reliability for vehicles equipped with CV technologies in the corridor.	• Change in 95th percentile Travel Time • Change in Buffer Time • Change in the proportion of equipped trucks traveling at or above speed limit • Change in the number of rapid deceleration of trucks during inclement weather events • Change in the proportion of vehicles traveling 5 mph at or above the work zone speed limit	• WYDOT Radar-based Speed Sensors • BSM Part 1 • NPMRDS • WYDOT RWIS Weather Station	• Before/After using Observed data
3.	The pilot deployment will reduce negative impacts on the environment through reduction in crashes and increases in speed adherence.	• Change in the vehicle emissions • Change in fuel consumption	• Simulation of incident/crash situations	• Modeling analysis to assess the impacts of the With vs Without cases
4.	By increasing situational awareness, the pilot deployment will result in improved public agency efficiency and decision-making by transportation managers.	• Change in perception of agency awareness of conditions in the deployment corridors • Changes in the perceived accuracy of alerts/warnings/advisories/ traveler information	• WYDOT Crash Data • WYDOT Road Closure Reports • WYDOT DMS Records • WYDOT VSL System logs • WYDOT Incident Console Logs	• Qualitative perception data from surveys • Quantitative data from system logs

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
		• Changes in the perceived effectiveness of alerts/ warnings/advisories/ traveler information • Changes in timeliness of agency responses to changing travel conditions • Number and type of operational changes (such as signal timing adjustments) and business practice changes made by transportation managers • Perceived impact/effectiveness of operational and business practice changes. • Changes in notification and/or response times to major incidents and crashes. • Changes in perceived effectiveness of traffic management system responses to changing traffic conditions.	• WYDOT TRAC data • Pikalert Motorist advisories and warnings • TMC generated TIMs, alerts, and warnings • Mobile Road Weather observations • Interviews and surveys	
5.	As the market penetration of connected vehicles increases, benefits will increase in terms of reduced queues, delays, emissions, and increased vehicle throughput during inclement weather conditions.	• Average Trip Time per vehicle (VHT/V) • Average User Delay/Wait Time • Average Speeds • Average vehicle-miles traveled per vehicle	• Simulation	• Modeling analysis to assess the impacts of the With vs Without cases
6.	As the market penetration of connected vehicles increases, non-equipped vehicles traversing the pilot deployment area will see reductions in queues, delays, and emissions.	• Average Trip Time per vehicle (VHT/V) • Average User Delay/Wait Time • Average Speeds • Average vehicle-miles traveled per vehicle	• Simulation	• Modeling analysis to assess the impacts of the With vs Without cases

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
7.	The safety, mobility, environmental, and public agency efficiency benefits exceed the costs associated with deploying the CV technologies in the deployment corridors.	• Total Deployment Costs ○ Development ○ Procurement ○ Installation ○ Operations ○ Maintenance ○ Salvage • Dollar Value of Benefits ○ Safety ○ Mobility ○ Environmental ○ Public Agency Efficiency	• Safety Analysis • Mobility Analysis • Environmental Analysis • Public Agency Efficiency Analysis • Agency Cost Records •	• Benefit/Cost
8.	Incremental increases in connected vehicle deployment will result in higher benefit-cost ratio up to a certain deployment cost threshold.	• Benefit-cost ratio at various market penetrations	• Cost data • Dollar value of benefits	• Simulation
9.	End users will be satisfied with the performance of the CV applications and with the impact of the CV deployment on their travel	• Perception of whether advisories/ alerts/warnings/traveler information were: ○ Timely ○ Sufficiently detailed ○ Easy to understand ○ Accurate ○ Useful ○ Appropriateness • Perceived impact (if any) that alerts/warnings/advisories/ traveler information had on safety and/or mobility. • Attitudes towards the consistency of the alerts (Did they fell they consistently received an alert under similar situations?)	• Surveys/ Interviews	• Qualitative perception data from surveys

ID	Evaluation Hypothesis	Performance Measure	Data Sources	Analysis Type
		• Attitudes toward CV systems (related to trust in information, privacy and security, etc.)		
10.	End users will be satisfied with the performance of the connected vehicle devices.	• Overall satisfaction with performance of connected vehicle devices • Number and nature of problems with connected vehicle devices	• Survey/ Interviews	• Qualitative perception data from surveys
11.	The Wyoming CVPD agencies have the financial and institutional frameworks in place to provide for the long-term sustainability of the CV pilot deployment.	• Changes needed in business processes • Changes needed in agency systems and technologies capabilities – • Changes needed in agency culture • Changes needed in the organizational structure and workforce requirements • Changes needed in institutional arrangements and collaborations. • Changes needed in performance measurement practices • Perceived impact/effectiveness/ acceptance of those changes. • Perceived extent to which safety, mobility, environmental, and public agency efficiency goals were met. • Lessons learned by agencies.	• Stakeholder Surveys/ Interviews	• Qualitative perceptions from interview data

6.3 System Performance Reporting

During Phase 2, two system performance reports were delivered to USDOT (Interim: September 2017; Final: April 2018). Those reports focused on establishing the pre-deployment (baseline) conditions. This involved 11 of the 21 PMs. Those baseline conditions are established and ready for comparison purposes with post-deployment data (Phase 3).

An extensive quantity of data will be collected during Phase 3 to support a successful system performance measurement of the Wyoming CV Pilot Demonstration. The majority of the data collection will occur during the 2018-2019 winter (October 2018 through May 2019). Analysis of this data will be focused on the summer of 2019 resulting in a final system performance report by the end of Phase 3 (draft: mid-September 2019; final: October 2019). The Phase 3 System Performance Report will contain:

- Description of Phase 3 data collected and shared through the CV-PEP/SDC platform.
- Description of analysis of each performance measure, analysis results, and an assessment of target achievement.
- List of (performance measurement activity) challenges experienced during the Phase 3 evaluation efforts.
- Identification of lessons learned that will help understand the analysis results.
- An assessment of CV system sustainability.
- Overall conclusions and recommendations.

7 Roles and Responsibilities

The successful execution of this Final Phase 2 Performance Measurement and Evaluation Support Plan requires the strong commitment and participation of key team members, partners, and stakeholders during Phase 3 Pilot Demonstration. The responsibilities of each group is dependent on their project role. Table 7-1 below defines the roles and responsibilities of each group to execute a successful evaluation of the Wyoming CV Pilot Project.

Table 7-1. Roles and Responsibilities of the CV-Pilot Team.

Project Role	Responsibility (Performance Measurement support)
Wyoming CV Pilot system development and execution	• Support Performance Measurement data collection and analysis efforts.
Wyoming CV Pilot Performance Measurement team	• Conduct PM & ES Plan as defined including data collection, analysis, and reporting. • Support Independent Evaluators with data and other assistance as needed. • Prepare Phase 3 System Performance Report.
Independent Evaluators	• Conduct independent evaluation, coordinate efforts with Wyoming PM team, 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.

8 Schedule

The Wyoming Performance Measurement team prepared a detailed Phase 2 Performance Measurement Schedule and has been providing schedule progress reports bi-weekly to the USDOT throughout Phase 2. At the conclusion of Phase 2 it is expected that all WBS tasks in that schedule will be complete.

The initiation of Phase 3 will include the development of a similar PM Schedule defining detailed Phase 3 tasks. Once approved by USDOT, bi-weekly schedule progress reports will similarly be provided to USDOT throughout the Phase 3 activities. Phase 3 activities will include:

- Collection of performance data specifically required to evaluate the PMs identified in this plan. Also ensuring that the data is uploaded to the CV-PEP/SDC platform for analysis and sharing.
- Analyzing each of the PMs by executing the evaluation designs identified herein.
- Reporting analysis results in the Phase 3 System Performance Report.

These activities will span the Phase 3 schedule beginning in May 2018 through October 2019. Data collection will begin immediately with summer work zone activities but be mainly focused during winter months between October 2018 and May 2019. Analysis and reporting will be completed during the summer of 2019 with a draft Phase 3 System Performance Report being submitted in mid-September 2019. Note, the Phase 3 schedule is currently in flux and may change slightly to ensure all technical requirements are achieved and the operational systems are working properly.

9 Conclusions

This Updated 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. It reflects the knowledge gained during Phase 2 including the establishment of pre-deployment (baseline) conditions; and, the development of the final Wyoming CV Pilot system details, installation, and testing. This Plan identifies 21 specific performance measures contained within 8 performance categories which represent the major expected benefits and outcomes of the Wyoming Pilot including:

- Improve road weather condition reports received into the TMC
- Improve ability of the TMC to generate alerts and advisories
- Effectively disseminate and receive I2V and V2I 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 21 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.

Data needs and evaluation approaches are identified for each performance measure. This Plan forms the basis for a successful evaluation. Refer to our *Final System Performance Report, Baseline Conditions* for additional details of pre-deployment conditions, analysis approaches, and data requirements. This PM Plan defines how the Wyoming team's evaluation will be executed and specifically supports Phase 3 data collection, analysis, and reporting activities.

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