Connected Vehicle Pilot Deployment Program Phase 2

System Architecture Document – WYDOT CV Pilot

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Notice

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

This Phase 2 document presents the Systems Architecture Document for the physical objects and applications identified in the Concept of Operations document. The intent is to describe, at a high level, the architecture components of the Wyoming Connected Vehicle Pilot and their respective interfaces. The approach is loosely based on the ISO/IEC/IEEE 42010 2011 Systems and Software Engineering – Architecture description. Finally, this 2018 revised version is an update to an earlier version of the report, reflecting more thoroughly fleshed out concepts and insights gained by the site during and at the end of Phase 2.

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1 Introduction

1.1 Purpose of the Document

This document is the System Architecture Document (SAD) for The Wyoming Department of Transportation (WYDOT) Connected Vehicle (CV) Pilot project for the United States Department of Transportation's (USDOT) CV program. The SAD describes the system architecture from multiple architecture perspectives including:

1. Enterprise Architecture View
2. Functional Architecture View
3. Physical Architecture View of Systems and Interfaces
4. Data and Information Flow View
5. Physical Architecture View of Applications and Support Functions
6. Communications Architecture View
7. Security Architecture View

This document identifies the sub-systems, internal and external interfaces, and interface standards necessary to develop and build the WYDOT CV Pilot. Requirements for these subsystems were previously defined in the System Requirements Specification (SyRS). Further design information is detailed in the System Design Document (SDD).

1.2 Identifying Information

Architecture Name: WYDOT CV Pilot System Architecture

System-of-Interest: Connected Vehicle System of Systems including the Vehicle System and the Wyoming CV System.

1.3 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. 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, V2I, 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.

1.4 Definition of Terms and Acronyms

Table 1-1. Glossary of Terms.

Term	Definition
Basic Safety Message	Connected V2V safety applications are built around the capability to transmit BSMs, following the Society of Automotive Engineers (SAE) J2735 standard. The BSM is transmitted over DSRC over a range of approximately 300 meters. In general, BSMs are broadcast frequently to provide connected vehicles with data content necessary for the different safety-oriented applications. The BSM is divided into two parts: • Part I, transmitted approximately 10 times per second, contains the core data elements: Message Count, Temporary ID, Time (through a Second Mark), Latitude, Longitude, Elevation, Positional Accuracy, Transmission State, Speed, Heading, Steering Wheel Angle, Acceleration, Brake System Status, and Vehicle Size.

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

Term	Definition
	• Part II, transmitted less frequently, is added to Part I depending on events (e.g., Anti-lock Braking System (ABS) activated) and contains a variable set of data elements drawn from many optional data elements (availability by vehicle model varies)
Broadcast	Sharing data with no specific destination. All broadcast data is sent unencrypted but is signed with a certificate (based on the Institute of Electrical and Electronics Engineers (IEEE) standard 1609.2).
Data	Data is raw (unorganized and unprocessed) digital messages sent between components. From SAE J2735: Representations of static or dynamic entities in a formalized manner suitable for communication, interpretation, or processing by humans or by machines.
Data Ingest	Obtaining and importing data for use or storage.
Host Vehicle	A connected vehicle that receives messages from a remote vehicle. In this document, the host vehicle is also used to describe the originator of a vehicular transmission of information to an RSU.
Information	Processed data that is organized, structured or presented in a given context to make it useful
Independent Evaluator	USDOT-sponsored evaluators that will focus on measures not covered by the Wyoming team's evaluation, impacts of larger scale CV deployments, and national programmatic aspects of this CV Pilot project, combined with other similar projects being conducted. The IE works to understand how the project outcomes can contribute to the future of the CV Program nationally.
Message	A well-structured set of data elements and data frames that can be sent as a unit between devices to convey some semantic meaning in the context of the applications (adapted from SAE J2735).
On-Board Unit	This represents the package of DSRC radios, computing, sensors and HMI that will be installed on a vehicle. This is similar to the Retrofit Safety Device used in the Safety Pilot Program.
Receive Data	A connected device accepts a data package broadcast or transmitted by another connected device.
Remote Vehicle	A connected vehicle that periodically and dynamically broadcasts a message about its general situation to a host vehicle.
Requirements	Set of information necessary to accomplish one action.
Roadside Units	This represents the package of DSRC radios, computing, communications that will be installed on the roadside on I-80
WYDOT Road Segment	A road segment is defined as a link in Traffic Management Data Dictionary (TMDD) v3.03c: a roadway or transit right-of-way between two nodes. WYDOT has implemented road segments to fully cover I-80 in both directions.
Transmit	Sharing data directed to a specific receiver. In the case of transmission between Systems, all transmitted data is signed and encrypted, where required, based on SAE J2945/1.
Transportation Management Center	Center that collects information and informs the public about changing travel conditions.
WGS-84	Latest revision of the standard for use in cartography, geodesy, and navigation including by global positioning systems (GPS).

Table 1-2. Acronym List.

Acronym/ Abbreviation	Definition
ABS	Anti-lock Braking System
BSM	Basic Safety Message
DB	Data Broker
DW	Data Warehouse
CA	Construction Administration
CAN bus	Controller Area Network bus
ConOps	Concept of Operations
CRL	Certificates Revocation List
CV	Connected Vehicle
CVOP	Commercial Vehicle Operator Portal
CVRIA	Connected Vehicle Reference Implementation Architecture
DMS	Dynamic Message Signs
DN	Distress Notification
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
ESS	Environmental Sensor Station
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
HMI	Human-Machine Interface
I2V	Infrastructure-to-vehicle
I-80	Interstate 80
IC	Incident Console
ICD	Interface Control Document
IE	Independent Evaluator
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IRB	Institutional Review Board
ISO	International Organization for Standardization
ITIS	Integrated Transport Information System
ITS	Intelligent Transportation System
LTS	Location and Time Service
MAP	Mapping for Intersection
MoU	Memorandum of Understanding
NCAR	National Center for Atmospheric Research
NWS	National Weather Service
OBU	On-Board Unit
ODE	Operational Data Environment
OSADP	Open Source Application Development Portal

Acronym/ Abbreviation	Definition
RCRS	Road Condition Reporting System
RSU	Roadside Units
RWH	Road Weather Hazard
RWIS	Road Weather Information System
SAE	Society of Automotive Engineers
SCMS	Security Credential Management System
SDW	Situation Data Warehouse
SET-IT	Systems Engineering Tool for Intelligent Transportation
SPaT	Signal Phase and Timing
SSP	Satellite Service Provider
SWIW	Spot Weather Impact Warning
SyRS	System Requirements Specification
TIM	Traveler Information Message
TMC	Transportation Management Center
TMDD	Traffic Management Data Dictionary
TPI	Third-Party Interface
TRAC	Transportation Reports and Action Console
UoW	University of Wyoming
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
VSL	Variable Speed Limit
WHP	Wyoming Highway Patrol
WYDOT	Wyoming Department of Transportation
WTI	Wyoming Traveler Information system
WZW	Work Zone Warning

1.5 References

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

Table 1-3. References.

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1.6 Approach

This SAD loosely follows the format and requirements laid out in the ISO/IEC/IEEE 42010 2011 Systems and software engineering – Architecture description, which is an international standard for the documentation of the system architecture. The 42010 standard is designed to be used on large complex systems, however, because the goal of the WYDOT CV Pilot is a limited deployment for the I-80 corridor, the authors take some liberties with the required rigor and detail typically contained in a 42010-type architecture document. For example, our models are expressed, for the most part, using simple block diagrams as opposed to an industry standard systems engineering based modeling language. 42010 does not prescribe a specific approach as long as the information is communicated effectively and this document upholds that spirit.[2]

The remainder of this document if organized as follow:

- Section 2 provides an explanation of the stakeholders and concerns for the pilot.
- Section 3 details the System of Interest.
- Section 4 details the system architecture viewpoints, views and models.

1.7 Architecture Evaluation

The primary objectives of this pilot include:

- Deploy and operate a set of vehicles equipped with OBUs with DSRC connectivity.
- Deploy RSUs with DSRC connectivity that can transmit advisories and alerts to equipped vehicles along I-80.
- Ensure adequate communications backhaul from the RSU to the WYDOT TMC.
- Leverage the data provided from the equipped vehicles to develop and demonstrate a suite of V2V and V2I applications.

This document expands on the system concepts defined in the Application Deployment Plan (Gopalakrishna, et al., 2016a) and SyRS (Gopalakrishna, et al., 2016b) documents created in

[2]This document was based on a template created by Rich Hilliard which can be found at http://www.iso-architecture.org/42010/templates/. The template is licensed under a Creative Commons Attribution 3.0 Unported License which can be found at http://creativecommons.org/licenses/by/3.0/.

Phase 1. The architecture described here was developed to make relevant information directly available to, and shared among, equipped fleets. Information will also be shared through linkages with fleet management centers (who then will communicate it to their trucks using their own communication systems) and other external agencies and partners.

This document describes multiple architecture views of the proposed system to define the system fully for designers and stakeholders so they understand the intended system and implement it accurately. Each view describes and models the system by using block diagrams. This document includes architectural descriptions of the proposed system, which include Connected Vehicle Reference Implementation Architecture (CVRIA) and other descriptions the WYDOT team has found valuable from experience, see Section 4.

The approach to creating the SAD was to use as many pieces of the already-designed system architecture as possible. This includes reviewing and updating Systems Engineering Tool for Intelligent Transportation (SET-IT) diagrams created during Phase 1 to incorporate the updated SyRS and the Application Deployment document information. These documents contain information on standards that will be used and application-specific requirements and design that will need to be incorporated into the overall system architecture design document.

1.8 Rationale for Key Decisions

The architecture described in this document was developed by the project team to support WYDOT in achieving its objective to improve safety and reliability on the I-80 corridor especially during periods of adverse weather and when work zones are present. To achieve this primary objective, several new or modified capabilities, functions, processes, interfaces, and other changes were identified:

1. Capability changes – the proposed system will:
    a) Add capability to collect highly-localized event, weather and road condition information from equipped commercial, specialty and public fleet vehicles
    b) Add capability to use collected information effectively to generate localized, timely notification both to fleet managers and to truckers on the road about adverse weather conditions
    c) Add capability to support V2V communication of situational awareness that will take the management center out of the loop and improve timeliness and accuracy of alerts and advisories
    d) Add limited capability to provide parking availability and status information to equipped trucks on the road during adverse weather conditions
    e) Add capability to provide customized alerts and advisories to trucks based on their location along the I-80 corridor using roadside infrastructure
2. System processing changes – the proposed system will:
    a) Ingest, quality-check and process data gathered from connected vehicles and generate segment-level alerts and advisories
    b) Provide capability for fleet management centers to request alerts and advisories, parking availability based on location
    c) Store data generated from vehicles and controlling systems for performance measurement and evaluation

3. Interface changes – new interfaces will be developed to support activities and to manage, gather, compile and share data related to:
    a) Interfaces between vehicles, roadside, WYDOT centers and USDOT services for Core Services for the CV environment
    b) Interfaces between host and remote vehicles for V2V Applications, specifically applications that relate to collision warning and communicating/receiving/relaying distress notifications (DNs)
    c) Interfaces between vehicles and infrastructure for V2I Applications, specifically applications meant to raise awareness of hazardous conditions, such as work zones and road/weather condition
    d) Interfaces for integration of CV applications with existing Wyoming Traveler Information System (WTIs)
    e) Interfaces with in-vehicle systems and third party applications for road weather advisories for motorist, freight, maintenance and emergency response vehicles
    f) An interface to support third-party dissemination of road condition
4. Personnel changes – no new personnel are expected to be added as a result of the proposed system but roles and responsibilities of existing WYDOT staff and pilot participants are expected to evolve during the course of system development and demonstration. Changes are expected in the following areas:
    a) TMC Operator roles and responsibilities – TMC operators have additional responsibilities in terms of monitoring alerts and advisories generated by the proposed system for accuracy and effectiveness
    b) Weather providers/in-house meteorologist – In-house meteorologists will have new data sources to incorporate into advisory and forecast models
    c) Specialty and public fleet drivers – Snow plow drivers and highway patrol troopers who are part of the proposed system will need training on how to interpret in-vehicle alerts and advisories
    d) Truck drivers – Truck drivers who are part of the proposed system will need training on how to interpret in-vehicle alerts and advisories
    e) Fleet management center personnel will need training on how to use the new services developed as part of the proposed system in their operations
    f) System developers and maintainers – WYDOT's Geographic Information System/Intelligent Transportation System (GIS/ITS) group along with external support consultants will be responsible for the maintenance of the proposed system adding to their current roles and responsibilities
5. Environment changes – no significant changes are expected in the high-level operational environment of the I-80 corridor due to the proposed system.
6. Operational changes – some operational changes are expected to occur at WYDOT TMC as a result of the proposed system:
    a) WYDOT's policies on VSLs, road condition advisories, incident response are expected to change as result of the proposed system
    b) Additionally, WYDOT TMC's role in parking management activities will increase beyond its current limited scope
7. Support changes

a) The inter-site backhaul communication capability offered by the Telecommunications Program will become more critical to support the changes in the new proposed system. These changes may require an analysis of data transfer capabilities at various locations in the corridor prior to deployment to ensure that the communications channel can support the data exchanges required for the CV applications.

2 Stakeholders and Concerns

The following subsections describe the user classes and other involved personnel in the proposed system.

2.1 Stakeholders

The following are the stakeholders, in no particular order, for the proposed system:

- U.S. Department of Transportation
- WYDOT – Traffic, Construction, Maintenance, GIS/ITS, IT, Telecom Programs
- Wyoming Highway Patrol (WHP)
- Fleet Managers
- Wyoming Trucking Association
- Adjacent State DOTs
- Third party application developers
- System integrators and vendors

2.2 User Profiles

The following user profiles are impacted by the system.

Table 2-1. User Profiles in the Proposed System.

User Group	Owner	Short Description	Changes to responsibilities and interaction with the system
1. TMC - Operators	WYDOT	Traffic Management Operators responsible for managing advisory, control strategies from the TMC in Cheyenne. Responsible for VSL, DMS, Traffic Incident Management etc.	Personnel will have to factor new sources of data and information into their decision making. Their primary interface will be through the Transportation Reports and Action Console (TRAC) system which will include information from the CV environment.
2. WHP - Dispatch	WYDOT	Personnel providing the dispatch and center capability for highway patrol on I-80. Includes port of entry operations. For the purpose of user needs, this group also includes State homeland security systems and personnel who are involved in emergency response when event-scale warrants emergency operations protocol. This group also manages the port-of	Will see increased communication about road conditions and incident notifications from the TMC as a result of the notifications from CV Pilot. No direct engagement with *Wyoming CV System*

User Group	Owner	Short Description	Changes to responsibilities and interaction with the system
		entries and are responsible for commercial vehicle safety enforcement.	
3. ITS Maintenance	WYDOT	WYDOT maintenance staff specifically for ITS devices	ITS maintenance will be responsible for a new set of devices that need to be maintained as per the performance requirements
4. Fleet Management Centers	Various	Personnel and systems at participating fleet management centers who will receive information only from the Commercial Vehicle Operator Portal (CVOP).	These management centers will see new capabilities realized though improvements in the CVOP.
5. Snow Plow Operators	WYDOT	Operators of snow plow vehicles who are on the frontlines of weather event response. Personnel are also responsible for providing road condition updates and situational awareness of travel conditions on I-80.	Snow plow operators will see additional in-vehicle advisories and alerts on their HMI. They will also continue their road condition updates
6. WHP – Field	WYDOT	Operators of highway patrol cars on I-80 who are on the frontlines for incident response, traffic control and enforcement on I-80. From a user needs perspective, this group could also include local police, fire and medical crews that provide first responder capability along the I-80 corridor. This group also manages the port-of entries and are responsible for commercial vehicle safety enforcement.	Field patrol officers will see additional forward collision warning advisories and alerts. They will also be responsible for setting up portable RSUs around incidents and work zones.
7. Commercial Truck Drivers	Various	Commercial truck drivers who travel the I-80 corridor as part of their freight movement with OBUs installed in their vehicles	Drivers of connected trucks will see a significant change to their driving environment including in-vehicle alerts and advisories through a new interface. Drivers may also see an increased amount of communication with their fleet managers and more location-specific information communicated to them.

2.3 Interactions among user classes

A greater degree of interaction between the WYDOT TMC user groups and fleet management centers is expected to occur in the proposed system. Similarly, a greater degree of communication is required between WYDOT field personnel (snow plow and highway patrol) and the TMC to support truck advisories and warnings.

2.4 Other Involved Personnel

The following personnel are also involved in the operations of the proposed system:

- USDOT Security Credential Management System (SCMS) Operators – Personnel responsible for operating the SCMS.
- USDOT Independent Evaluation Contractor – Personnel involved in USDOT-sponsored impact evaluation.
- Third party application developers – Application developers with interest in using data products created by the proposed system.
- System vendors and integrators – Private sector system vendors and integrators involved in the development and operation of the proposed system.
- WYDOT 511 App Users – WYDOT 511 App users provide valuable information on road conditions and parking availability that will be used by the system to notify truckers.

2.5 User Needs

Through the process of identifying user needs, the team has identified what the project stakeholders want from the intended system. Three main groups of stakeholder needs include:

i) Centers' Needs, such as TMC, highway patrol (dispatch), and fleet management centers, truck facility operators, amongst others.

ii) Field Needs, related to commercial truck drivers, personal auto travelers, maintenance supervisors, snow plow operators, and highway patrol (in the field).

iii) Wide Area Needs, namely 511 phone, application and website consumers and media.

A detailed description of the stakeholder needs is provided in the *Connected Vehicle Pilot Deployment Program Phase 1, Concept of Operations (ConOps)* Document (Gopalakrishna et al., 2015). Given the overlap between the identified stakeholder needs, they were combined and analyzed to develop the needs for the system, see Table 2-2.

Table 2-2. User Needs for CV Pilot System.

UN #	List of User Needs
1	Support warnings of impeding forward collision in a host vehicle based on information received from a remote vehicle.
2	Support ability to provide situational awareness of road conditions on the corridor to an equipped vehicle.
3	Support notification of distress conditions to and from equipped vehicles.
4	Support notification of warnings about work zones to equipped vehicles.
5	Support Spot Weather Impact Warning (SWIWs) to equipped vehicles.
6	Support WYDOT Corridor Management & Traditional Traveler Information Program Services.
7	Need capability to monitor and update CV Pilot field devices system health (up-time, communication strength, device status) remotely during normal and adverse weather conditions.

UN #	List of User Needs
8	Need to develop an HMI that minimizes the distraction and does not pose a burden on the work load of the driver.
9	Need capability through the pilot of logging time-stamped data for various pilot elements
10	Need a capability to collect, manage, store data collected from equipped fleets as part of the pilot.
11	Need to be able to share data to/from vehicles to field, and back-office systems in both real-time and non-real time for various CV applications.
12	Need to ensure that data transfer is secure. Non-reputable, signed, and secured data sent and received by vehicles in this pilot.
13	Need to be able to share mobile data at required latency for various pilot applications.

3 System of Interest

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

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

- **Deploy and operate around 400 vehicles equipped with OBU with DSRC connectivity**. These vehicles will be a combination of snow plows, fleet vehicles, emergency vehicles and private trucks that will broadcast a BSM, collect vehicle, weather and road condition data, and provide it remotely to the WYDOT TMC. These vehicles will also receive in-vehicle alerts through the infrastructure and wirelessly from various applications developed as part of the pilot through a HMI.
- **Deploy around 75 RSUs with DSRC connectivity** that are able to transmit advisories and alerts through Traveler Information Messages (TIM) to equipped vehicles along I-80.
- **Leverage the data provided from the equipped vehicles** to develop and demonstrate a suite of V2V and V2I applications. As part of the pilot, several applications will be developed to support wide-area travel advisories, VSL postings, forecast road condition information, spot-specific warnings, work zones, DNs, and parking notifications.
- **Enable overall improvements in WYDOT's traffic management and traveler information practices** by using data collected from connected vehicles.

The CV Pilot is considered a System of Systems, with two Systems of Interest: The *Vehicle System* and the *Wyoming CV System*, illustrated in Figure 3-1. The *Vehicle System* includes four Sub-Systems that represent the various vehicle and equipment types to be used in the pilot. These Sub-Systems vary in their data collection and sharing capabilities. The *Wyoming CV System* includes the infrastructure used in the pilot and back-office systems in charge of the various processes that lead to the generation and distribution of advisories and alerts. Together, the Vehicle and *Wyoming CV System*s support a variety of V2V and V2I applications. Both systems interface with external systems, including WYDOT, USDOT and the National Weather Service (NWS).

The CV Pilot Project will, at its core, provide key information to the drivers through five on-board applications: (1) Forward Collision Warning (FCW); (2) I2V Situational Awareness; (3) Distress Notification (DN); (4) Work Zone Warning (WZW); and (5) Spot Weather Impact Warning (SWIW). In addition, the CV Pilot project will support overall traffic management and traveler information services offered by WYDOT. These applications are explained in more detail in Section 4.5. Physical Architectural Views by Application and Support Functions.

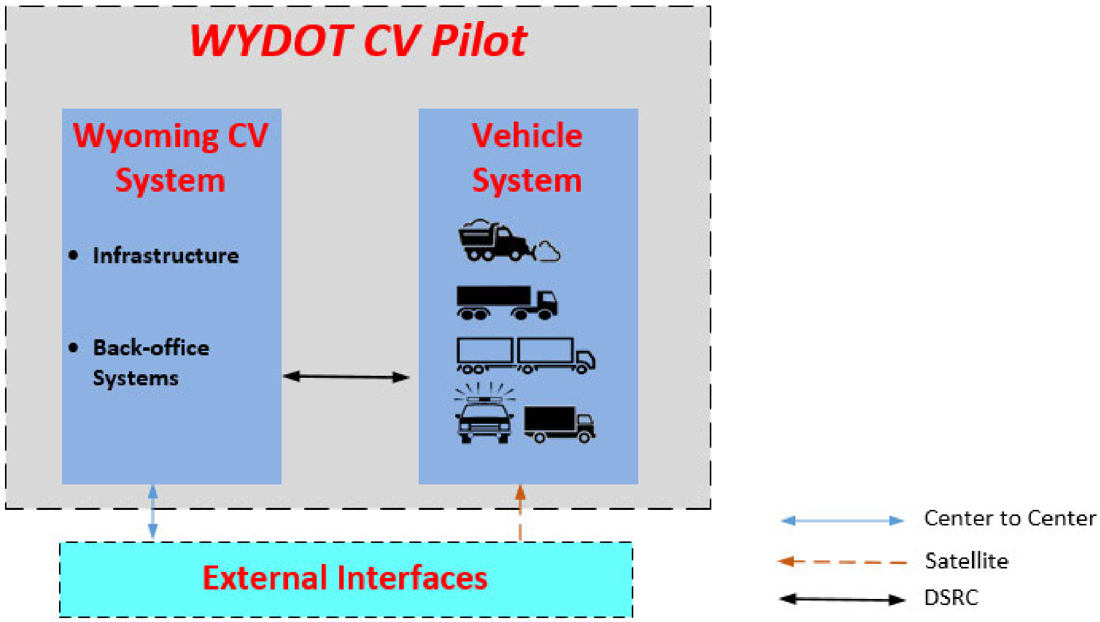

Figure 3-1. WYDOT CV Pilot System of Systems. (Source: WYDOT)

Through these applications and functions, WYDOT hopes to improve operations on the corridor especially during periods of adverse weather and when work zones are present. By means of the anticipated outcomes of the pilot, fleet managers will be able to make better decisions regarding their freight operations on I-80, truckers will be made aware of downstream conditions and provided guidance on parking options as they travel the corridor, and automobile travelers will receive improved road condition and incident information through various existing, improved and new information outlets.

4 Viewpoints, Views and Models

This chapter contains multiple architecture views; each view adheres to the conventions of an architecture viewpoint. This section describes the architectural viewpoints, views and models important to the pilot thru the use of block diagrams. In detail, this section describes the following views:

1. **Enterprise Architecture View**, describing the relationships between organizations required to support the overall system architecture.
2. **Functional Architecture View**, describing abstract functional elements (processes) and their logical interactions (data flows) that satisfy the system requirements.
3. **Physical Architecture View of Systems and Interfaces**, describing the physical objects (systems and devices), their application objects, and the high-level interfaces between those physical objects. This is the most fundamental model of the architecture. Each block is a specific, tangible, physical entity in the system.
4. **Data and Information Flow View**, describing the flow of messages (e.g., BSM and TIM) and data between elements of the system.
5. **Physical Architecture View of Applications and Support Functions,** describing the physical objects and interfaces that enable the operation of on-board applications.
6. **Communications Architecture View**, describing the communications protocols between system objects.
7. **Security Architecture View,** describing the SCMS that generates the security certificates necessary to manage messages securely from connected devices.
8. **CV Pilot Interoperability Support and Information Flow "Triples"**, identifying project reports where further information on these topics may be found.

4.1 Enterprise Architecture View

The enterprise architecture view shows the relationship between organizations required to support the overall system architecture. The following subsections detail the partners of the WYDOT CV Pilot and their roles.

4.1.1 Deployment Team and Partners

WYDOT leads the deployment team of Phase 2 and Phase 3. Figure 4-1 presents the deployment team and partnerships, distinguished by the nature of engagement that WYDOT expects to have with the entity for the pilot. Four main types of partnership agreements are used as part of the pilot:

- Intra-agency agreements that define various roles and responsibilities for WYDOT departments.
- Memorandums of Understanding (MoUs) with participating freight partners.

- Contractual agreements to support the program development, systems integration and training needs.
- Vendor Purchase Agreements that will be initiated to procure equipment for the CV Pilot.

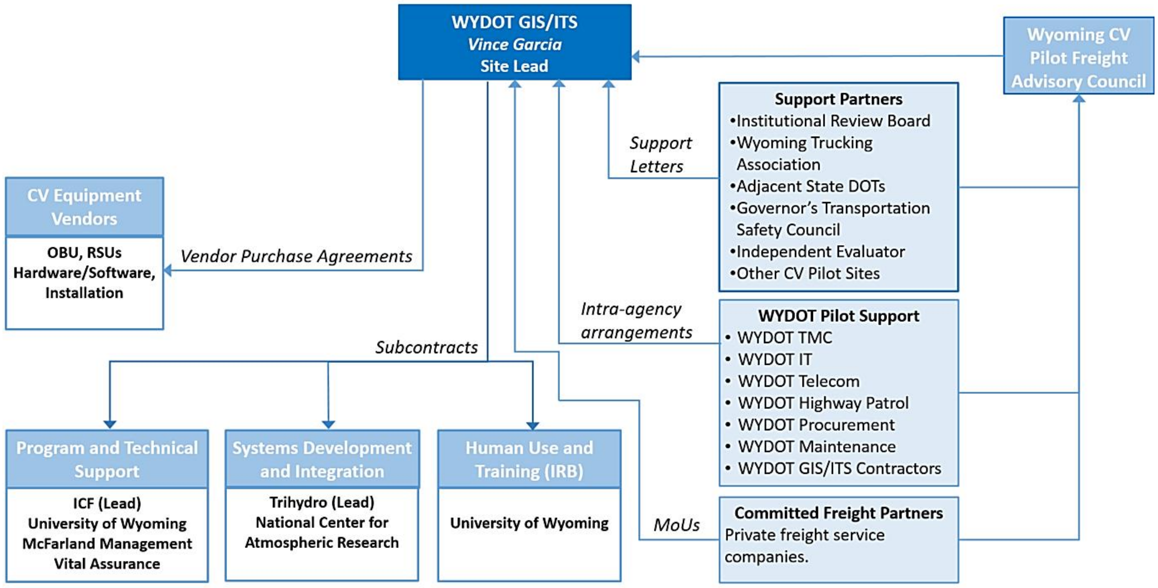

Figure 4-1. Deployment Partnership. (Source: WYDOT)

4.1.1.1 Wyoming Department of Transportation

WYDOT as the grant recipient for the pilot, is the overall lead and responsible for the governance of the Phase 2 and Phase 3 of the pilot. Led by the GIS and ITS group, WYDOT is responsible for delivering the scope of work identified in the grant award. WYDOT is supported by a contractor team and partners to deliver the pilot per the agreement between USDOT and WYDOT. Several of WYDOT's departments are involved in the pilot, including:

- Traffic Management Center Personnel
- Telecommunications
- Highway Patrol
- Maintenance
- ITS Maintenance
- Information Technology (IT)
- Planning
- Contracts/Procurement
- GIS/ITS Contractors

4.1.1.2 Subcontractors

WYDOT issued three contracts to support the pilot:

- **Program and Technical Support Contract** – A team led by ICF International, who led Phase 1 of the Pilot, provides overall program management support and support to various systems engineering tasks and lead the performance management, evaluation, and outreach activities. Program and Technical Support services in addition to ICF includes:

- University of Wyoming (UoW, directly contracted with WYDOT, technical scope of work overseen by ICF)[3] – supports the performance management and evaluation of the CV Pilot system in Phase 2 and Phase 3.
- McFarland Management (directly contracted with WYDOT, technical scope of work overseen by ICF) – coordinates all performance management and evaluation activity for the pilot.
- Vital Assurance (sub-contractor to ICF) – a group of consultants that includes Dr. Denny Stephens, a national expert in development, field deployment, testing and demonstration of connected vehicle technology in commercial vehicles and automobiles. Dr. Stephens supports the definition of the system architecture, system design and testing approaches for the Phase 2 pilot.

- **Systems Development and Integration Lead –**Led by the systems integration lead, Trihydro staff is responsible for system design, application development, testing during Phase 2 and monitoring of systems operations in Phase 3. Trihydro includes one additional firm:
  - National Center for Atmospheric Research (NCAR) – responsible for the development of the weather-related application portions for the CV Pilot, including integrating the Pikalert System with the overall CV Pilot.
- **Human Use and Training Lead –** WYDOT contracted directly with the UoW to support human use approvals and trainings. While UoW is a subcontractor to WYDOT (Lead Agency) who will supervise their work, UoW serves as the oversight agency of all Human Use activities (the Institutional Review Board (IRB) of record). This contract includes amendments to the IRB but also support to the testing and training of CV Pilot elements using the university truck and car simulators.

4.1.1.3 Vendors

The following equipment and technology are being procured through WYDOT's procurement guidelines in Phase 2 of the pilot:

- On-Board Units – several types of units are being procured from one or more vendors. OBU procurement includes support costs and some installation costs; might also include costs for supporting equipment such as cabling, tablet interfaces, and antennas. OBU vendors are being requested to supply hardware and software with a three-year support contract. All custom software paid for by the pilot will be posted on the Open Source Application Development Portal (OSADP) using an Apache 2.0 license. Software included with the hardware will remain the intellectual property of the supplying vendor.
- RSUs – vendors are being requested to supply hardware and software with a three-year support contract. All custom software paid for by the pilot will be posted on the OSADP

[3] Both UoW and McFarland Management are directly contracted with WYDOT to minimize the overhead, fees and sub-admin costs that will arise out them being a subcontractor to ICF. UoW as a state entity has a lower indirect burden for public agencies allowing for cost efficiencies.

using an Apache 2.0 license. Software included with the hardware will remain the intellectual property of the supplying vendor.

- Mobile Weather Sensors – vendors are being requested to supply hardware and software with a three-year support contract. All custom software paid for by the pilot will be posted on the OSADP using an Apache 2.0 license. Software included with the hardware will remain the intellectual property of the supplying vendor.
- Support for Third-Party Integration –includes anticipated costs to support integration of CV Pilot data by external third parties (DriveWyze, Omnitracks, Inrix, etc.).
- Hardware/Software Development – to support back-office systems including data warehouses, databases.
- Installation Support Contracts – for installation of RSUs and OBUs.

4.1.1.4 Fleet Partners

Fleet participation is critical to the success of the project. Participation includes making vehicles available for on-board equipment installation, subscriptions to WYDOT's commercial vehicle operator portals, training, and participation in performance measurement activities, as stablished in the Performance Measurement and Evaluation Support Plan (Kitchener, et al. 2016).

With the IRB approval, WYDOT will enter into MoUs with fleet partners for the pilot. WYDOT actively seeks a diversity of trucking firms to participate in the pilot starting with small local firms to large national carriers.

4.1.1.5 Support Partners

The WYDOT CV Pilot also interacts with external entities. The USDOT and other supporting contractors play a significant role in this project. USDOT participation includes the provision of several USDOT-developed interfaces necessary for the deployment of the system's applications (e.g., the Operational Data Environment (ODE) and Situational Data Warehouse (SDW)).

Additionally, USDOT hired an Independent Evaluator (IE) who is in charge of providing independent evaluation of the CV Pilot System. The IE team will focus on measures not covered by the Wyoming team's evaluation, impacts of larger scale CV deployments, and 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.

The WYDOT CV Pilot also has support from the UoW IRB, adjacent State DOTs and trucking associations as part of the pilot.

4.1.1.6 WYDOT CV Pilot Freight Advisory Council

With an eye towards the post-pilot operations, Wyoming DOT is setting up a new freight advisory council to provide advisory support for the pilot. The freight advisory council consists of representatives from WYDOT, fleet partners who are participating in the pilot, local freight stakeholders who use CVOP, Transportation Safety Council, and the Wyoming Trucking Association. Wyoming DOT anticipates that the freight advisory council will meet quarterly starting in Phase 3. The freight advisory council is a sounding board for WYDOT to discuss pilot development. As the project progresses, the advisory council will support WYDOT in the post pilot transition planning assisting in setting priorities for application updates, and supporting growth in number of fleets that have access to this technology.

4.1.2 Summary of Partners

Table 4-1 summarizes the role and responsibilities of the different partners that are part of the CV Pilot.

Table 4-1 Summary of Partner's Roles.

Partner	Elements Owned	Data/Services Provided	Data/Services Consumed	Agreement
GIS/ITS	Wyoming CV System. WYDOT Vehicle Fleet.	Back office services and management of Wyoming CV System.	All CV-Pilot data	—
Traffic Management Center		Data for Project Evaluation.	New/upgraded operation systems. Road weather condition and incident data.	Intra-agency
Tele-communications		Support services for installation and maintenance of OBU, RSU and DSRC licensing.		Intra-agency
Highway Patrol	Highway patrol vehicles and officers.	Participate in the evaluation of CV technology.	Road weather condition and incident data	Intra-agency
Maintenance	WYDOT Vehicle Fleet (snow plow vehicles and drivers).	Evaluation of CV technology.	Road weather condition and incident data	Intra-agency
Contracts/ Procurement		Oversee contracting and purchasing.		Intra-agency
Information Technology		Support for back-office administration of the Wyoming CV System and CV Pilot website development.		Intra-agency
Public Affairs Office		Support for outreach activities.		Intra-agency
WYDOT Safety and Planning Groups		Engagement with various internal stakeholders around safety data, freight planning.		Intra-agency
ICF		Support Overall program management and systems engineering. Support to various tasks, lead the performance management, evaluation, and outreach activities.		Contract
Trihydro	Vehicle fleet.	Lead the system design, application development, testing during Phase 2 and monitoring the	Road weather condition and incident data	Contract

Partner	Elements Owned	Data/Services Provided	Data/Services Consumed	Agreement
		operations of the system in Phase 3.		
University of Wyoming	Truck and car simulators.	Act as the IRB of record. Support continued human use approvals and trainings. Support the testing and training of CV pilot elements. Support the performance management and evaluation of the CV Pilot system.	Human use and training data	Contract
McFarland Management		Coordinate all performance management and evaluation activity for the pilot.	System performance data	Contract
Vital Assurance		Support in defining the system architecture, system design and testing approaches for the pilot in Phase 2.		Contract
NCAR	Pikalert system	Support the development of the weather-related application portions for the CV Pilot.	CV and non-CV weather data	Contract
Fleet Partners	Integrated and Retrofit Vehicles	Provide vehicle fleet and drivers.	Road weather condition and incident data	MoU and Support Letter
Vendors	OBUs, RSUs, weather sensors, and back-office systems	Provide hardware, software, customization, installation and maintenance support.	Hardware/Software performance data	Purchase Agreements

4.2 Functional Architecture View

This section describes functions to be performed by the *Vehicle System* and the *Wyoming CV System*. The *Vehicle System* will perform eight functions:

1. Collect CV Data – Connected vehicles wirelessly receive BSMs from other connected vehicles.
2. Collect TIMs – Wirelessly receives packets containing traveler information from the *Wyoming CV System* and distress information from other connected vehicles.
3. Manage and Process Information for Applications – Manages and processes information for the five on-board applications (described in Section 4.5. Physical Architectural Views by Application and Support Functions).
4. Provide In-Vehicle Application Alerts – Provides prioritized alerts and advisories for the Vehicle Operator.
5. Broadcast Vehicle Data – Broadcasts, at a predefined rate, vehicle information (BSMs and DNs) to other connected devices and to the *Wyoming CV System*.
6. Transmit Vehicle Data – Transmits vehicle probe data to the *Wyoming CV System*. The transmission includes event logs and DNs (including those of other connected vehicles).

7. Store Data – Locally stores selected data collected and generated (both from the field and the applications) until they are transferred to the *Wyoming CV System*.
8. OBU Management – Logs availability and operational capability, including validating and obtaining certificates, time and location accuracy, logging system information, and routine wellness check.

The Wyoming *CV System* performs six functions:

1. Collect CV Information – Collects data from the *Vehicle System*. Data collected includes BSMs Part I and Part II, event logs, other probe data (e.g., weather sensors), and DNs.
2. Generate Road Weather Alerts and Advisories – Generates segment-level advisories and alerts of both current and forecast road and weather conditions based on customizable thresholds.
3. Support Information Brokerage – Distributes Road Weather Alerts and Advisories to the WYDOT's interfaces.
4. Distribute TIMs – Distributes the TIM to the *Vehicle System* and the SDW.
5. Store Data – Data generated are stored by the system.
6. Manage and Maintain System – The WYDOT Maintenance team monitors the system for availability and operational capabilities.

In addition to on-board vehicle applications, information generated by the Wyoming CV System is expected to be used to support WYDOT traffic management and traveler information. WYDOT expects to use the information from the pilot for the following purposes:

- **Setting and removing VSL along the I-80 corridor –** VSLs will be managed through the Wyoming Traveler Information (WTI) interface. When segment-level alerts and advisories are received from the *Wyoming CV System* in WTI, the TMC operator will have the option to reduce speed according to the normal operation protocols. Similarly, when speed limits are reduced due to information available from the TMC, this information will be communicated with the *Wyoming CV System* and shared as part of the TIM. The VSL zones utilize changeable yet enforceable speed limits in 143 miles along four (4) segments – 23 miles around Evanston, 25 miles around Green River, 57 miles along Elk Mountain and 47 miles between Cheyenne and Laramie.
- **Supporting 511 and other traveler information** – Road weather collected by the Wyoming CV System will be ingested into and processed by the Pikalert system for dissemination to the public. In addition, incident information collected by the CV system will be used to directly update the WTI. The WTI system, upon database saves, has the integrated logic to automatically update the 511 systems (web, phone, email/text messages, app) in near real time.
- **Supporting road weather advisories and freight-specific travel guidance through CVOP** – Information from the *Wyoming CV System* will update the CVOP system to provide freight-specific information to subscribed fleet partners. Currently, more than 800 firms subscribe to CVOP.

The functional architecture view describes the abstract functional elements or processes and their logical interactions via data flows that satisfy the system requirements. Figure 4-2 depicts the functional diagram of the Systems of Interest along with the external interfaces that interact with the CV Systems. Section 4.3 describes in more detail the internal and external interactions of each system.

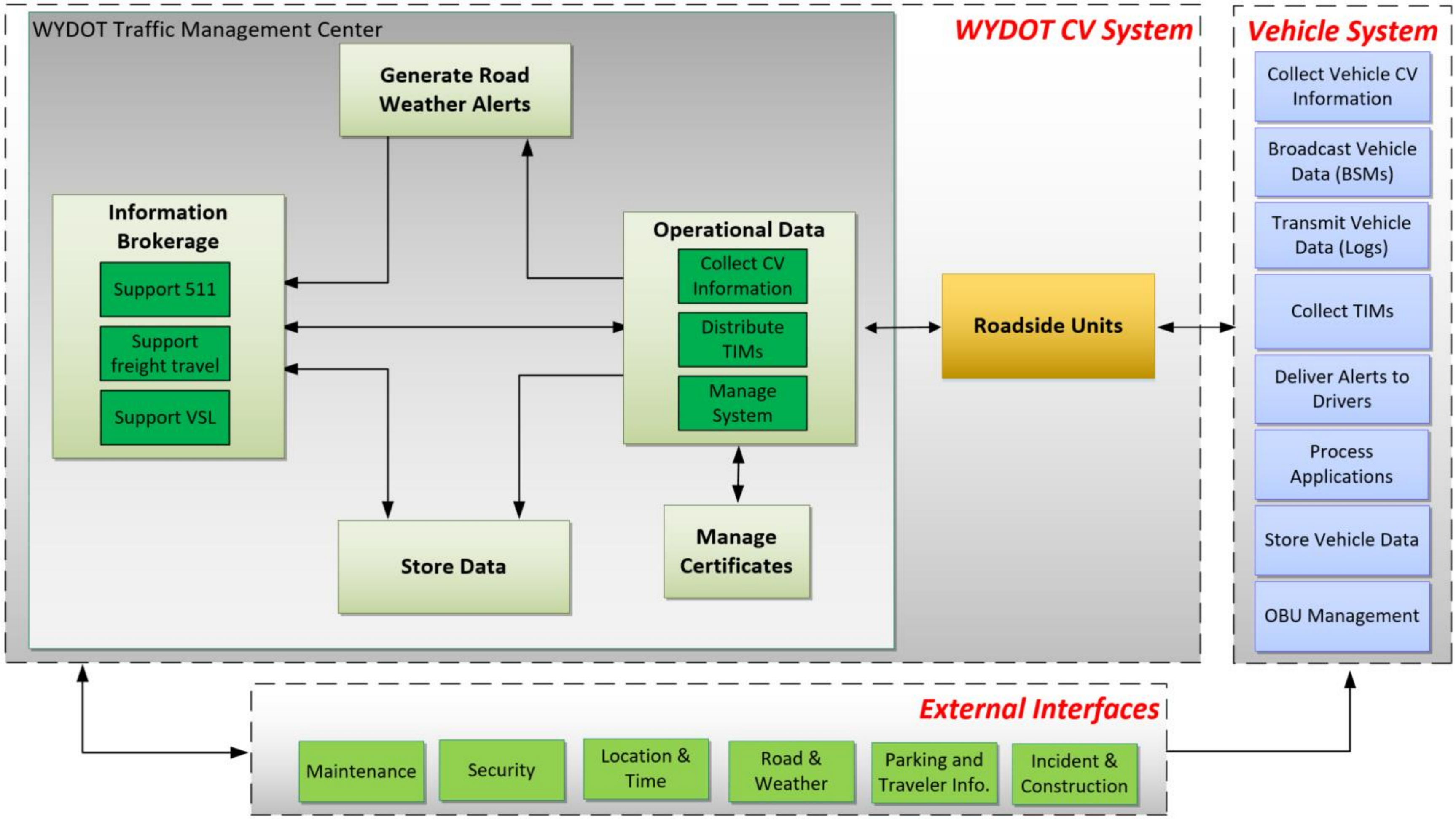

Figure 4-2. Functions of the Wyoming CV System and the Vehicle System. (Source: WYDOT)

4.3 Physical Architecture View of Systems and Interfaces

The physical view model represents the block diagram of the systems and interfaces in the WYDOT CV Pilot. Figure 4-3 provides a detailed graphical view of the physical architecture of the WYDOT CV Pilot and interactions that occurs within and between the different entities. Figure 4-4 shows a similar view of the architecture generated using the SET-IT Tool. This view illustrates the result of design decisions made by the WYDOT team for implementing the Vehicle and Wyoming CV Systems. Furthermore, these figures present the physical architecture that is used by the project team to establish plans for system integration and testing, as well as to track and report readiness for deployment.

The next subsections describe each entity in the figure and the logical connections between them.

4.3.1 CVRIA view of Applications

Figure 4-4 and later diagrams in this report were developed using the SET-IT and the CVRIA. The USDOT describes SET-IT as a “software tool that integrates drawing and database tools with the CVRIA so that users can develop project architectures for pilots, test beds and early deployments.” While constantly evolving, the CVRIA is a “set of system architecture viewpoints that describe the functions, physical and logical interfaces, enterprise relationships, and application dependencies within the connected vehicle environment. Both tools seek to standardize the use and development of the CV environment.

Figure 4-5 presents the legend for SET-IT and CVRIA diagrams that identify the meaning of colors, line color and format, and line numbering. Letters and numbers are used to characterize data flow time and special context. Connector format describes flow status, cardinality, control and security. Box colors and icons are used to describe element types.

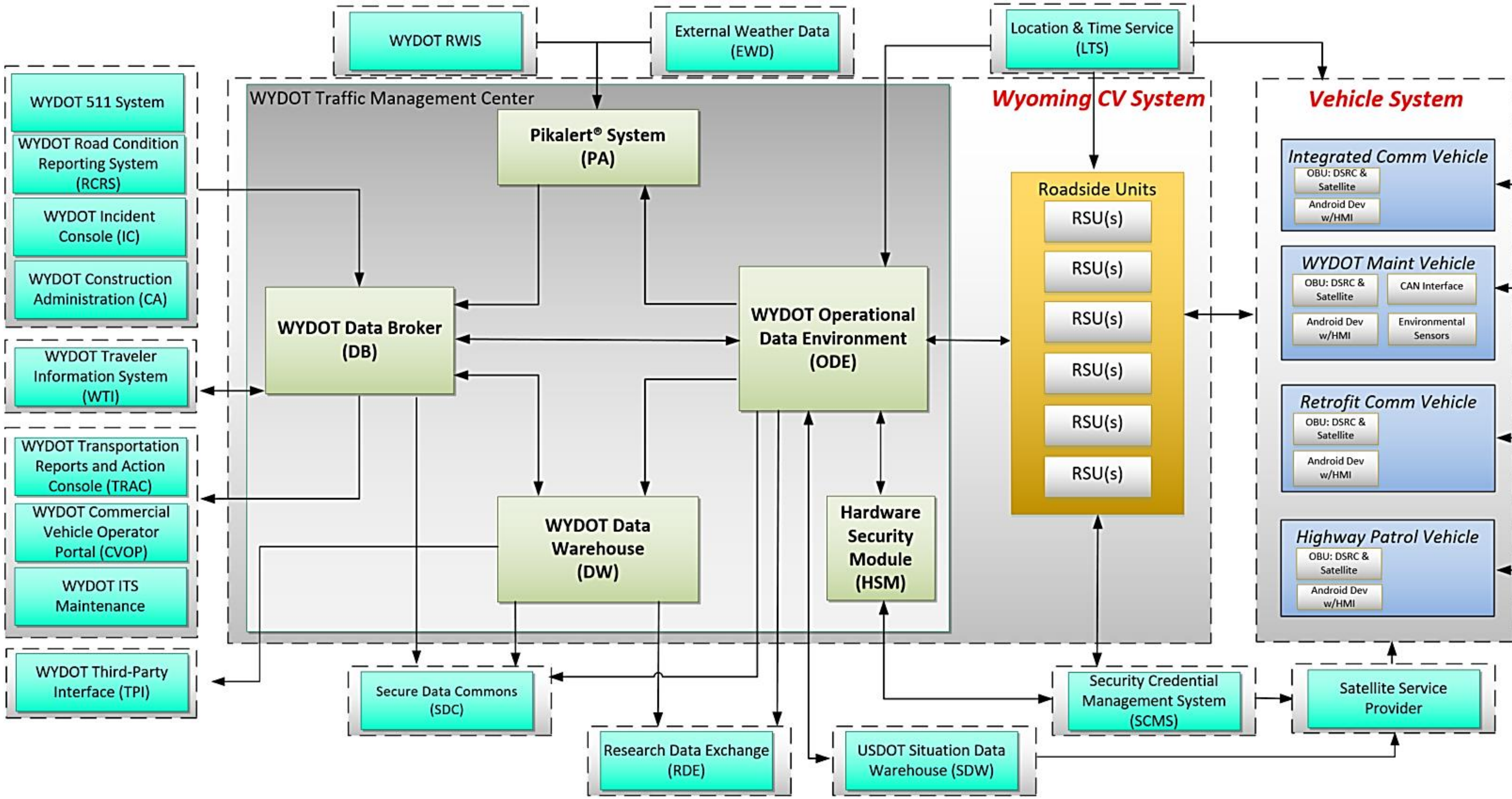

Figure 4-3. Physical View of WYDOT CV Pilot System Architecture. (Source: WYDOT)

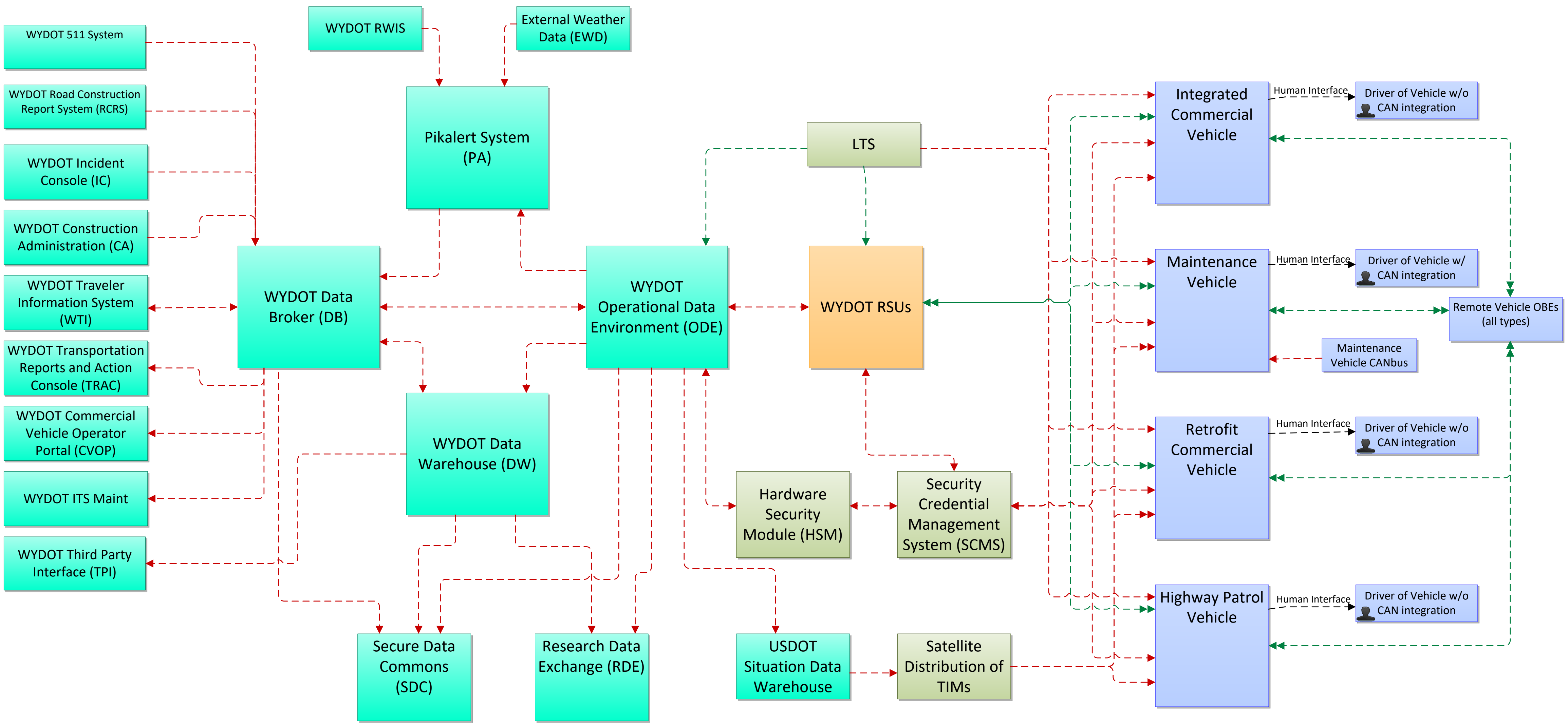

Figure 4-4. Physical View of WYDOT CV Pilot System Architecture from SET-IT. (Source: WYDOT)

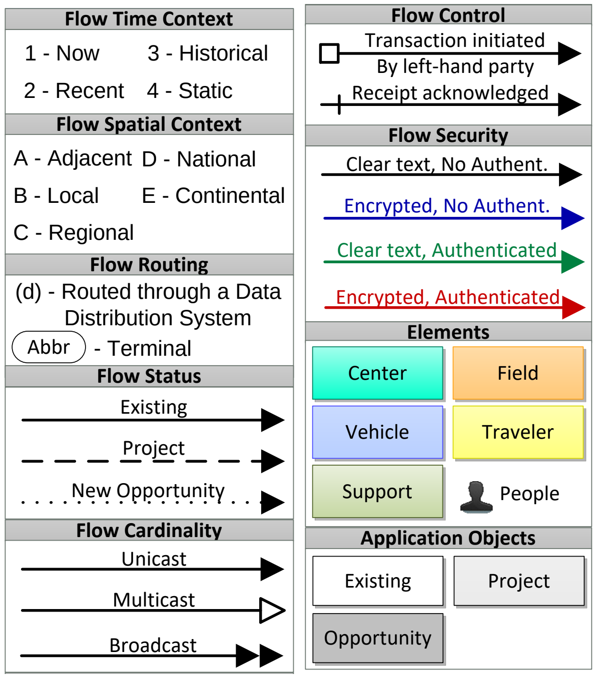

Figure 4-5. Legend for SET-IT and CVRIA Diagrams. (Source: WYDOT)

4.3.2 Wyoming CV System

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

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

- RSU
- ODE
- Hardware Security Module (HSM)
- Pikalert System
- Data Broker (DB)
- Data Warehouse (DW)

4.3.2.1 Roadside Units

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

4.3.2.2 Operational Data Environment

The WYDOT ODE Sub-System receives information collected with connected devices, checks its quality, and then shares it with other Sub-Systems in charge of analyzing and distributing the information. The ODE also exports data to the SDW for USDOT-related activities. The ODE will be hosted at WYDOT TMC and uses the same codebase as the USDOT ODE. High-level requirements for the ODE are contained within the Task 4 ODE ConOps from the Southeast Michigan Test Bed Advanced Data Capture Field Testing. These include requirements for Validation, Integration, Sanitization, and Aggregation, which are combined in this document with the description of ODE processed data.

4.3.2.3 Hardware Security Module

The Wyoming CV Pilot uses the IIS/GHS[4] rented, black box hardware security module (HSM) in the Cheyenne TMC. In essence, the HSM will manage the Wyoming CV System's certifications. It has a Representational State Transfer (RESTful)[5] endpoint that receives an unsigned TIM and outputs a signed TIM. The HSM also has a link to the ISS/GHS Certificate Management System (CMS) to get updated certifications. It should be noted that its internal workings are a black box that is proprietary code, and therefore WYDOT will not have access to it. WYDOT will physically have two 1U rack[6] units that each have dual power supplies and are fail over in capability. The units also have a gig Ethernet connection with IPv4 and IPv6.

4.3.2.4 Pikalert System

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

4.3.2.5 WYDOT Data Broker

WYDOT DB receives information from the ODE, Pikalert and some external systems, analyzes them, and shares them with the corresponding system or service including other sources. The DB supports the information brokerage of road weather alerts and advisories to WYDOT's Third-Party Interface (TPI), TRAC, WTI, Road Condition Reporting System (RCRS), and CVOP. Additionally, this system takes in incident information from the Incident Console (IC), work zone data from the Construction Administrator and parking availability information from the 511

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[4] IIS/GHS is the company hosting the pilot's certificate management system (i.e., INTEGRITY Software Services/Green Hills Software).

[5] https://en.wikipedia.org/wiki/Representational_state_transfer

[6] Rack height unit 1.75" (https://en.wikipedia.org/wiki/Rack_unit)

Application. The DB also sends the information back to the ODE to support the dissemination of TIM to the RSUs and can also access historical data stored at the DW if needed.

4.3.2.6 WYDOT Data Warehouse

The WYDOT DW stores various TMC- and CV-related data. The DW includes timestamped and geotagged logs of CV and non-CV data—information collected, generated and shared within the *Wyoming CV System*—that will be used for performance measurement, as stablished in the Performance Measurement and Evaluation Support Plan (Kitchener, et al. 2016).

4.3.2.7 Allocation of Functions to Wyoming CV System Physical Components

The functional architecture described in Section 4.2 and the physical architecture described in this section were drafted during development of system requirements as described in the WYDOT CV Pilot Phase 1 SyRS. The functions described in Section 4.2 were allocated to subsystems. Vehicle system functions were all allocated to vehicle OBUs. The allocation of Wyoming CV System functions to subsystems is illustrated graphically through comparing Figure 4-2 and Figure 4-3 and is summarized in Table 4-2 below.

Table 4-2. Allocation of Wyoming CV System Functions to Subsystems.

Function	Allocated Subsystem
Collect CV Information	ODE
Generate Road Weather Alerts and Advisories	Pikalert
Support Information Brokerage	DB
Distribute TIMs	ODE
Store Data	DW
Manage and Maintain System	ODE

4.3.3 Wyoming CV System External Interfaces

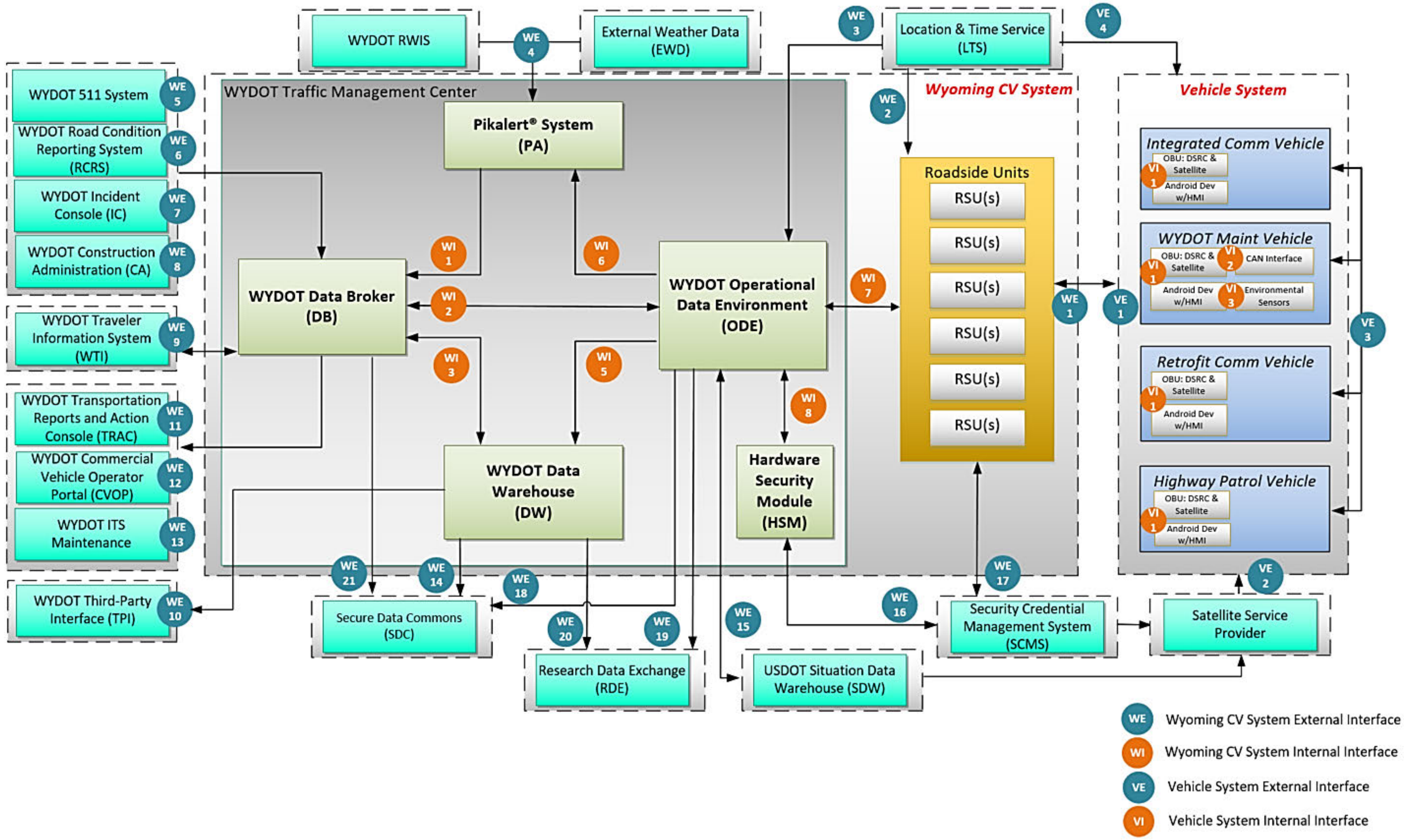
Figure 4-6 shows the physical architecture with interfaces numbered for reference and discussion here and in following sections. The Wyoming CV System includes the following external interfaces for exchanging data and information with external WYDOT and USDOT systems.

- **I2V DSRC Communications Interface** (Interface WE1) Wireless DSRC interface provides communication between Wyoming CV System and Vehicle System through exchange of messages conforming to SAE J2735 and SAE J2945/1.
- **Location and Time Service (LTS)** (Interfaces WE2 and WE 3) – Provides location and time information, which is later used to geotag and timestamp all information produced by the systems of interest.[7]
- **EWD and RWIS** (Interface WE4) – EWD provides regional weather data shared through data sources outside of WYDOT, such as the National Oceanic and Atmospheric Administration's Meteorological Assimilation Data Ingest System and USDOT. **RWIS** provides atmospheric and pavement condition information collected through

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

Environmental Sensor Stations (ESS) deployed as part of the WYDOT RWIS network in the field.

- **WYDOT 511 Application** (Interface WE5) – Provides information to the public regarding I-80's road weather and traffic conditions (e.g., road closure). The application is currently being updated to also share crowdsourced truck parking information with the CV Pilot.
- **WYDOT RCRS** (Interface WE6) – An Android tablet-based application that resides in WYDOT snow plows which enables field personnel (e.g., snowplow operators) to report weather and roadway pavement conditions following WYDOT's 8 Code (roadway condition), 9 Code (atmospheric) and 10 Code (other road condition) system.
- **WYDOT IC** (Interface WE7) – Provides timestamped and geotagged incident information on incidents along I-80 obtained from the WHP and other sources (e.g., maintenance).
- **WYDOT Construction Administration (CA)** (Interface WE8) – Provides timestamped and geotagged information of WYDOT's scheduled and unscheduled work-zone activities along I-80.
- **WTI** (Interface WE9) – Supports traveler information services to the public and to fleet management centers via various means (website, 511, 511 App, text, email, and alerts).
- **WYDOT TPI** (Interface WE10) – A standardized interface based on the TMDD standard that can be used to support delivery of traveler information to external centers and information service providers.
- **WYDOT TRAC** (Interface WE11) – An operator console used in the TMC to monitor and manage planned, ongoing, and forecast events and actions on facilities monitored by the TMC. The TRAC provides a tabular list of currently ongoing events that require operator attention. These events may be entered manually and can be reported based on other systems like RCRS, radio communications with field personnel and citizen reports.
- **WYDOT CVOP** (Interface WE12) – A subscription-based website created by WYDOT for providing advanced notification of forecasted conditions to commercial travelers and fleet managers. Currently there are over 800 companies subscribed to the CVOP. As part of the CV Pilot System, the CVOP will be enhanced to include current weather information for segments on I-80.
- **WYDOT ITS Maintenance** (Interface WE13) – Provides a mechanism to report service outages and resumption of services of WYDOT's ITS equipment.
- **Secure Data Commons (SDC) / Research Data Exchange (RDE)** (Interfaces WE14, WE18, WE19, WE20, and WE21) **–** Provides WYDOT CV Pilot data to the independent evaluators and the RDE for use in independent analysis and impact evaluation across multiple CV pilots.
- **USDOT SDW** (Interface WE15) – A service operated by USDOT that stores near real-time data and shares them with the remote users and developers for further distribution. As shown, this interface also supports communication of messages through **Satellite Service Provider (SSP)** satellites, allowing the system to transmit traveler-related information.
- **USDOT SCMS** (Interfaces WE16 and WE17) – Generates security certificates to manage messages securely from connected devices. As shown, this interface also supports communication of messages through **SSP** satellites, allowing the system to SCMS-related information.



NOTE: The Wyoming CV System Interface WI4 (PA→DW) was not implemented in the final system design.

Figure 4-6. Physical View of WYDOT CV Pilot System Architecture with Numbered Interfaces. (Source: WYDOT)

4.3.4 Vehicle System

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

- Ability to share and receive information via DSRC communication from other connected devices (vehicles and RSUs).
- Ability to broadcast BSM.
- An HMI that allows alerts and advisories to be communicated with the driver.

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

4.3.4.1 WYDOT Maintenance Vehicles

This Sub-System represents the maintenance fleets operated by WYDOT. This includes, but is not limited to, snow plow vehicles assigned to the I-80 corridor. These vehicles represent a set of vehicles over which WYDOT has full control as part of their operations. As such, some of the vehicles will be equipped with the full package of environmental sensors and equipment necessary to support the CV Pilot applications.

Around 95 vehicles are expected to be part of this sub-system, but not all with the same capabilities. Al vehicles will have the ability to:

- Receive TIMs via DSRC and Satellite.
- Broadcast BSM Parts I and II.

Whereas 50 of them are expected to be able to:

- Collect weather sensor data.

All vehicles within this subsystem will have the capability to integrate its network via a Controller Area Network (CAN bus) connection. Although it should be noted that the actual number of vehicles to have this connection is expected to be a limited and will be determined at a later stage of deployment.

4.3.4.2 WYDOT Highway Patrol Vehicles

This Sub-system represents the highway patrol fleet assigned to the I-80 corridor. While also operated by WYDOT, these vehicles represent a set over which WYDOT has less flexibility given the nature of their operations. Around 35 highway patrol vehicles are expected to be part of this sub-system, which will have the ability to:

- Receive TIMs via DSRC and Satellite.
- Broadcast BSM Parts I and II.

4.3.4.3 Integrated Commercial Vehicles

This connected trucks Sub-System represents a subset of commercial trucks owned and operated by fleet partners involved in the pilot. Similar to Highway Patrol Vehicles, no external weather sensor data will be collected from these systems (i.e., only data from the vehicle) and there is not CAN Bus integration. To summarize, this Sub-system will include the abilities to:

- Receive TIMs via DSRC and Satellite (or other remote communication methods).
- Broadcast BSM Parts I and II.

In essence, these vehicles represent the capability to use vehicle data collected from trucks in the pilot. WYDOT anticipates that about 250 trucks will have these functionalities.

4.3.4.4 Retrofit Commercial Vehicle

This Sub-system is intended to simulate a commercial-off-the-shelf system—which is different from the one installed on the integrated commercial vehicles—that enables a vehicle to communicate data through DSRC to other connected devices and receive TIMs through DSRC or satellite. About 25 vehicles are expected in this category and their abilities include:

- Receive TIMs via DSRC and Satellite (or other remote communication methods).
- Broadcast BSM Parts I and II.

4.3.5 Vehicle System External Interfaces

The vehicle system includes three external interfaces.

I2V DSRC Communications Interface (Interface VE1, vehicle component of Interface WE1) Wireless DSRC interface which supports local wireless communication between Wyoming CV System and Vehicle Systems through exchange of messages conforming to SAE J2735 and SAE J2945/1.

SSP (Interface VE2) – Provides communication capabilities through satellites, allowing the vehicles to obtain SCMS- and traveler-related information.

V2V DSRC Communications Interface (Interface VE3) – Wireless DSRC interface which V2V communication through exchange of messages conforming to SAE 2735.

LTS (Interface VE4) – Provides location and time information, which is later used to geotag and timestamp all information produced by the vehicle systems.[8]

4.4 Data and Information Flow View

A key objective of the WYDOT CV Pilot system is to capture, process, and deliver useful and valuable information to drivers and other system stakeholders. As described earlier, this will be accomplished through the integrated interaction of multiple systems and subsystems which exchange data and information. These interactions are enabled by physical and software interfaces that communicate (link) the Wyoming CV System, Vehicle Subsystems and External interfaces enumerated in Figure 4-6.

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

For this Pilot, *data* is considered raw (i.e., unorganized and unprocessed) digital messages sent between components. Whereas *information* is processed data that is organized, structured or presented in a given context to make it useful. In this sense, information are the messages, advisories and alerts delivered to drivers and other system stakeholders.

Table 4-3 below summarizes the data and information exchange between the components and subsystems between each interface in the CV Pilot System. They are described here in this table in generic terms. When implemented in the CV Pilot System design, these information exchanges will be in the form of discrete digital messages. Specifications for the messages will be documented in the forthcoming WYDOT CV Pilot System Design Document.

It is important to note that some interfaces in Figure 4-3 already exist and therefore are not considered as part of the development scope of this project. For example, while the Wyoming CV System will support updates to the 511 App on road closure, traffic, weather and public information on the corridor that may be generated, an interface is currently in operation for such updating purposes and the CV Pilot plans to use it.

The interfaces between Vehicle Systems (VE3) and between Wyoming CV System and Vehicle Systems (WE1 and VE1) are treated as external interfaces because they must support full external interoperability with CV vehicles from other CV Pilots and those instrumented by others in accordance with SAE J2735 and SAE J2945/1.

The interfaces between the SSP and the USDOT SDW and the SCMS are outside the oversight and control of the WYDOT CV Pilot. However, the successful integration of these interfaces is critical to the success of the Pilot. The implementation of these interfaces will be monitored closely by the WYDOT CV Pilot team. The team will work closely with the USDOT to develop and implement remedial actions in the case that these interfaces are not implemented successfully in time for WYDOT CV Pilot deployment. The WYDOT CV Pilot is prepared to interface directly from WYDOT ODE to the SSP if the USDOT SDW is not available.

4.4.1 Basic Safety Messages

Connected V2V safety applications are built around the capability to transmit BSMs, following the SAE J2735 standard. The BSM is transmitted over DSRC over a range of approximately 300 meters. BSMs are tailored for low latency, localized broadcasts required by V2V safety applications. This same information may be captured by nearby RSUs and used by the WYDOT CV Pilot System for Situational Awareness and other I2V applications described later.

In general, BSMs are broadcast frequently to provide connected vehicles with data content necessary for the different safety-oriented applications. The BSM is divided into two parts:

- Part I, transmitted approximately 10 times per second, contains the core data elements.
  - Message Count
  - Temporary ID
  - Time (through a Second Mark),
  - Latitude,
  - Longitude,
  - Elevation,
  - Positional Accuracy,
  - Transmission State,

  - Speed,
  - Heading,
  - Steering Wheel Angle,
  - Acceleration,
  - Brake System Status,
  - Vehicle Size
- BSM Part II is added to Part I depending on events or configurations and contains a variable set of data elements drawn from many optional data elements detailed in the ICD.

Table 4-3. List of Data and Information Exchanges for each Interface in the CV Pilot System.

Interface	Origin	Destination	Data / Information Shared	Type*
WE1/ VE1	RSU	Vehicle System	TIM, Software Updates	External
WE1/ VE1	Vehicle System	RSU	SCMS-related (Misbehavior reports), CV-related (BSM, Event Log, Environmental Sensor (ES)), TIM, including DN	External
WE2	FLTS	RSU	Location and time	External
WE2	NTP	RSU	Time	External
WE3	NTP	ODE	Time	External
WE4	RWI	Pikalert	Atmospheric and pavement condition	External
WE4	EWD	Pikalert	Regional weather data	External
WE5	WYDOT 511 System	DB	Parking information	External
WE6	RCRS	DB	8 Code (roadway condition), 9 Code (atmospheric), 10 Code (crash and incident information)	External
WE7	IC	DB	Incident information	External
WE8	CA	DB	Scheduled and unscheduled WZ activities	External
WE9	WTI	DB	Posted speed, vehicle restrictions, messages, and closure information	External
WE9	DB	WTI	Current and forecasted segment-specific advisories/alerts	External
WE10	DW	TPI	Traffic condition	External
WE11	DB	TRAC	DN, Segment alerts	External
WE12	DB	CVOP	Current and forecasted segment-specific advisories/alerts	External
WE13	DB	ITS Maint.	System operational status	External
WE15	ODE	SDW	TIM	External
WE14	DW	SDC	Vehicle speed	External
WE18	ODE	SDC	BSM, DNM	External
WE21	DB	SDC	TIM, DN, Alerts and advisories within TIMs	External
WE20	DW	RDE	BSM, DNM, Custom JSON	
WE19	ODE	RDE	BSM, TIM	External

Interface	Origin	Destination	Data / Information Shared	Type*
WE22	DB	RDE	TIM, DN, Alerts and advisories within TIMs	External
WE16	HSM	SCMS	Request for certificates, Misbehavior reports	External
WE16	SCMS	HSM	Certificates, Certificates Revocation List (CRL)	External
WE17	RSU	SCMS	Request for certificates, Misbehavior reports	External
WE17	SCMS	RSU	Certificates, CRL	External
WI1	Pikalert	Data Broker	Alerts and advisories within TIMs	Internal
WI2	ODE	DB	DN	Internal
WI2	DB	ODE	TIM, Alerts and advisories within TIMs	Internal
WI3	DW	DB	Road condition report, TIM, DN, Alerts and advisories within TIMs	Internal
WI3	DB	DW	TIM, DN, Alerts and advisories within TIMs	Internal
WI5	ODE	DW	All collected and processed data	Internal
WI5	DW	ODE	Road section with mile marker information	Internal
WI6	ODE	Pikalert	CV weather data (BSM Part II, CAN Bus), ES	Internal
WI7	ODE	RSU	TIM, Software Updates	Internal
WI7	RSU	ODE	SCMS-related (Misbehavior reports), CV-related (BSM, Event Log, ES), TIM, including DN	Internal
WI8	HSM	ODE	Certificates	Internal
WI8	ODE	HSM	Request for certificates	Internal
VE2	Satellite	Vehicle System (except Hwy Patrol)	SCMS-related (Certificates, CRL), ODE-related, TIM	External
VE3	Vehicle System	Vehicle System	BSM, TIM, including DN	External
VE4	VLTS	Vehicle System	Location and time	External
VI2	CAN Bus	OBU	Vehicle status	Internal
VI1	OBU	HMI	Processed TIM, including DN, CAN Bus, Notifications from on-board applications	Internal
VI3	ES	HMI	ES, including one or more of the following: Precipitation Type, Solar Radiation, Wiper Frequency, Orientation, GPS Coordinates, Ground Temperature, Ground Profile, Ambient Temperature, Barometric Pressure, Humidity	Internal

*Internal: within the WYDOT CV Pilot System; External: between the CV Pilot System and External System Interfaces.

4.5 Physical Architectural Views by Application and Support Functions

As previously described, the WYDOT CV Pilot will develop five on-board applications that will provide key information to the drivers of equipped vehicles. In addition to on-board applications, information generated by the *Wyoming CV System* is planned to support ongoing WYDOT traffic management and traveler information services. WYDOT expects to use the information from the pilot for:

- Setting and removing VSLs along the I-80 corridor.
- Supporting 511 and other traveler information.
- Supporting road weather advisories and freight-specific travel guidance through WYDOT's CVOP.

The following subsections provide a view of the CV System Architecture from the application perspective. Each of the following subsections provides an overview of an application, followed by a physical architecture view from SET-IT. In order to maintain readable yet insightful architecture views, the figures only present the interfaces that directly relate to each application and support function. As such, some connections are not illustrated when compared to the complete set of interactions presented in Figure 4-3.

4.5.1 Forward Collision Warning Architectural View

FCW is a V2V communication-based safety feature that issues a warning to the driver of the connected host vehicle in case of an impending front-end collision with a connected vehicle ahead in traffic in the same lane and direction of travel on both straight and curved geometry roadways as illustrated in Figure 4-7. FCW will help drivers avoid or mitigate front-to-rear vehicle collisions in the forward path of travel. This application is critically important for safety along I-80 in conditions when snow plows are moving slower than following traffic and/or when visibility may be limited due to adverse weather. The application does not attempt to control the host vehicle to avoid an impending collision. This application will follow the description from standard SAE J2945/1 March 2016 Section 4.2.4.

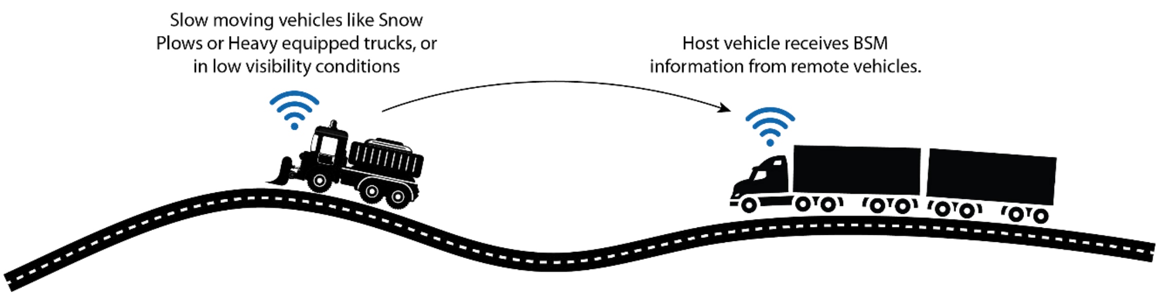


Figure 4-7. Forward Collision Warning Concept Diagram. (Source: WYDOT)

Figure 4-8 presents the physical architectural view of this application. Here, all vehicles broadcast their location and motion, through their BSM. Each vehicle, serving as its own host, compares its motion with vehicles ahead and issues alerts to the driver if it identifies potential for a forward collision.

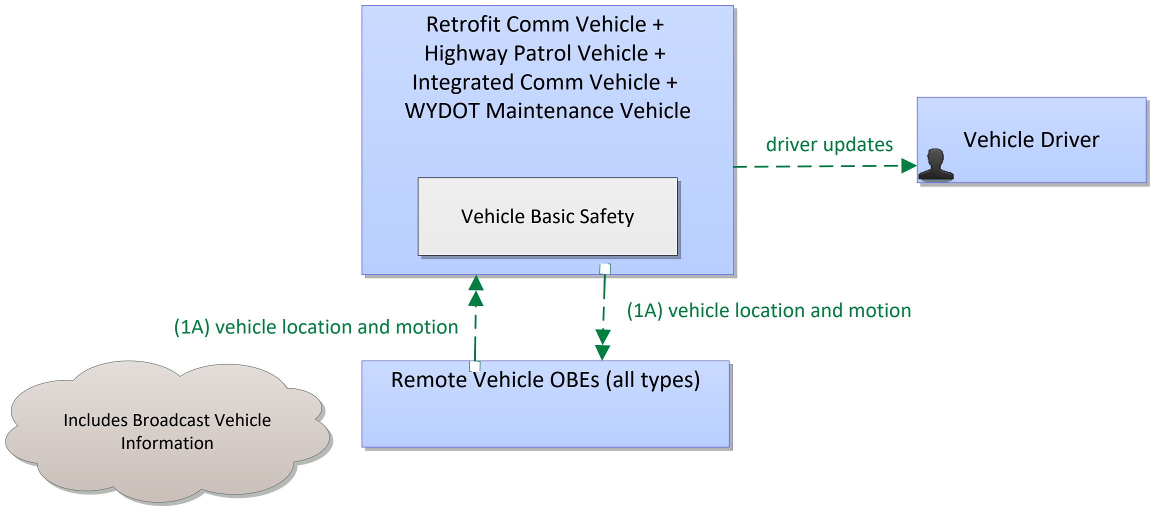


Figure 4-8. Physical Architectural View of the Forward Collision Warning Application. (Source: WYDOT)

4.5.2 Distress Notification Architectural View

This application enables connected vehicles to communicate a distress status back to Wyoming CV System when the vehicle's sensors detect an event that might require assistance from others (e.g., air bag deployed, vehicle disabled) or the vehicle's operator manually initiates a distress status. The vehicle generates and broadcasts a DN (e.g., Mayday) to the nearest RSU. The DN will include the location, time of message, distress message explanation, and vehicle category. The RSU forwards it on to the *Wyoming CV System* for notification of system operators and first responders.

Recognizing that this CV Pilot cannot provide continuous coverage of I-80 by RSUs, this application includes a V2V relay of DNs, illustrated in Figure 4-9. When a distressed vehicle (#1) is not within communication range of an RSU, the message is received by nearby connected vehicles (#2) traveling in the same and/or in opposite directions. These vehicles relay the Notification to the nearest RSU, whether upstream or downstream, which forwards it on to the *Wyoming CV System*.

The relay function also enables vehicles traveling the opposite direction (#2), to inform vehicles upstream (#3), traveling in the same direction as the distressed vehicle, of the need for caution ahead.

Although this application is loosely based on the Mayday application description from SAE J3067 Section 3.5.9.2.1, it is built on a higher priority TIM communication using SAE J2735 March 2016, Section 5.16, Part 3, Integrated Transport Information System (ITIS) advisory elements.

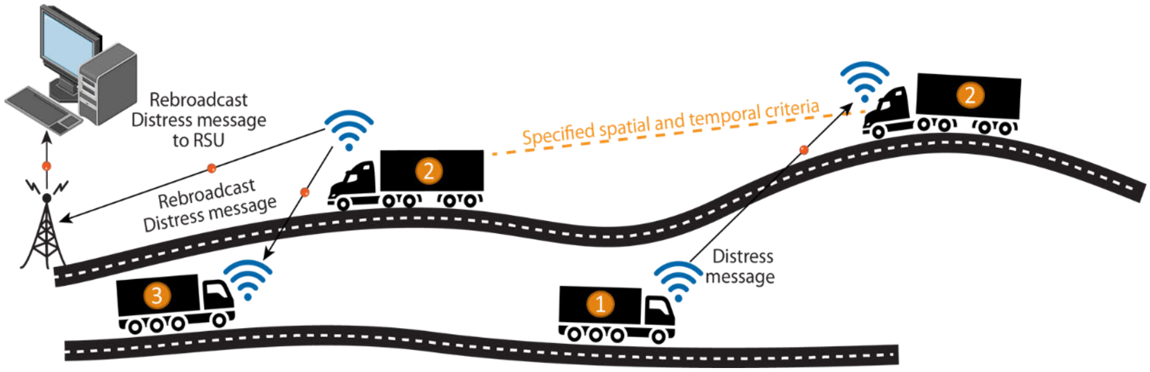


Figure 4-9. Distress Notification Concept Diagram. (Source: WYDOT)

The physical architecture of this application is illustrated in Figure 4-10. The information originates from the vehicle (automatically) or driver (manually) and is broadcast through nearby RSUs to the ODE and/or other vehicle subsystems capable of supporting DNs. WYDOT Maintenance Vehicles and Integrated Commercial Vehicles will have this capability. The vehicles receiving DNs relay this information to other vehicles driving in the opposite direction or the nearest RSU.

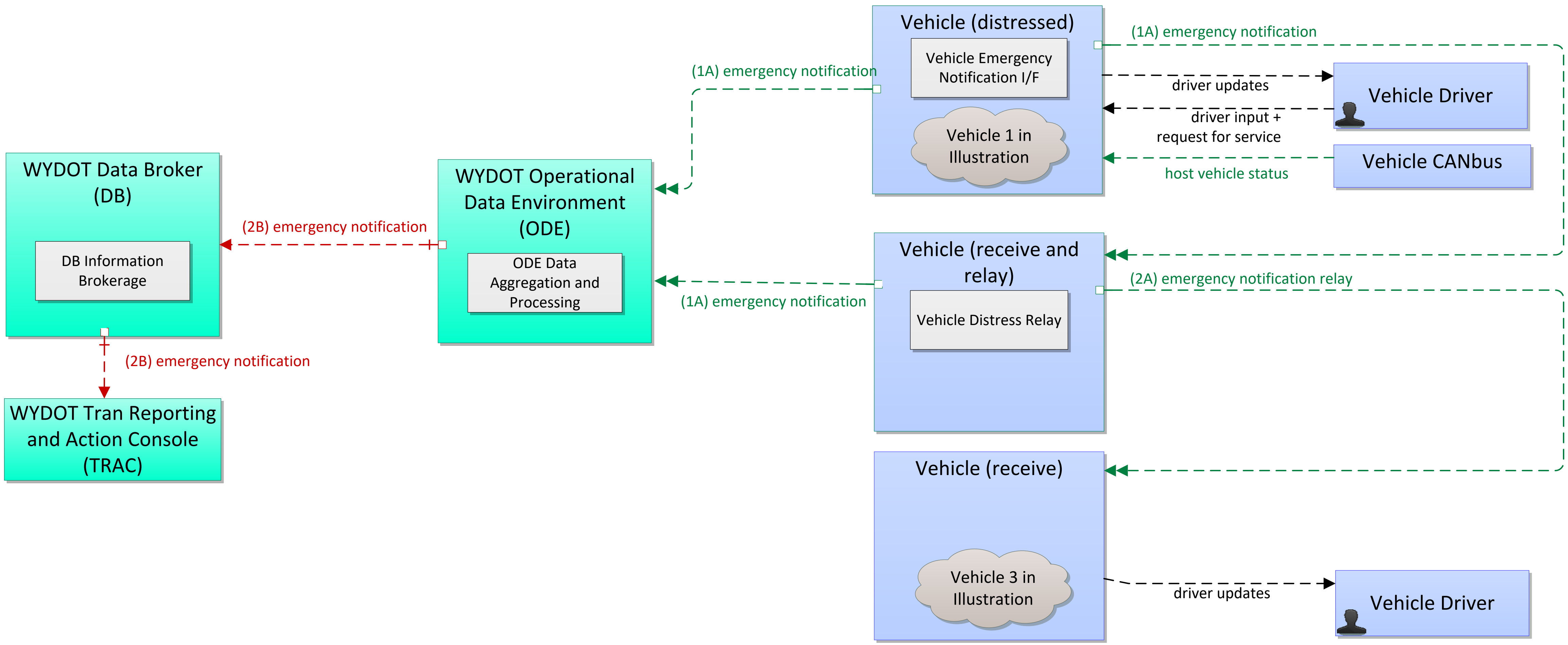


Figure 4-10. Physical Architectural View of the Distress Notification Application. (Source: WYDOT)

4.5.3 I2V Situational Awareness Architectural View

One of the important promises of Connected Vehicle technology is the delivery of up-to-date travel information to drivers that impact their safety and mobility. The WYDOT CV Pilot will implement an I2V Situational Awareness application that assembles important travel information from back-office systems and communicates that directly to drivers through both DSRC and satellite communications. This application enables delivery of relevant downstream road condition information to drivers along I-80 in Wyoming, including:

- weather alerts,
- speed restrictions,
- vehicle restrictions,
- road conditions,
- incidents ahead, truck parking, and
- road closures.

This information is expected to enhance both safety and traveler mobility along the corridor. The generic application is illustrated in Figure 4-11.

The 402 miles of Wyoming I-80 is too long to provide cost effective DSRC communications coverage. Accordingly, the WYDOT CV Pilot will implement satellite-based communications to send this situational awareness road condition information directly to satellite enabled connected vehicles along the entire length of Wyoming I-80, when out of range of DSRC communications. This application will follow the description from SAE J3067 August 2014 Section 2.9.3.6.

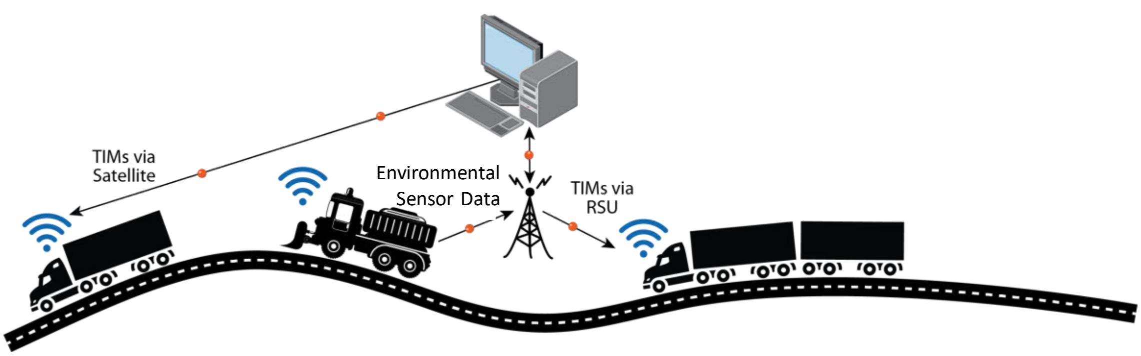


Figure 4-11. I2V Situational Awareness Concept Diagram. (Source: WYDOT)

The physical architecture for I2V Situational Awareness is presented in three diagrams, Figure 4-12 through Figure 4-14, for clarity and readability.

Figure 4-12 illustrates situational awareness data and information collection by the WYDOT DB from vehicles, from WYDOT Pikalert, and from other WYDOT data sources. Equipped vehicles transmit vehicle location and motion data in BSMs to the RSU which is forwarded to the ODE and DB in the form of traffic situation data. Vehicles equipped to capture data from their CAN Bus, send vehicle environmental data to RSUs through BSM Part 2. This environmental data is forwarded to the ODE, Pikalert and the DB. Selected WYDOT Maintenance Vehicles will be instrumented with environmental data sensors whose data will be collected and transmitted back to Pikalert and the DB.

Figure 4-12 also illustrates the capture and analysis of information from external weather sources as well as environmental situation data from vehicles for analysis and for generation of road weather advisories and alerts. These advisories and alerts will be processed by the DB and integrated with other situational awareness messaging as warranted.

Figure 4-13 shows dissemination of I2V Situational Awareness messages, compiled by the DB, back through the system to vehicles, the WYDOT DW and other data users. The DW contains the logic which determines when a Situational Data message should be issued and compiles the relevant information and sends it to the ODE. The ODE compiles a TIM containing alerts and information for drivers that can be sent to and used by vehicles. These TIMs are sent to the RSU and the SSP, which then transmit the information to the vehicle subsystems, and subsequently to the drivers. The information is also disseminated to WYDOT and USDOT DWs for archiving and analysis.

Figure 4-14 provides a more detailed view of the collection from data sources and dissemination to data users by the DB. As previously described, the DB is the subsystem responsible for collecting information from most of the external interfaces and distributing it to other WYDOT CV Pilot subsystems. Furthermore, it also distributes relevant information generated by the CV Pilot to the external interfaces. Table 4-4 summarizes how the DB interacts with the External Interfaces and other Subsystems, detailing the information shared.

Table 4-4. Data Flow within the Data Broker.

Interface	Origin	Destination	Data / Information Shared
WE5	511 System	DB	Parking information
WE6	RCRS	DB	8 Code (roadway condition), 9 Code (atmospheric), 10 Code (crash and incident information)
WE7	IC	DB	Incident information
WE8	CA	DB	Scheduled and unscheduled work-zone activities
WE9	DB	WTI	Current and forecasted segment-specific advisories/alerts
WE9	WTI	DB	Posted speed, vehicle restrictions, messages, and closure information
WE10	DW	TPI	Traffic condition
WE11	DB	TRAC	DN, Segment alerts
WE12	DB	CVOP	Current and forecasted segment-specific advisories/alerts
WE13	DB	ITS Maint.	System operational status
WI1	Pikalert	DB	Alerts and advisories within TIM
WI2	DB	ODE	TIM, Alerts and advisories within TIM
WI2	ODE	DB	DN
WI3	DB	DW	TIM, DN, Alerts and advisories within TIM
WI3	DW	DB	Road condition report, TIM, DN, Alerts and advisories within TIM

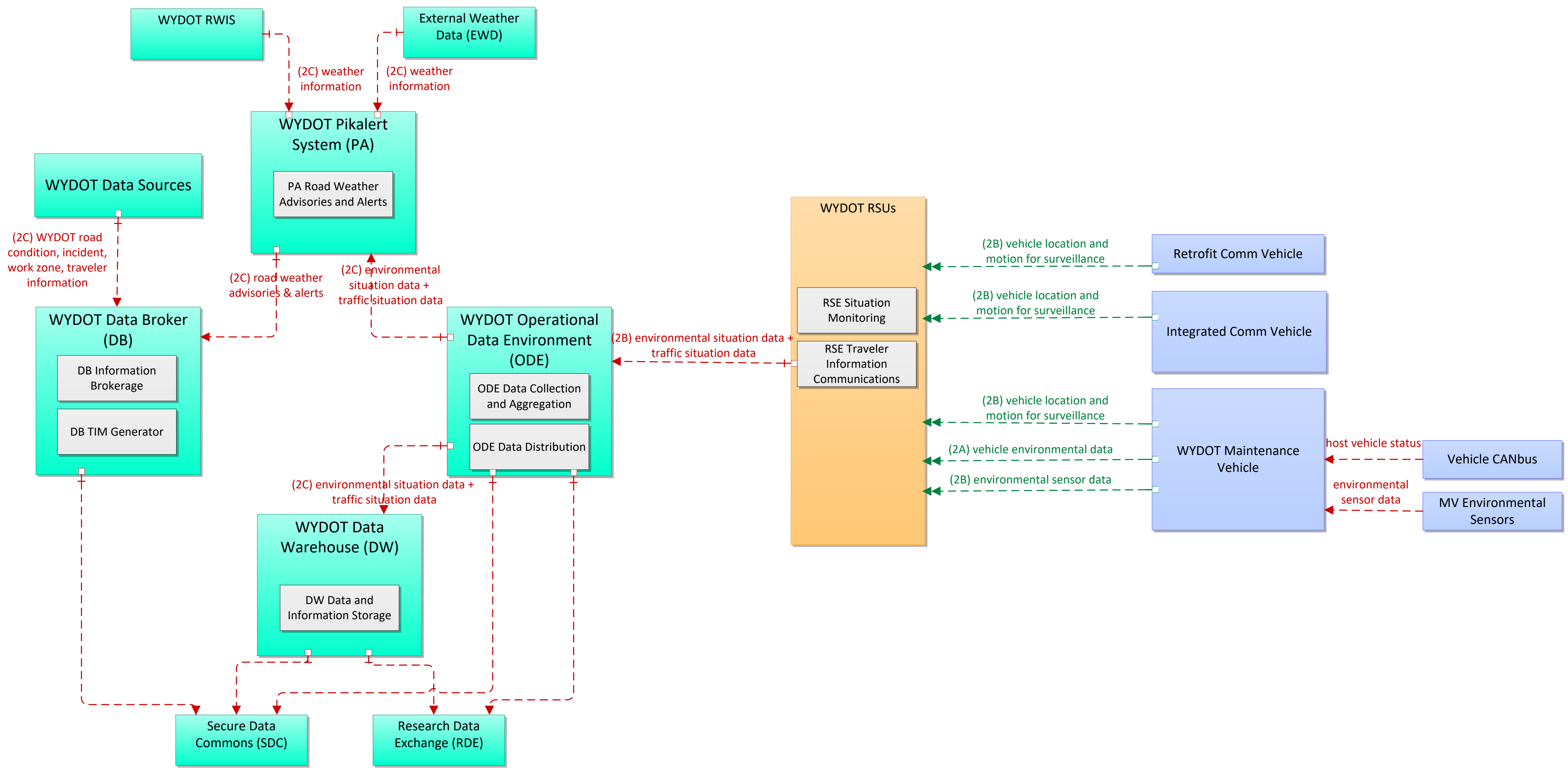


Figure 4-12. Physical Architectural View of the I2V Situational Awareness Application Data and Information Collection. (Source: WYDOT)

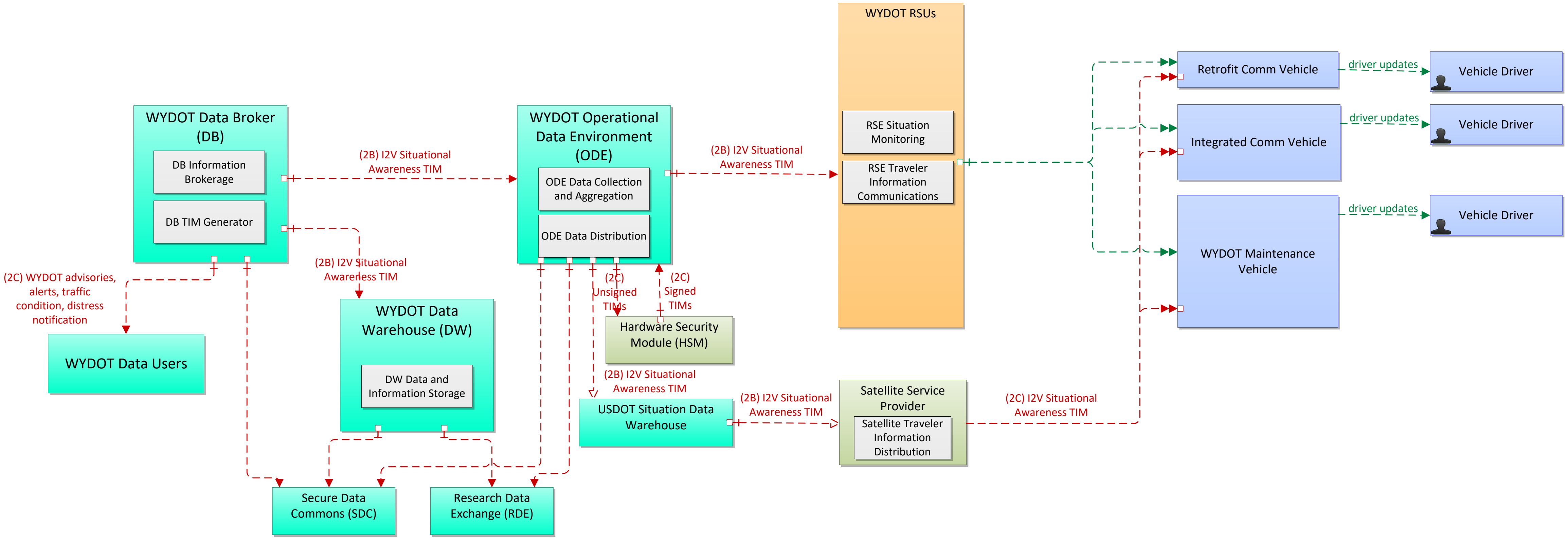


Figure 4-13. Physical Architectural View of the I2V Situational Awareness Application Message Dissemination. (Source: WYDOT)

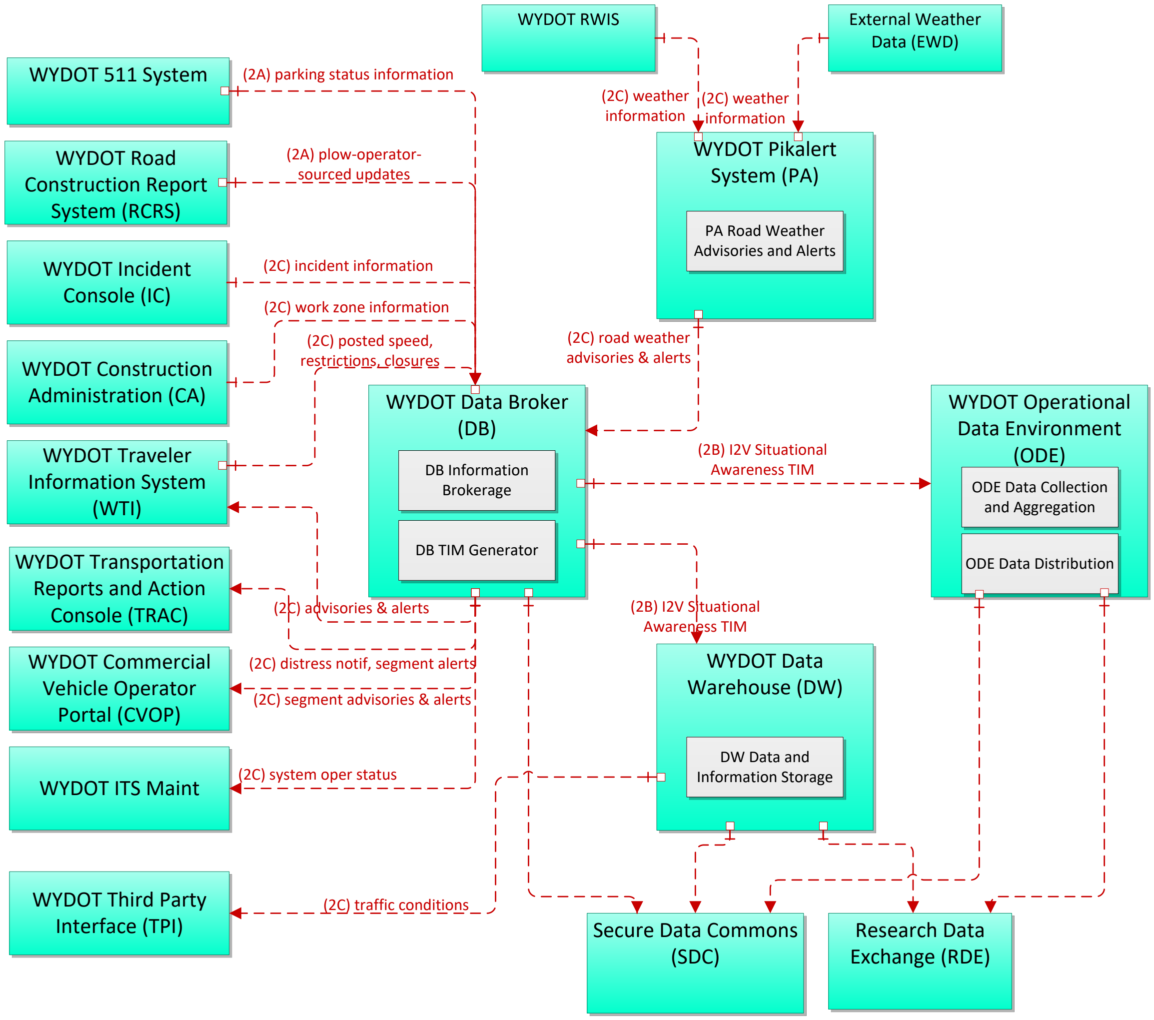


Figure 4-14. Physical Architectural View of the Details of WYDOT Data Broker Information Collection and Message Dissemination. (Source: WYDOT)

4.5.4 Spot Weather Impact Warning

SWIW is a special case of I2V Situational Awareness that enables hazardous road condition information due to weather, such as fog or icy roads, to be broadcast from a RSU and received by the connected host vehicles (see Figure 4-15). This application, however, is distinct from other I2V Situational Awareness applications in that it provides more localized information (i.e., at the segment level instead of area wide or region wide). This application will follow the TIM advisory content from part 3 defined in SAE J2735 Section 6.142 for ITIS data elements 6.54 for weather conditions and 6.55 for winds defined in SAE J2540_2.

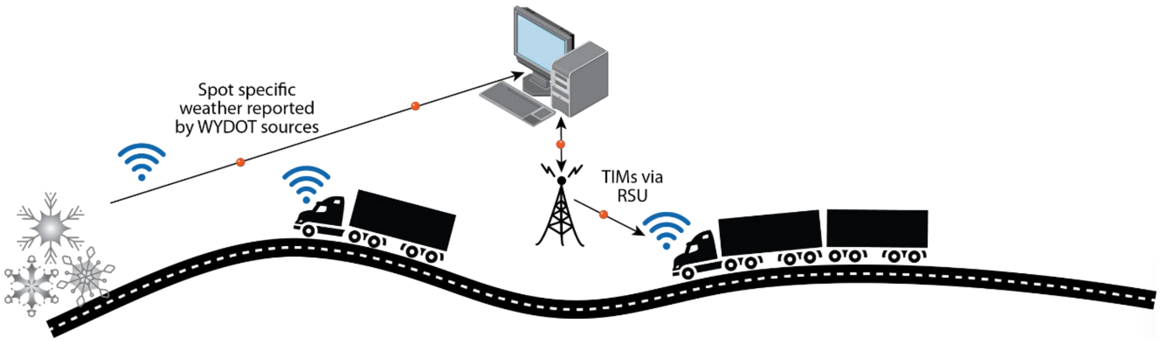


Figure 4-15. Spot Weather Impact Warning Concept Diagram. (Source: WYDOT)

This application shares the same physical architecture as the I2V Situational Awareness shown in Figure 4-12 through Figure 4-14. The Pikalert system receives CV (environmental sensors and CAN Bus) and non-CV (other weather sources) weather information, which are used to generate segment-level alerts. These alerts are then shared with the RSU that transmit road weather advisories and reduced speed notifications to equipped vehicles.

4.5.5 Work Zone Warning Architectural View

The WZW Application provides information about the conditions that exist in a work zone which the host vehicle is approaching (illustrated in Figure 4-16). This capability provides approaching vehicles with information about work zone activities that could present unsafe conditions for the workers or the host vehicle, such as obstructions in the vehicle's travel lane, lane closures, lane shifts, speed reductions or vehicles entering/exiting the work zone. This application will follow the TIM WZW described in SAE J2735 March 2016 Part 3 in Section 6.142.

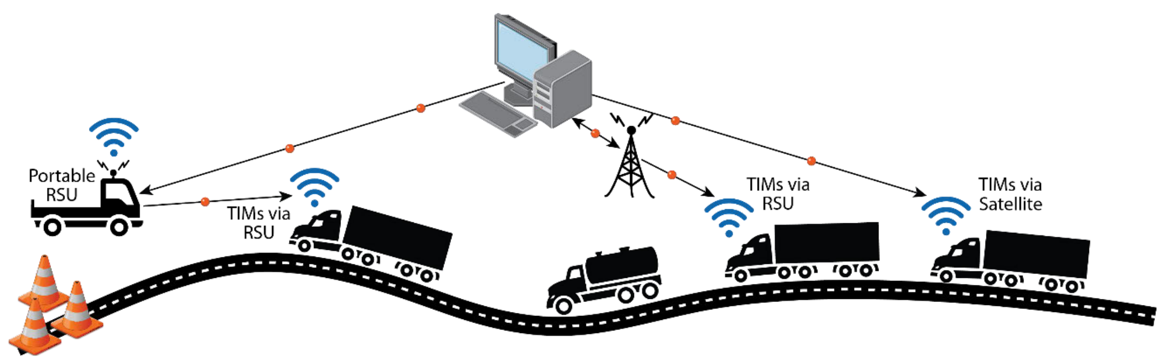


Figure 4-16. Work Zone Warning Concept Diagram. (Source: WYDOT)

Two unique elements of the WZW Situational Awareness application are illustrated in Figure 4-17. The figure illustrates that work zone field information is provided by WYDOT maintenance and field personal to the WYDOT CA. This information is then send to the DB for processing and, if warranted, issuance of an I2V Situational Awareness TIM with work zone information to vehicles and data users. The figure also illustrates that the WYDOT CV Pilot will deploy a portable RSU to deliver this work zone messages at selected work zone locations. This deployment ensures the delivery of these important messages to drivers when work zones may be distant from fixed RSU locations.

4.5.6 Truck Parking Availability Architectural View

Figure 4-18 illustrates another special implementation of the I2V Situational Awareness application in the WYDOT CV Pilot, one of truck parking availability. As part of this project, the WYDOT CV Pilot team will update the WYDOT 511 Application for personal information devices (e.g. smartphones) to capture crowdsourced truck parking information and to share that with commercial vehicle drivers, particularly during inclement road weather conditions. The capture and dissemination of commercial motor vehicle parking information on I-80 is illustrated in the figure.

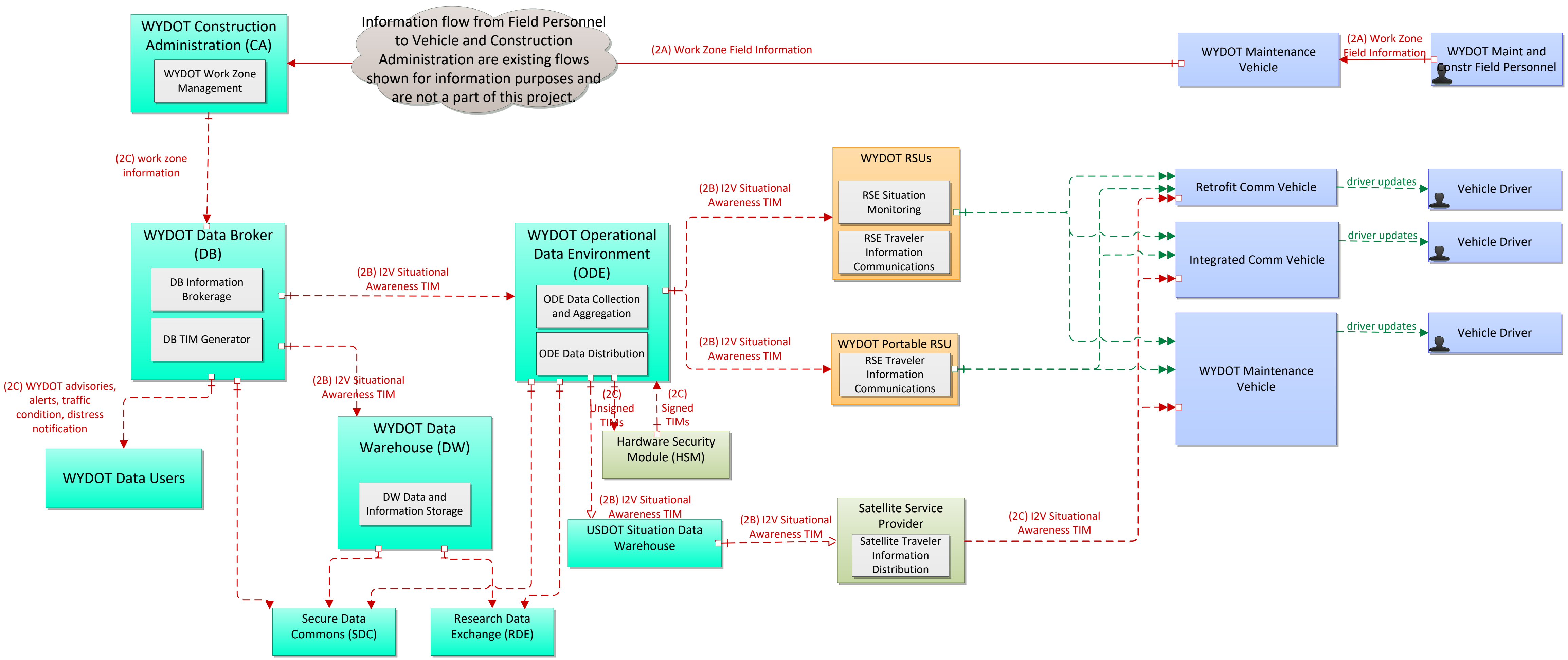


Figure 4-17. Physical Architectural View of the I2V Situational Awareness Application for Work Zone Messages. (Source: WYDOT)

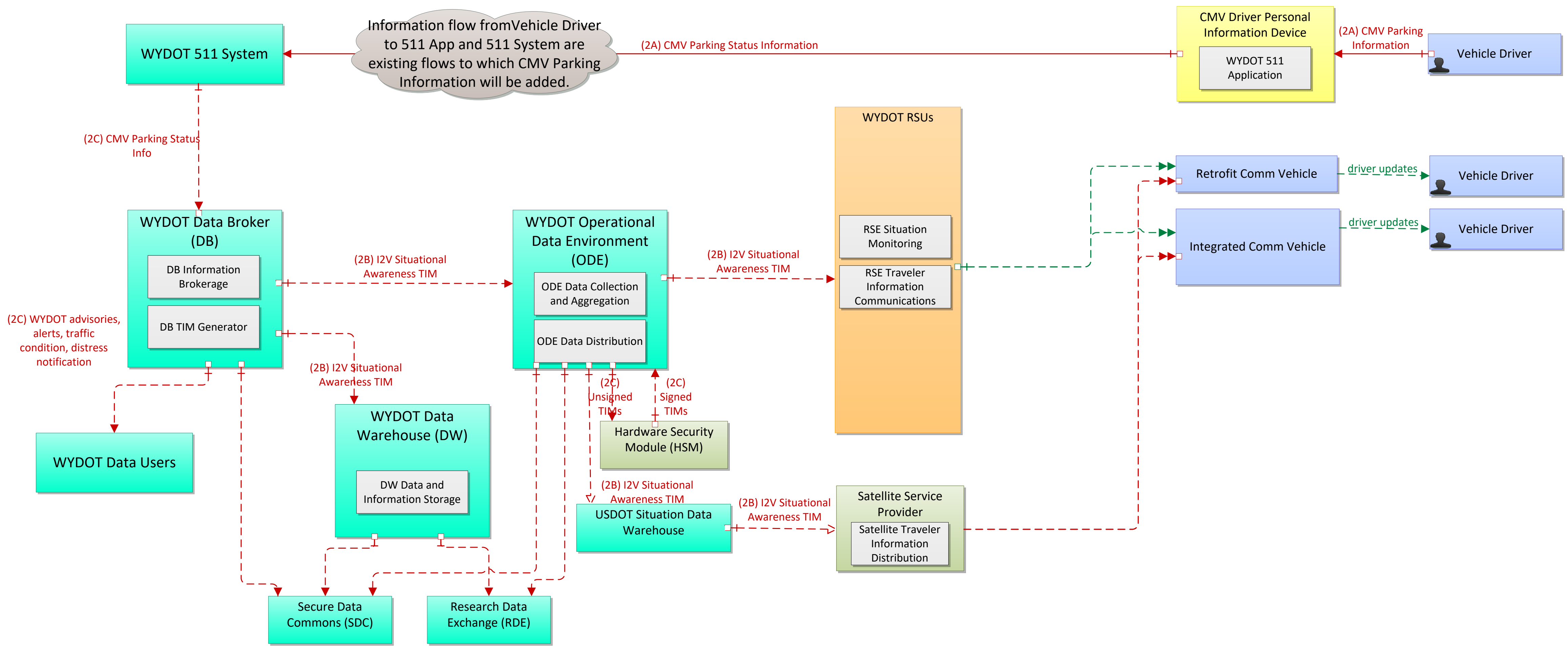


Figure 4-18. Physical Architectural View of the I2V Situational Awareness Application for Truck Parking Messages. (Source: WYDOT)

4.5.7 Supporting Functions Architectural View – Location and Time

All information collected and shared within and between subsystems is expected to be geotagged (when possible) and timestamped. This will be key in determining the applicability of the information and the appropriate action to process each message. The LTS interface provides GPS-based time information and data required for the determining location. Location is critical for all vehicle systems. Applications operating on RSUs and other components may need to know their location to determine how to process incoming or outgoing messages. Stationary components may obtain time via internet connections when available or via GPS satellite. Data required to determine location will be obtained via satellite.

Figure 4-19 illustrates the physical architecture of this interface. GPS will be the main source of location and time for all components. The ODE will obtain time information from Network Time Source, through an internal GPS. The RSUs receive location information from the field GPS and time from both the LTS (via NTP) and the field GPS. The LTS interface also provides time information to the ODE. While vehicles may have systems for determining their location, OBUs to be installed and used in the WYDOT CV Pilot will have onboard GPS processing chips to compute their location and time from satellite data via GPS antennas.

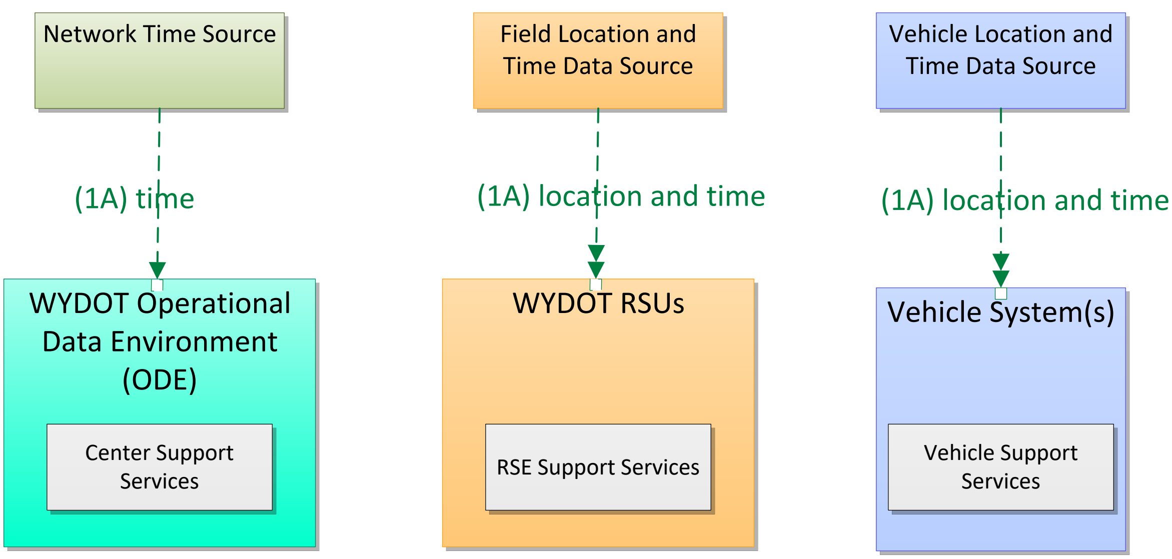


Figure 4-19. Physical Architectural View of the Location and Time Interface with the ODE, RSU, and OBU. (Source: WYDOT)

4.6 Communications Profile Architecture View

The CVRIA and SET-IT tools provide architecture Communications Views which describe the communications protocols necessary to provide interoperability and communications between Physical Objects in the Physical View. These profiles identify the communications protocols necessary to transport data described by an information flow between the systems and subsystems in the WYDOT CV Pilot. Detailed descriptions of each interface and the data flow across them may be found in the WYDOT CV Pilot ICD.

These communication profiles have been modified to show that the WYDOT CV Pilot system will utilize IETF IPv4 for Network Layer Communications across existing WYDOT backhaul and TMC system interfaces where IPv6 communications are not available. IPv6 will be used for DSRC communications, in addition to WSMP.

The 8 layers of the CVRIA NITSA Communications Model are described in SET-IT as follows:

- **ITS Application Information Layer:** The ITS Application information layer standards specify the structure, meaning, and control exchange of information between two end points.
- **Application Layer:** The application layer standards define the rules and procedures for exchanging encoded data.
- **Presentation Layer:** The presentation layer standards define the rules for representing the bits and bytes of information content to be transferred.
- **Session Layer:** The session layer provides the mechanism for opening, closing and managing a dialogue between application processes. Sessions may be asynchronous as in paired requests and responses (information exchanges), asynchronous as in an unsolicited publication of information, and may require acknowledgement or receipt.
- **Transport Layer:** The transport layer standards define the rules and procedures for exchanging application data between endpoints on a network.
- **Network Layer:** The network layer standards define the routing, message disassembly/re-assembly and network management functions.
- **Data Link Layer:** The data link layer standards define the rules and procedures for exchanging data between two adjacent devices over some communications media.
- **Physical Layer:** The physical layer is a general term used to describe the numerous signaling standards within this layer, typically developed for specific communications media and industry needs.

In addition, the Security Plane identifies standards that specify policies and system-to-system authentication, and encryption of data across one or more layers of the communications stack.

Key standards to be implemented for the ITS Application Information Layer throughout the WYDOT CV Pilot System include:

- ITE/AASHTO (2014). TMDD Standard v03.03c. Traffic Management Data Dictionary (TMDD) Standard for the Center to Center Communications. Volume I Concept of Operations and Requirements.
- SAE J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary,
- SAE J2945/1 Dedicated Short Range Communications (DSRC) Performance Requirements for V2V Safety Awareness.
- SAE J3067 Candidate Improvements to Dedicated Short Range Communications (DSRC) Message Set Dictionary Using Systems Engineering Methods.

The WYDOT CV Pilot Team expects to use existing standards identified in the lower seven layers of the Communication Profiles “as-is” (Application, Presentation, Session, Transport, Network, Data Link, and Physical Layers). The WYDOT CV Pilot Standards Plan located in the WYDOT CV Pilot ICD identifies lists key standards to be implemented in the WYDOT CV Pilot System, identifying which are expected to be used “as is” and which are expected to be implemented with variances.

Table 4-5. List of Data, Information Exchanges and SET-IT Communication Profile Template for each Interface in WYDOT CV Pilot.

WYDOT Interface #	Source Element	Destination Element	Communication Profile [SAD Section and Figure No.]	Application Information Standard
WE1/VE1	WYDOT RSUs	Vehicle System	DSRC-WSMP RSU Gateway SCMS [Sec 4.6.7/Fig 4-27, Sec 4.6.8/Fig 4-28, Sec 4.6.9/Fig 4-29]	J2735/1 Secure Copy (SCP)
WE1/VE1	Vehicle System	WYDOT RSUs		J2735/1 Secure Copy (SCP)
WE2	Field Location and Time Data Source	WYDOT RSUs	Time Position-Location-Interface [Sec 4.6.4/Fig 4-23]	NA
WE3	Network Time Source	WYDOT ODE	Time Position-Location-Interface [Sec 4.6.4/Fig 4-24]	Network Time Protocol
WE4	WYDOT RWIS System	WYDOT Pikalert System (PA)	WAW-WWWBrowser-JSON WAW-XML XML [Sec 4.6.1/Fig 4-20, Sec 4.6.2/Fig 4-21, Sec 4.6.3/Fig 4-22]	RWIS Interface Control Document (ICD)
WE4	External Weather Data	WYDOT Pikalert System (PA)		EWD ICD
WE5	WYDOT 511 System	WYDOT Data Broker		Custom JSON
WE6	WYDOT Road Condition Report System (RCRS)	WYDOT Data Broker		TMDD
WE7	WYDOT Incident Console (IC)	WYDOT Data Broker		TMDD
WE8	WYDOT Construction Administration (CA)	WYDOT Data Broker		TMDD
WE9	WYDOT Traveler Information System (WTI)	WYDOT Data Broker		TMDD
WE9	WYDOT Data Broker	WYDOT Traveler Information System (WTI)		TMDD
WE10	WYDOT Data Warehouse	WYDOT Third Party Interface (TPI)		TMDD
WE11	WYDOT Data Broker	WYDOT Transportation Reports and Action Console (TRAC)		TMDD
WE12	WYDOT Data Broker	CVOP		TMDD
WE13	WYDOT Data Broker	WYDOT ITS Maintenance		TMDD
WE15	WYDOT ODE	USDOT Situation Data Warehouse		J2735/1 SSP ICD

WYDOT Interface #	Source Element	Destination Element	Communication Profile [SAD Section and Figure No.]	Application Information Standard
WE14	WYDOT Data Warehouse	Secure Data Commons	AWS S3 Bucket [Sec 4.6.11]	Vehicle speed
WE18	WYDOT ODE	Secure Data Commons	AWS S3 Bucket [Sec 4.6.11]	BSM, DNM, Custom JSON
WE21	WYDOT Data Broker	Secure Data Commons	AWS S3 Bucket	n/a
WE20	WYDOT Data Warehouse	Research Data Exchange	AWS S3 Bucket [Sec 4.6.11]	BSM, DNM, Custom JSON
WE19	WYDOT ODE	Research Data Exchange	AWS S3 Bucket [Sec 4.6.11]	BSM, TIM
WE22	WYDOT Data Broker	Research Data Exchange	AWS S3 Bucket [Sec 4.6.11]	TIM, DN, Alerts and advisories within TIMs
WE16	HSM	SCMS	SCMS [Sec 4.6.9/Fig 4-29]	SCMS
WE16	SCMS	HSM		SCMS
WE17	WYDOT RSUs	SCMS	SCMS [Sec 4.6.9/Fig 4-29]	SCMS
WE17	SCMS	WYDOT RSUs		SCMS
WI1	WYDOT Pikalert System (PA)	WYDOT Data Broker	Internal	TMDD
WI2	WYDOT ODE	WYDOT Data Broker	Internal	DN, TIM Content
WI2	WYDOT Data Broker	WYDOT ODE		TIM Content
WI3	WYDOT Data Warehouse	WYDOT Data Broker	Internal	TMDD DN, TIM Content
WI3	WYDOT Data Broker	WYDOT Data Warehouse		TMDD DN, TIM Content
WI5	WYDOT ODE	WYDOT Data Warehouse	Internal	TMDD
WI5	WYDOT Data Warehouse	WYDOT ODE	Internal	TMDD
WI6	WYDOT ODE	WYDOT Pikalert System (PA)	Internal	TMDD BSM, CAN, ES Content
WI7	WYDOT ODE	WYDOT RSUs	RSU-C2F-SNMP RSU-C2F [Sec 4.6.5/Fig 4-25, Sec 4.6.6/Fig 4-26]	J2735/1 Secure Copy (SCP)
WI7	WYDOT RSUs	WYDOT ODE		J2735/1 Secure Copy (SCP)
WI8	HSM	WYDOT ODE	Internal	IEEE 1609.2, IETF 7230, IETF 4648

WYDOT Interface #	Source Element	Destination Element	Communication Profile [SAD Section and Figure No.]	Application Information Standard
WI8	WYDOT ODE	HSM	Internal	IEEE 1609.2, IETF 7230, IETF 4648
VE2	Satellite Service Provider	Vehicle System	SSP ICD (proprietary)	SSP ICD
VE3	Highway Patrol Vehicle Integrated Comm Vehicle Retrofit Comm Vehicle WYDOT Maintenance Vehicle	Highway Patrol Vehicle Integrated Comm Vehicle Retrofit Comm Vehicle WYDOT Maintenance Vehicle	DSRC-WSMP [Sec 4.6.7/Fig 4-27]	SAE J3067, J2945/1 and J2735
VE4	Vehicle Location and Time Data Source	Vehicle System	Time Position-Location-Interface [Sec 4.6.4/Fig 4-23]	NA
VI2	Vehicle CAN bus	OBU	Vehicle-On-Board [Sec 4.6.10/Fig 4-30]	Vehicle OEM ICD
VI1	OBU	HMI		Custom JSON
VI3	MV Environmental Sensors	HMI		Custom JSON

Heading Descriptions for Table 4-5**:**

1. WYDOT Interface Number: The interface number from Physical View, Figure 4-6
2. Source Element: The device which provides data for the flow
3. Destination Element: The device which consumes the data for the flow
4. Communication Profile: Communication protocol(s) used [Section number and Figure number in SAD describing the SET-IT Communication Profile]
5. Application Information Standard: Key standard(s) governing this information exchange

4.6.1 Wide Area Wireless (WAW) using JSON as encoding method

Figure 4-20 from SET-IT describes applicable IETF JSON and W3C web browser standards (e.g., HTML5 and Web Sockets) for transmissions over wide area wireless communications. This profile may be applied to Interfaces WE5, WE6, WE7, WE8, WE9, WE10, WE11, WE12, WE13, and WE15 as summarized in Table 4-5.

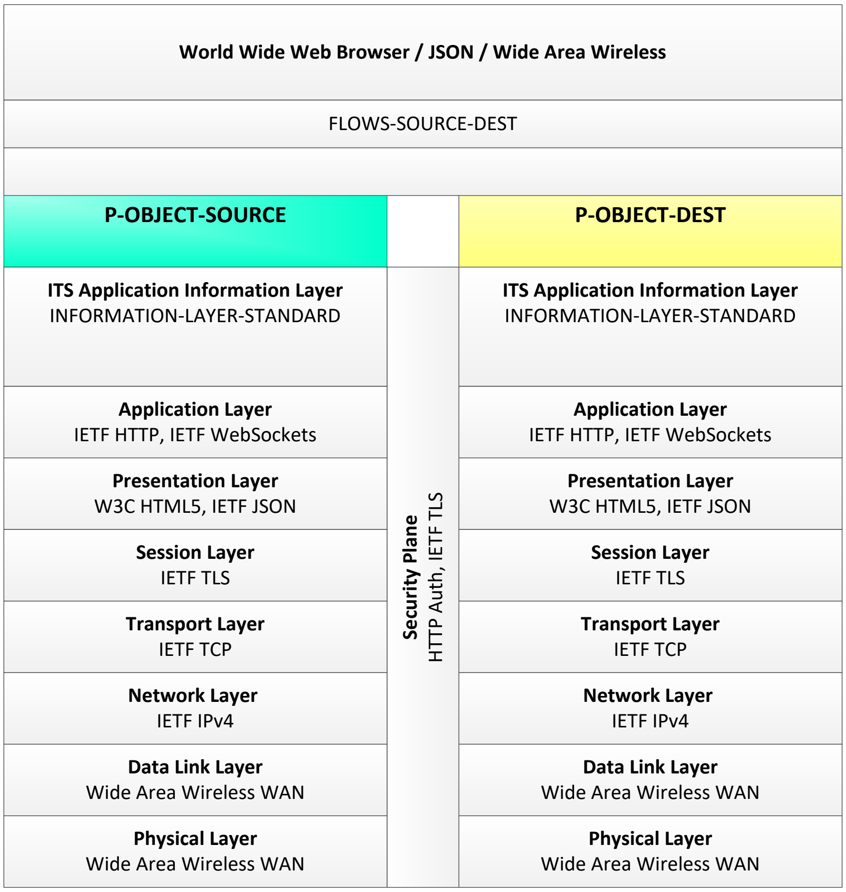


Figure 4-20. SET-IT Communication Profile for World Wide Web Browser/ JSON / Wide Area Wireless. (Source: WYDOT)

4.6.2 Wide Area Wireless using XML as encoding method

Figure 4-21 from SET-IT describes applicable XML and W3C web services standards used in transmissions over wide area wireless communications. This profile may be applied to Interfaces WE5, WE6, WE7, WE8, WE9, WE10, WE11, WE12, WE13, and WE15 as summarized in Table 4-5.

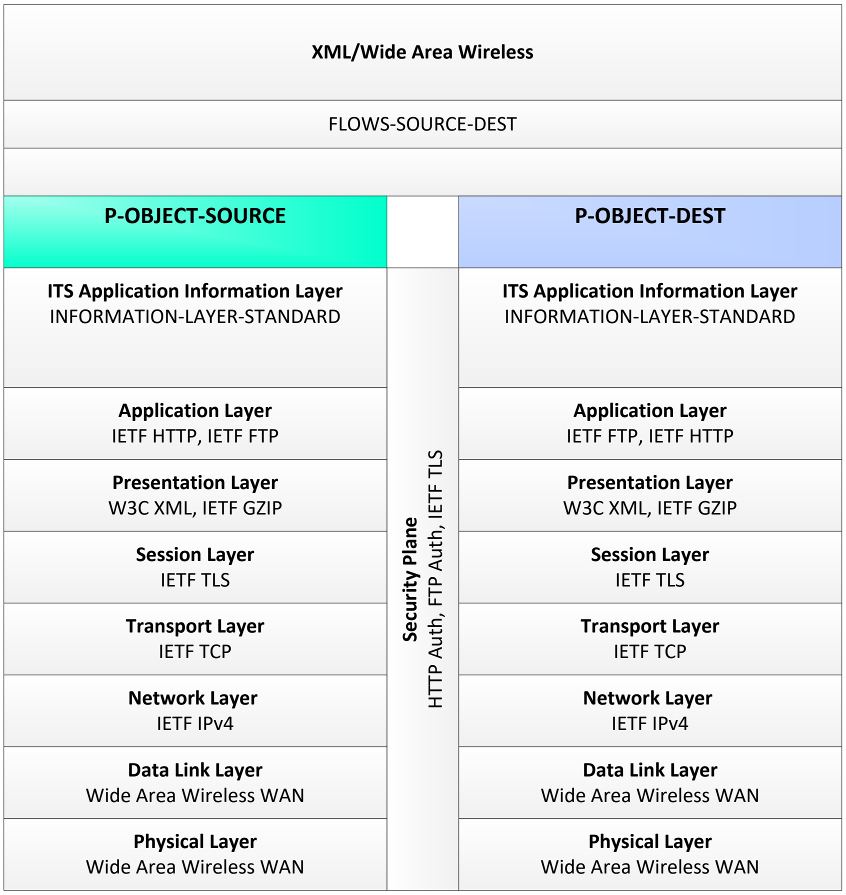


Figure 4-21. SET-IT Communication Profile for XML / Wide Area Wireless. (Source: WYDOT)

4.6.3 eXtensible Markup Language

Figure 4-22 describes a set of standards applicable to communications between entities using the Web Services standards of the World Wide Web Consortium (W3C) and the IETF (Internet Engineering Task Force). Information messages are encoded using the eXtensible Markup Language (XML). This profile may be applied to Interfaces WE5, WE6, WE7, WE8, WE9, WE10, WE11, WE12, WE13, and WE15 as summarized in Table 4-5.

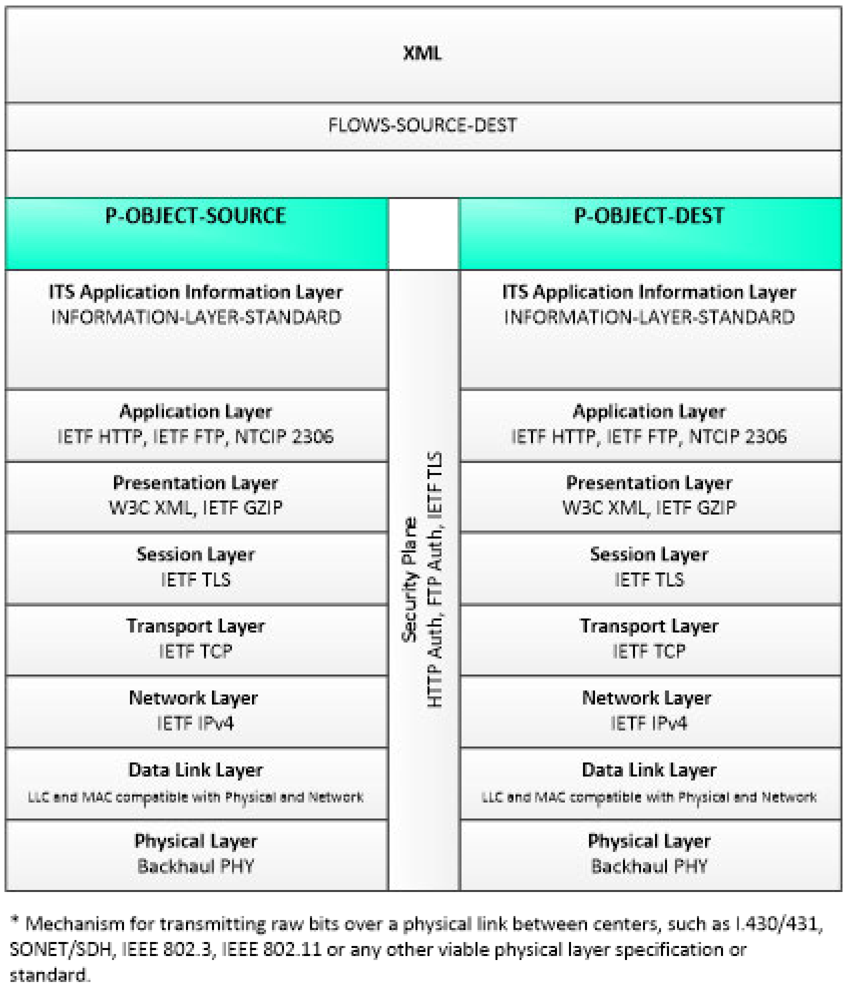


Figure 4-22. SET-IT Communication Profile for XML. (Source: WYDOT)

4.6.4 Time and Position-Location Interface

Figure 4-23, showing only physical objects and flow, describes communications between connected vehicle equipment and on board geolocation equipment such as a GPS receiver. This profile may be applied to Interfaces WE2 and VE4 as summarized in Table 4-5.

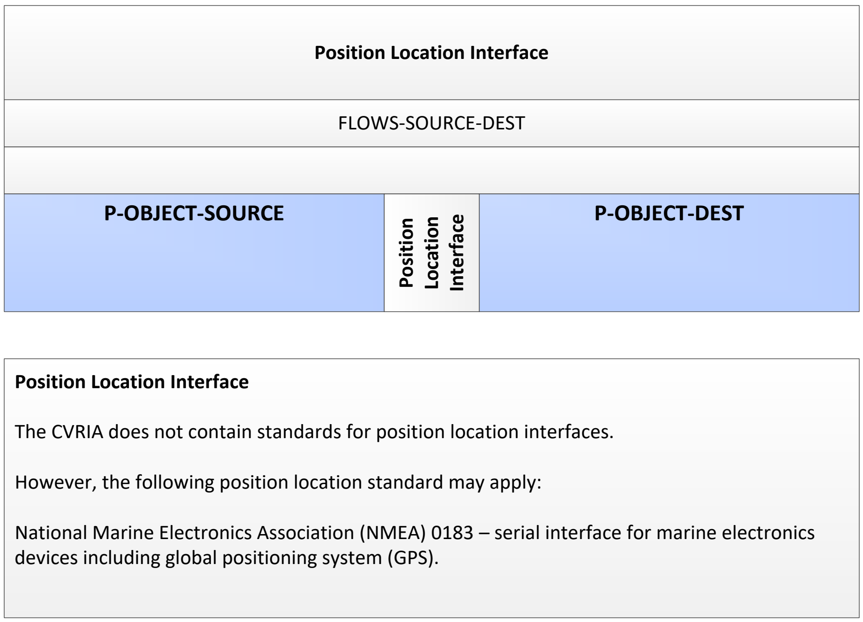
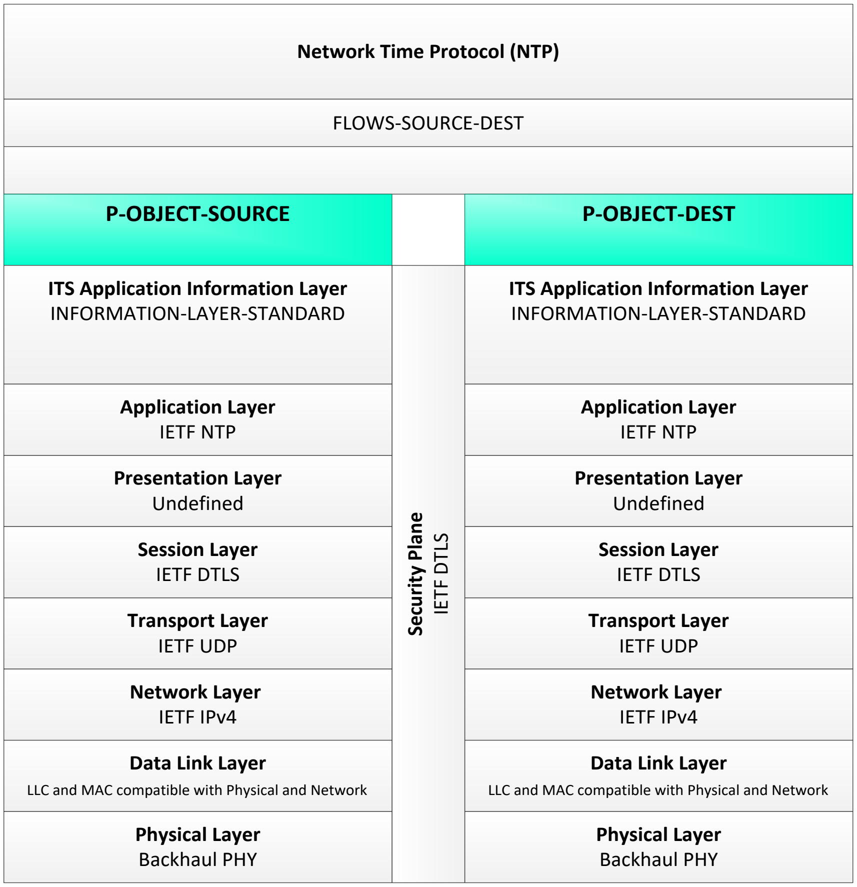


Figure 4-23. SET-IT Communication Profile for Position Location Interface. (Source: WYDOT)

Figure 4-24 includes a collection of standards that support the Network Time Protocol that allows NTP servers to provide time synchronization services to other NTP servers and clients. This profile may be applied to Interfaces WE2, WE3, and VE3 as summarized in Table 4-5.

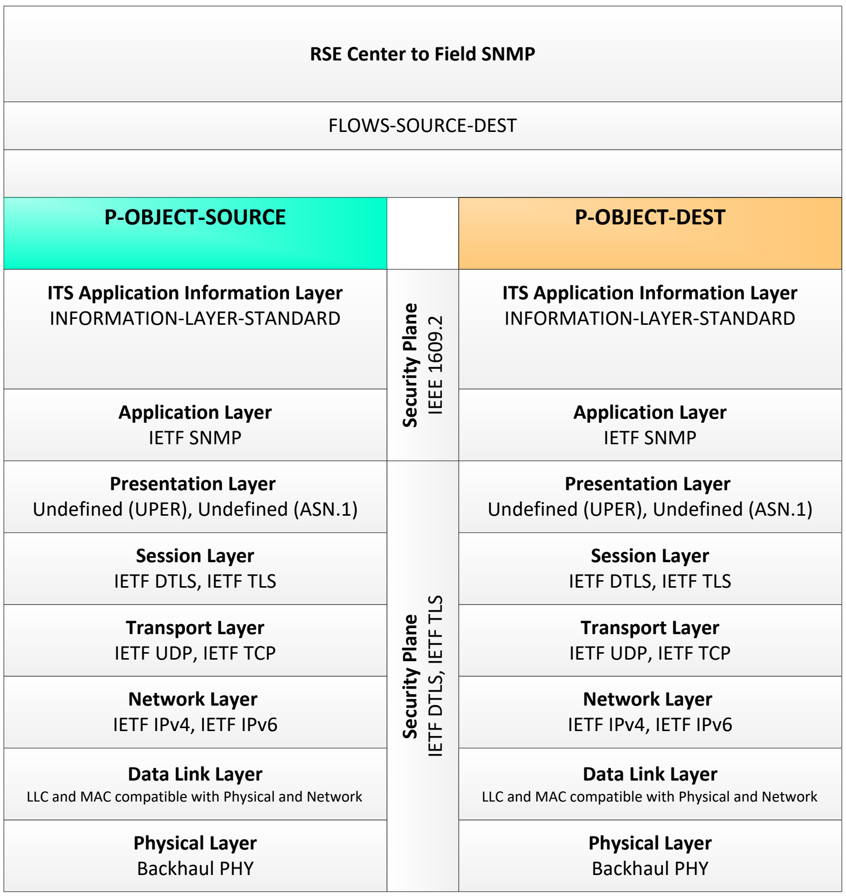


* Mechanism for transmitting raw bits over a physical link between centers, such as I.430/431, SONET/SDH, IEEE 802.3, IEEE 802.11 or any other viable physical layer specification or standard.

Figure 4-24. SET-IT Communication Profile for Network Time Protocol. (Source: WYDOT)

4.6.5 RSE - Center to Field Communications - SNMP

Figure 4-25 identifies applicable standards for Center to Field communications with RSEs.[9] This profile uses the Simple Network Management Protocol (SNMP), an Internet-standard protocol for managing devices on IP networks. This profile may be applied to Interface WI7 for selected RSUs as summarized in Table 4-5.



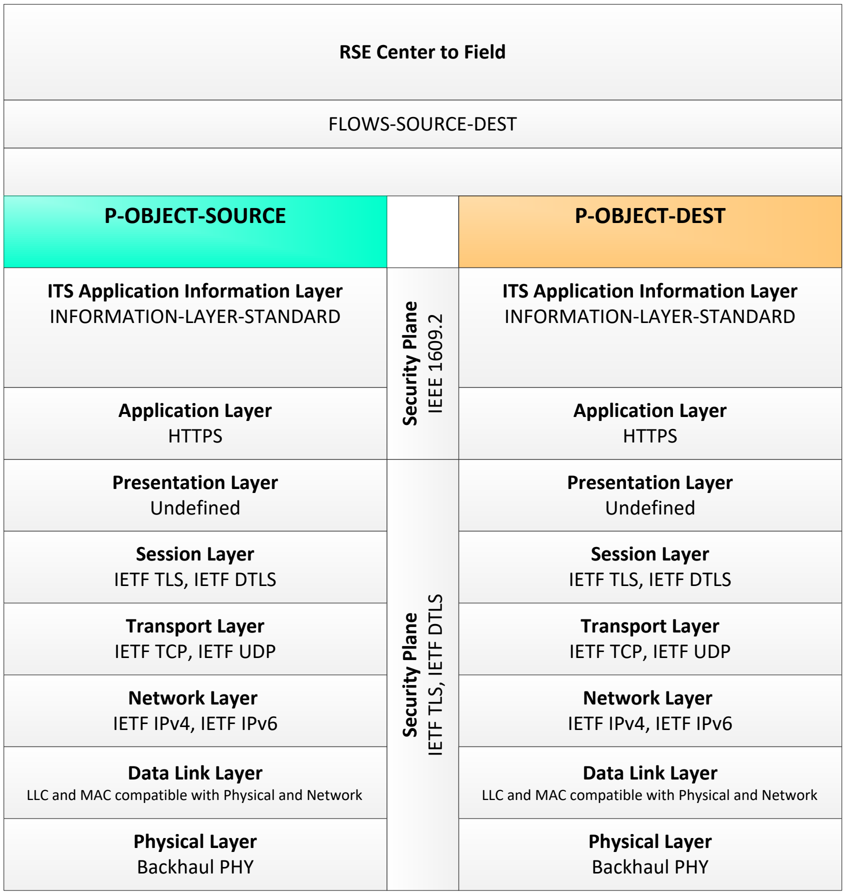
* Mechanism for transmitting raw bits over a physical link between the center and field, such as I.430/431, SONET/SDH, IEEE 802.3, IEEE 802.11 or any other viable physical layer specification or standard.

Figure 4-25. SET-IT Communication Profile for RSE Center to Field SNMP. (Source: WYDOT)

[9] Note that the current version of SET-IT uses RSE (roadside equipment) for components that are now commonly known as RSUs

4.6.6 RSE - Center to Field Communications

Figure 4-26 describes applicable standards for Center to Field communications with RSEs. Common internet standards (HTTPS and TCP) are used in this profile. This profile may be applied to Interface WI7 for selected RSUs as summarized in Table 4-5.



* Mechanism for transmitting raw bits over a physical link between the center and field, such as I.430/431, SONET/SDH, IEEE 802.3, IEEE 802.11 or any other viable physical layer specification or standard.

Figure 4-26. SET-IT Communication Profile for RSE Center to Field. (Source: WYDOT)

4.6.7 Vehicle-to-Vehicle/Infrastructure using WSMP Interfaces

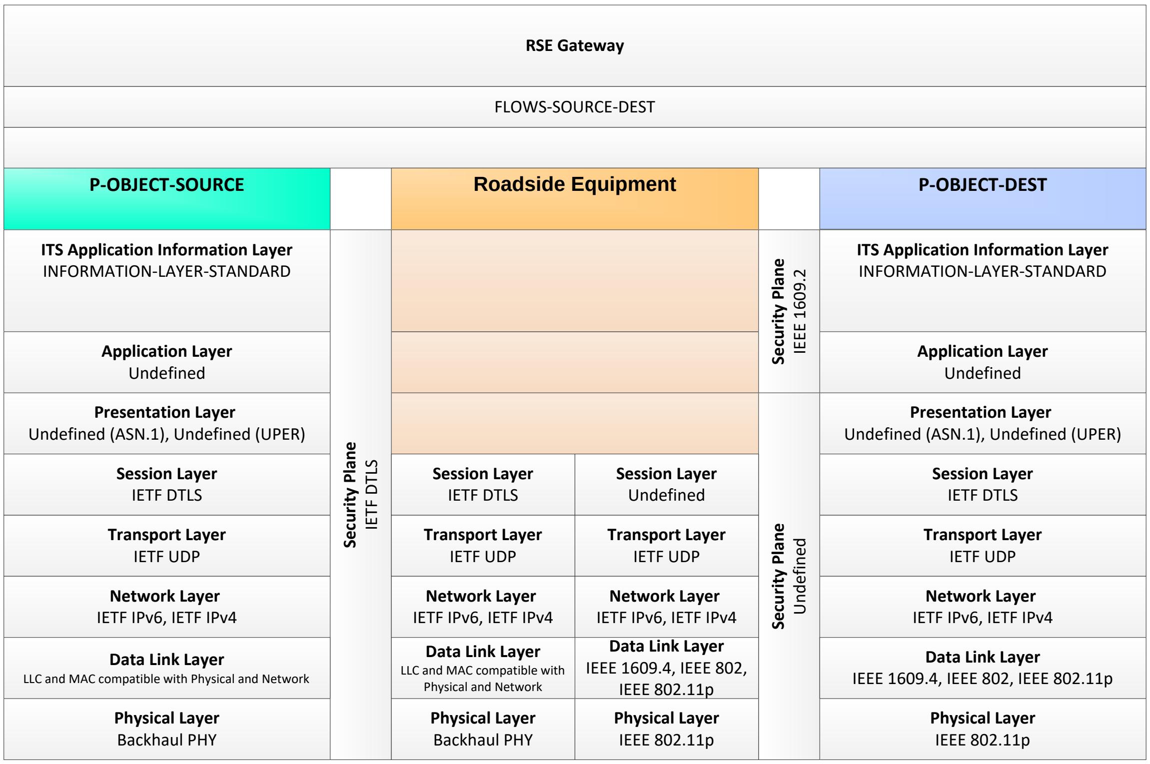
Figure 4-27 describes a set of standards applicable to broadcast, near constant, low latency vehicle- to-vehicle and vehicle-to-infrastructure communications using the WAVE Short Messaging Protocol (WSMP) over the 5.9GHz spectrum. This profile may be applied to Interface WE1/VE1 and VE3 as summarized in Table 4-5.

DSRC-WSMP		
FLOWS-SOURCE-DEST		
P-OBJECT-SOURCE		**P-OBJECT-DEST**
ITS Application Information Layer INFORMATION-LAYER-STANDARD	**Security Plane** IEEE 1609.2	**ITS Application Information Layer** INFORMATION-LAYER-STANDARD
Application Layer Undefined		**Application Layer** Undefined
Presentation Layer Undefined (ASN.1), Undefined (UPER)	**Security Plane** Undefined	**Presentation Layer** Undefined (ASN.1), Undefined (UPER)
Session Layer Undefined		**Session Layer** Undefined
Transport Layer IEEE 1609.3 WSMP		**Transport Layer** IEEE 1609.3 WSMP
Network Layer IEEE 1609.3 WSMP		**Network Layer** IEEE 1609.3 WSMP
Data Link Layer IEEE 1609.4, IEEE 802 MAC, IEEE 802.11p		**Data Link Layer** IEEE 1609.4, IEEE 802 MAC, IEEE 802.11p
Physical Layer IEEE 802.11p		**Physical Layer** IEEE 802.11p

Figure 4-27. SET-IT Communication Profile for DSRC-WSMP. (Source: WYDOT)

4.6.8 Vehicle Communications via RSE Gateway

Figure 4-28 describes an alternative set of standards used in vehicle communications where one or more RSEs act as a gateway with the vehicle as destination. This profile may be applied to Interface WE1/VE1 as summarized in Table 4-5.

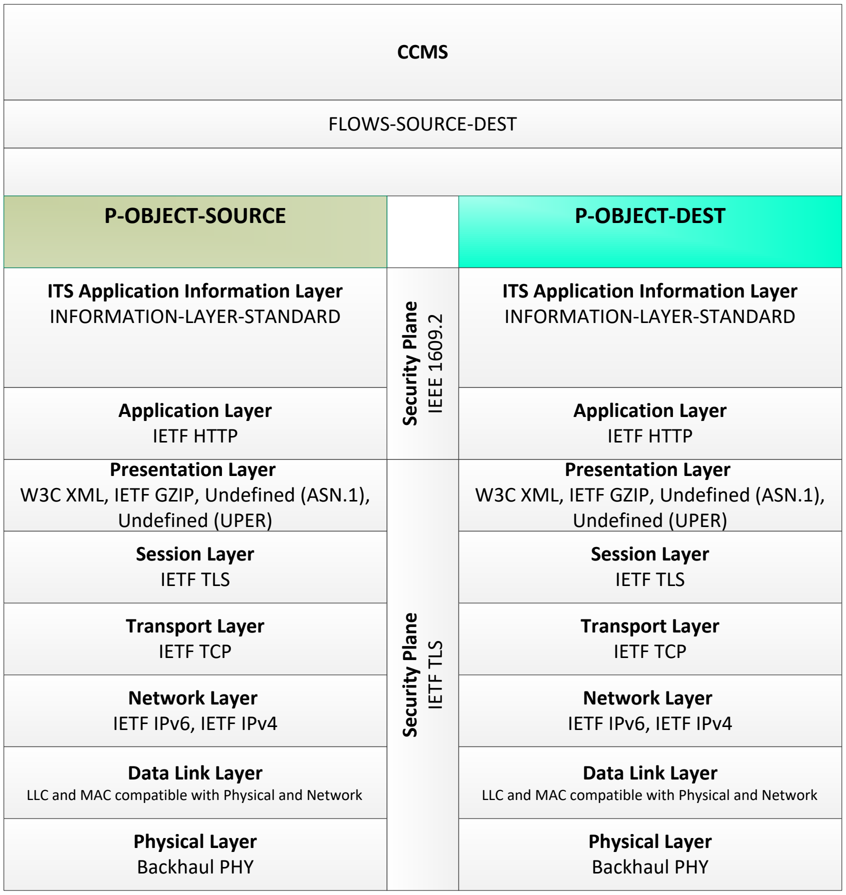


* Mechanism for transmitting raw bits over a physical link between the center and vehicle, such as I.430/431, SONET/SDH, IEEE 802.3, IEEE 802.11 or any other viable physical layer specification or standard.

Figure 4-28. SET-IT Communication Profile for RSE Gateway. (Source: WYDOT)

4.6.9 SCMS Communications

Figure 4-29 identifies applicable standards for secure communications with the USDOT SCMS also known as the Cooperative ITS Credentials Management System. This profile may be applied to Interface WE16 and WE17 as summarized in Table 4-5.



* Mechanism for transmitting raw bits over a physical link between centers, such as I.430/431, SONET/SDH, IEEE 802.3, IEEE 802.11 or any other viable physical layer specification or standard.

Figure 4-29. SET-IT Communication Profile for SCMS. (Source: WYDOT)

4.6.10 Vehicle-On-Board

Figure 4-30, showing only physical objects and flow, describes communications between equipment that reside on the vehicle. The CVRIA does not contain any specific information on standards for on-board vehicle communications. This profile may be applied to Interface VI1 as summarized in Table 4-5.

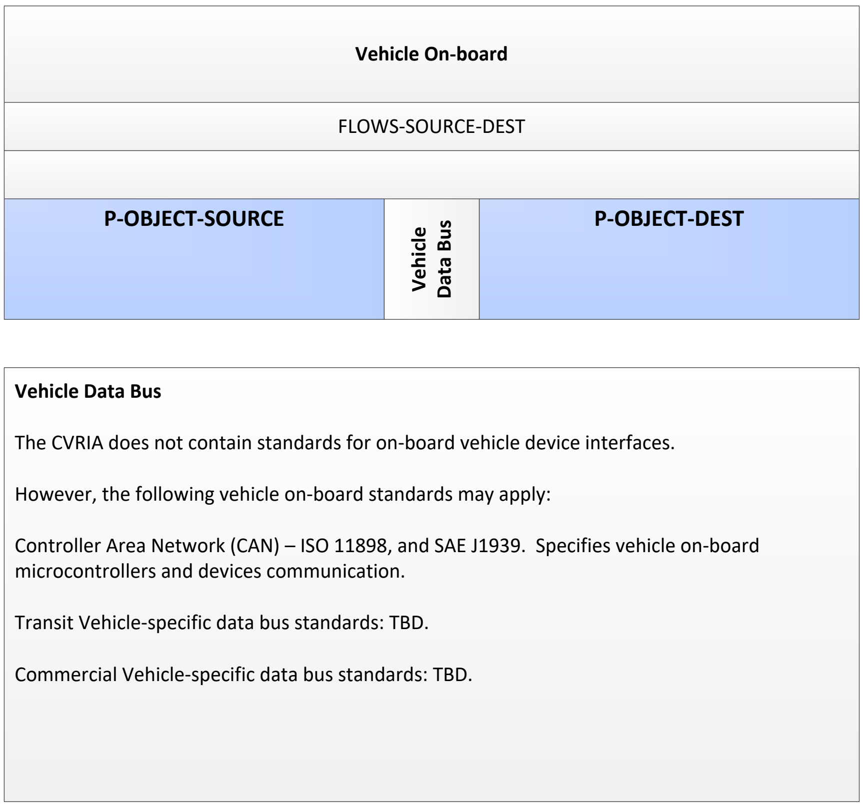


Figure 4-30. SET-IT Communication Profile for Vehicle Onboard Communications. (Source: WYDOT)

4.6.11 Satellite Service Provider

Interface VE2 provides communication capabilities through satellites, allowing the system to transmit TIM traveler-related information and SCMS data to vehicles. The specifications for this interface is proprietary to the provider and will be implemented in accordance with the provider's ICD.

4.6.12 AWS S3 Bucket

The WYDOT TMC will interact with the CV PEP (Interfaces WE14, WE18, and WE21) and the RDE (Interfaces WE19, WE20, and WE22) using an Amazon S3 cloud storage bucket to store ingested data for transfer to these external entities. The TMC manually publishes non-structured data to the CV PEP and RDE either in situations where the data is infrequently published or when the data cannot efficiently be structured.

Manually uploaded data is classified as data that will be uploaded by individuals at the pilot site. This data may not be well structured or have a consistent file format. Some of this data may be in complex file formats that are difficult to process by means of simple ETL logic systems. These manual uploads also may be prone to errors such as incorrect upload location, incomplete time stamp information, etc.

Data to be uploaded will be copied to a monitored directory. When data files are detected, the monitoring application will upload the files to the AWS S3 bucket.

4.7 Security Architecture View

The CV Pilot uses the USDOT's SCMS to generate the security certificates necessary to manage messages securely from connected devices. The SCMS design calls for the use of a Public Key Infrastructure where a central authority issues credentials in the form of short-lived pseudonym certificates to certified devices (e.g., OBU on vehicles) that possess a valid enrollment certificate. These short-lived certificates are used to sign BSMs prior to transmission. The device changes these pseudonym certificates on a regular basis over the course of each trip in order to protect the end user privacy. The purpose of attaching certificates and signing each BSM is to allow the receiver to determine if the transmitter is authorized and to ensure the integrity of the signed message. This is accomplished by verifying the digital signature on the message and verifying the transmitter's short-lived certificate by following the chain of trust, verifying the transmitter has adequate credentials to send the message contents, as well as verifying that the credentials have not expired. The receiving device must also verify that the credentials of the transmitter have not been placed on a global revocation list that is managed and distributed by the SCMS.

The process for obtaining an enrollment certificate was developed in such a way that no single organization has sufficient information to re-identify a device. It will take the cooperation of two entities to re-identify a device (e.g., in response to a court order).

The SCMS is also capable of providing V2I enrollment and application certificates to RSUs. Application certificates are required in order for the RSU to digitally sign any messages that it transmits, such as TIM, Signal Phase and Timing (SPaT), and Mapping for intersection (MAP) messages. This ensures that any device receiving these messages can verify that they were transmitted by an authorized device in the CV environment. These V2I certificates are distinct from the certificates issues to vehicles (V2V certificates) because privacy is not a requirement for RSU as they are typically owned by a public agency or toll authority.

While the original plan was to use the CAMP PoC SCMS, that plan has changed. The WYDOT CV Pilot is using the GHS/ISS commercial SCMS with CV Pilot certificates. Figure 4-31 provides the physical architectural view of the interaction between the SCMS and the WYDOT CV Pilot. The SCMS will interact with an Operator, which will send credential management input and in hand will be allowed to interact with the system. The SCMS also receives device enrollment and misbehavior reports from and provides security policy, network, credentials and CRLs information to the different Vehicle Subsystems, the RSUs sand the ODE.

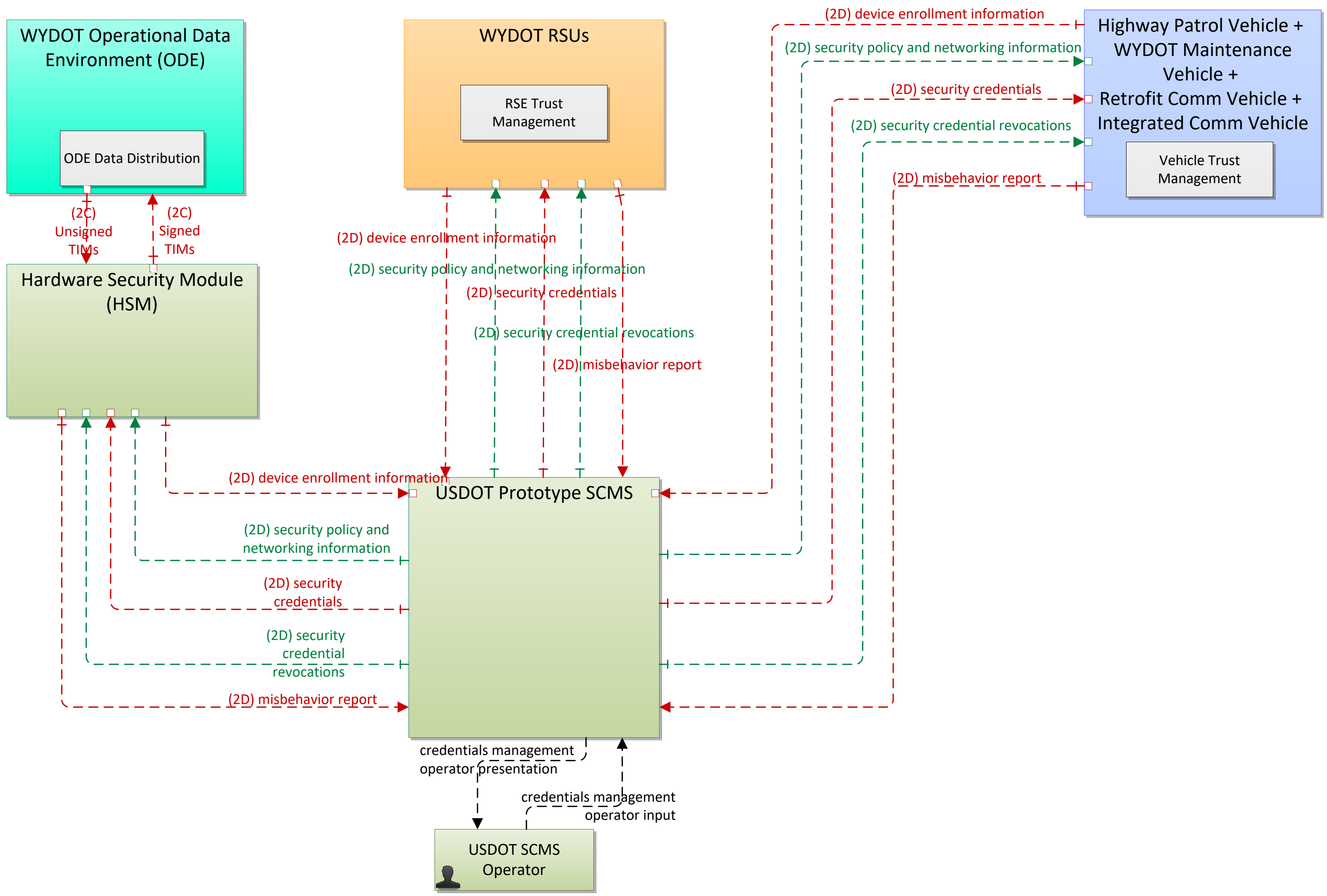


Figure 4-31. Security View of WYDOT CV Pilot System Architecture. (Source: WYDOT)

4.8 Traceability to User Needs and Requirements

As noted previously, the functional architecture described in Section 4.2 and the physical architecture described in Section 4.3 were drafted during development of system requirements as described in the WYDOT CV Pilot SyRS. The Requirements Specification also provides detailed traceability of user needs to system requirements and system requirements to subsystem requirements in Chapter 7 of the document. Table 7-1 of the SyRS maps the user needs identified for the pilot with the system- and interface-level requirement. Table 7-2 traces the Sub-System requirements to applicable System- and Interface-level requirements. Further details pertaining to traceability are incorporated into the WYDOT CV Pilot System Design Document (SDD).

4.9 CV Pilot Interoperability Support and Information Flow “Triples”

A vital requirement for the successful deployment of connected vehicle technology is the interoperability of communications between vehicles and between vehicles and infrastructure across the United States. Recognizing this need, the USDOT has assembled a CV Pilots Technical Roundtable, which meets regularly to discuss strategies to overcome technical obstacles, to develop and implement strategies to ensure interoperability between the respective CV Pilot systems in this deployment and to provide a foundation that supports interoperability in future deployments. The WYDOT CV Pilot team actively participates and contributes in the CV Pilot Roundtable meetings and activities.

Two of the ongoing Roundtable activities supporting interoperability are:

- Development of “Message Set Spreadsheets” which fully define a template for consistent and interoperable exchange of key messages, the BSM, MAP, SPaT and TIM messages.
- Development of “Triples Spreadsheet” which describe information flows between system components, identifying the source, destination, information flow, and standard to be used for the communication.

This resulting outcome of these activities are now captured in the WYDOT CV Pilot Interface Control Document (ICD). Relevant descriptions of messages and triples for this pilot are found there.

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