BASIC INFRASTRUCTURE MESSAGE DEVELOPMENT AND STANDARDS SUPPORT FOR CONNECTED VEHICLES APPLICATIONS

Task 3

Connected Vehicle Standards and Related Activities

White Paper

April 24, 2018

Prepared for:

Connected Vehicle Pooled Fund Study

Prepared by:

Southwest Research Institute®

http://swri.org

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1. INTRODUCTION

This white paper was developed as part of the Connected Vehicle Pooled Fund Study (CV PFS) project "Basic Infrastructure Message Development and Standards Support for Connected Vehicles Applications."

1.1 Project Background

In a connected vehicle (CV) environment, vehicles which are equipped with Dedicated Short-Range Communication (DSRC) devices broadcast Basic Safety Messages (BSMs), and a standard such as SAE J2735 has been well defined for what information is in the BSM. On the other hand, from the infrastructure side, which infrastructure information will be or needs to be broadcasted is relatively unknown and has not been well investigated yet. While some of the infrastructure related information, i.e., a Signal Phase and Timing (SPaT) message, and a map data (MAP) message (including intersection ID, reference point, orientation, lane width, type, etc.), are already included in the current standards, there are other pieces of infrastructure information that may benefit CV applications; such as speed limit (particularly where that might be variable), standard signage in the area, presence of school zones, work zones and lane closures, messages displayed on variable messages signs or highway advisory radios, etc.

With this background, it was recently suggested that a corollary message to the BSM from the infrastructure, a Basic Infrastructure Message (BIM), needs to be investigated. Having a standard (or near standard) BIM would help the original equipment manufacturers (OEMs) and third-party application providers to understand that there will be some infrastructure for them to rely on, and will give them some basis for the kind of message they can expect from the infrastructure. At the same time, this will also help the public transportation agencies to know what kind of information to broadcast from their roadside equipment (RSE).

Once a standard (or near standard) BIM is developed, the next step would be to work with the appropriate standards development organization and committee to get the BIM standard message under consideration as a standard. Likewise, there is an urgent need for the public agencies (actual operators and maintainers of the infrastructure) to be able to influence the decisions related to the standards for vehicular data, such as BSM, as well. For a variety of reasons (budget, expertise, travel constraints, time availability, etc.), the operating agency personnel have not engaged in these standards development exercises, but have an important interest in their outcomes. Also, many of the states are not even fully aware of what standards exist or what the status of them is. With that being said, it is important to establish a means with which the CV PFS team can track standards related activities and influence the development of these standards.

1.2 Project Goals

The goals of this project are:

- Develop a BIM
- Establish a means to collaborate with the relevant standards development organizations

1.3 Purpose of This Document

This white paper was developed under Task 3 of the project: "Standards and Related Activities Review". This paper is intended to capture information regarding the current CV standards and the various programs in which they are being used. This includes deriving a comprehensive list of infrastructure related messages from relevant standards. The information in this document will be used in subsequent project tasks to develop the BIM. To keep this paper within a reasonable size, the information in the current standards and related activities are summarized and links to more information is provided as footnotes.

1.4 References

Please note that this reference list is not exhaustive. Throughout this document, references are also made in footnotes or are otherwise noted.

1.4.1 *Normative References*

1.4.1.1 SAE Publications

SAE J2945-0	Dedicated Short Range Communications (DSRC) Systems Engineering Process Guidance for J2945/x Documents and Common Design Concepts, Prop Draft June 2017
SAE J2735	Dedicated Short Range Communications (DSRC) Message Set Dictionary, March 2016 [SAE J2735]
SAE J2540-2	ITIS Phrase Lists (International Traveler Information Systems), November 2009
SAE J2945-2	Dedicated Short Range Communications (DSRC) Performance Requirements for V2V Safety Awareness, Prop Draft Sept 2017

1.4.1.2 IEEE Publications

Available from IEEE, 445 Hoes Lane, Piscataway, NJ 08854-4141, Tel: 732-981-0060, www.ieee.org.

IEEE 1609.2™-2016	IEEE Standard for Wireless Access in Vehicular Environments - Security Services for Applications and Management Messages
IEEE 1609.3™-2016	IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Networking Services
IEEE 1609.12	1609.12-2016 - IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Identifier Allocations

It should be noted that there are additional standards in the 1609 suite which are not directly referenced here but which may also be of assistance to implementers.

1.4.1.3 ISO Publications

Copies of these documents are available online at http://webstore.ansi.org/

ISO/IEC 8824-1:1998	Information technology - Abstract Syntax Notation One (ASN.1): Specification of basic notation.
ISO/TS 19091	Intelligent transport systems -- Cooperative ITS -- Using V2I and I2V communications for applications related to signalized intersections

1.4.2 *Other References*

All documents cited here are considered non-normative.

BIM Task 2	SwRI deliverable: Infrastructure Information Elements Review, Draft Nov 2017

2. EXISTING CV STANDARDS

The following sections summarize the relevant standards that are applicable to the development of CV applications that may have direct and indirect application to a BIM. The diagram, shown in Figure 1, provides context of existing CV standards including IEEE 1609, SAE J2735 and J2945/X, Security Credential Management System (SCMS), Traffic Management Data Dictionary (TMDD), National Transportation Communications for ITS Protocol (NTCIP), and ISO TS 19091 standards.

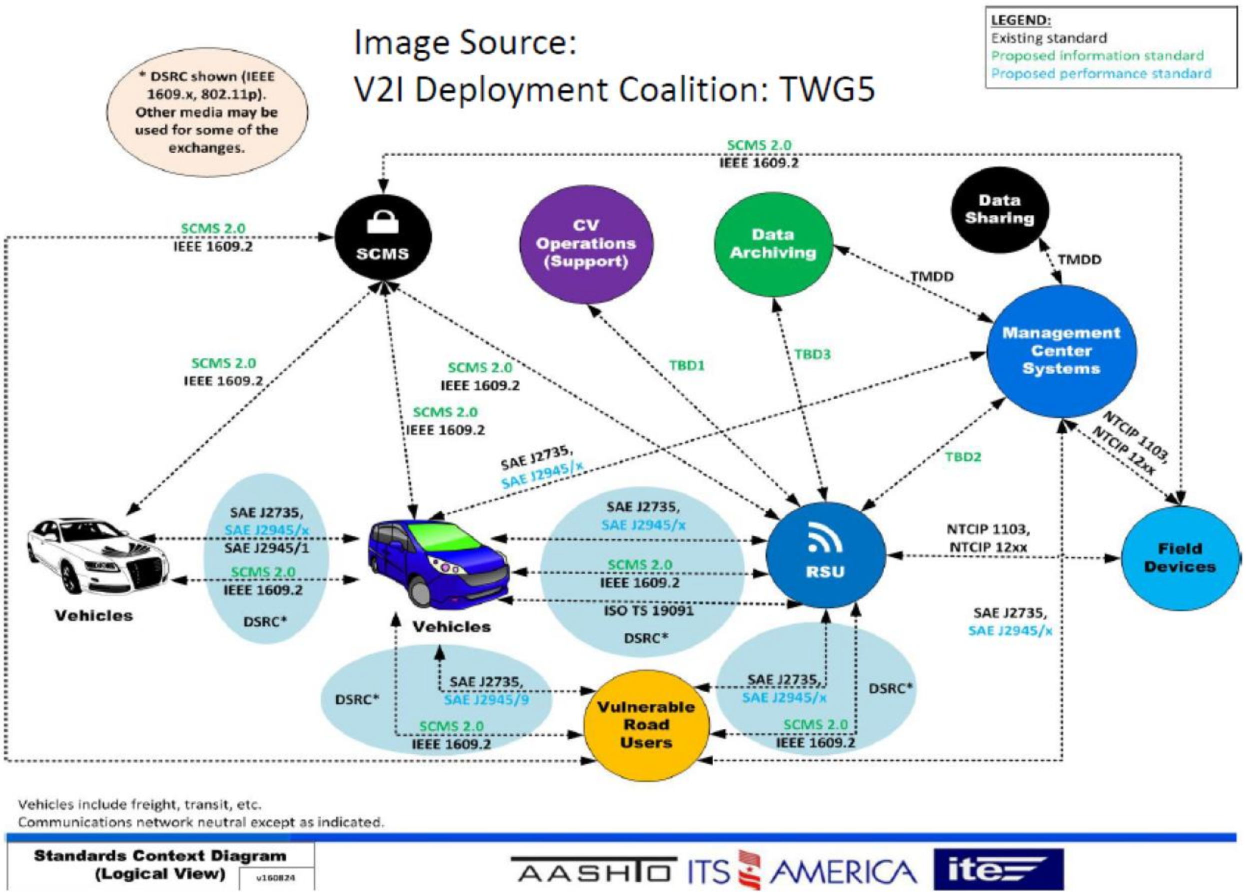

Figure 1. CV Standards Context Diagram.

2.1 IEEE 802.11 – (Medium Access Control and Physical Layers for Wireless Local Area Networks)

IEEE 802.11, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, is a mature standard last published in 2012. The standard specifies how to implement wireless local area network (WLAN) connectivity for fixed, portable, and moving stations (STAs) operating in the 900MHz and 2.4, 3.6, 5, 45, and 60GHz frequency bands, as shown in Figure 2. The standard considers a system in two major parts: the MAC of the data link layer (DLL) and the PHY. These two parts correlate to the lowest layers of the ISO/IEC basic reference model of Open Systems Interconnection (OSI) (ISO/IEC 7498-1: 1994). The standard models the two parts by providing MAC definition and procedures, layer management, PHY service specification, frame formats, MAC sublayer functional description, MAC sublayer management entity (MLME) for association and authentication procedures, Robust Security Network Association (RSNA) and pre-RSNA security, Fast Basic Service Set (BSS) transition, and mesh STA procedures.

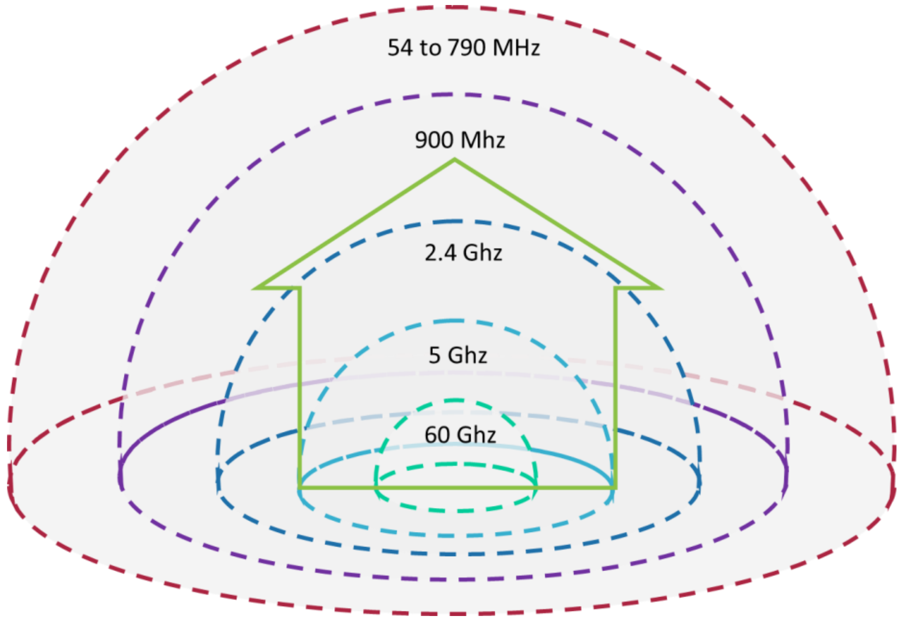

Figure 2. IEE 802.11 Frequency Bands.

IEEE 802.11 contains 16 revisions that are primarily concerned with the logical link control, MAC, and PHY dependent on physical medium used. The most notable of the revisions are 802.11b, 802.11g, 802.11a, and 802.11p. The 802.11b revision is a well-supported and stable standard that operates in the 2.4GHz range, with 11 channels, 3 non-overlapping, and has a maximum data rate of 11Mbps. Many devices, such as microwaves, cordless telephones, and Bluetooth devices also utilize the 2.4GHz so wireless devices using the 802.11b standard commonly experience interference. The 802.11g revision is an extension of 802.11b; however, it has a maximum data rate of 54Mbps. The 802.11a revision operates in the 5GHz range, with 12 channels, 8 non-overlapping. The 802.11a standard does not suffer the interference issues shared by 802.11b and 802.11g. The 802.11p revision incorporates wireless access in vehicular environments (WAVE) to support Intelligent Transportation Systems (ITS) communication, including Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Device (V2D), collectively termed Vehicle to Everything (V2X). The 802.11p standard operates the 5GHz frequency range using 75Mhz bandwidth (i.e., 5.850-5.925GHz) which is half the bandwidth of 802.11a and thus takes twice the transmission time. The 802.11p standard is a lower layer that IEEE 1609.X, discussed in the next section, is based on. Communication using 802.11p assumes that V2I communication would occur only a brief time and therefore allows communication to occur without following association and authentication procedures meaning that RSNA security mechanisms cannot be utilized so security measures are implemented at a higher network layer, IEEE 1609.X.

A final take away from this standard is to note that the MLME Association message includes an 'EmergencyServices' as part of a client's association request to a wireless access point (AP). This message specifies that the non-AP STA intends to associate for unauthenticated access to emergency services [802.11, p125]. The 802.11i and 802.11u standards describe mechanisms for securing emergency communication.

2.2 IEEE 1609.X –WAVE Family of Standards

IEEE 1609.X WAVE Family of Standards defines a range of standards for security techniques to protect services using 5.9GHz DSRC for WAVE (DSRC/WAVE) given the processing and bandwidth necessary for safety-critical applications. These standards utilize IEEE 802.11p to define the PHY and MAC layers and specifies the architecture and standardized set of services and interfaces to implement secure V2I and V2V wireless communications. The standards suite consists of following standards:

- IEEE 1609.0 - IEEE Guide for WAVE - Architecture
- IEEE 1609.2 - IEEE Standard for WAVE- Security Services for Applications and Management Messages
- IEEE 1609.3 - Standard for WAVE - Networking Services
- IEEE 1609.4 - IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Multi-Channel Operation
- IEEE 1609.11 - Over-the-Air Electronic Payment Data Exchange Protocol for ITS
- IEEE 1609.12 - Standard for WAVE - Identifier Allocations

An example for the WAVE reference model is shown in Figure 3.

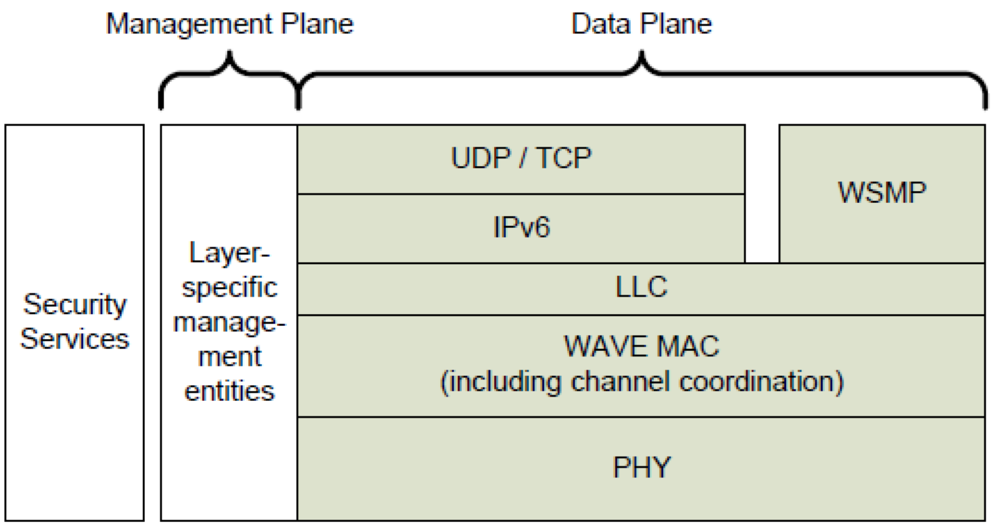

Figure 3. WAVE Reference Model [IEE1609.2, pg12].

2.2.1 IEEE 1609.0 - IEEE Guide for WAVE – Architecture

IEEE 1609.0 IEEE Guide for WAVE - Architecture standard defines the architecture, operations, and services required for multi-channel WAVE communications in a moving vehicular environment, such as CV and AV. The standard is expected to be used in conjunction with the other standards along with IEEE 802.11p. The standard is active, with the latest version published in 2013.

2.2.2 IEEE 1609.2 - Security Services for Applications and Management Messages

IEEE 1609.2 IEEE Standard for WAVE Security Services for Applications and Management Messages standard defines the secure message formats and processing for use by WAVE devices. The standard describes the methods to secure services for WAVE management messages and application messages. The WAVE Security Services discussed in this standard are the WAVE Internal Security Services and WAVE Higher Layer Security Services, shown in Figure 4.

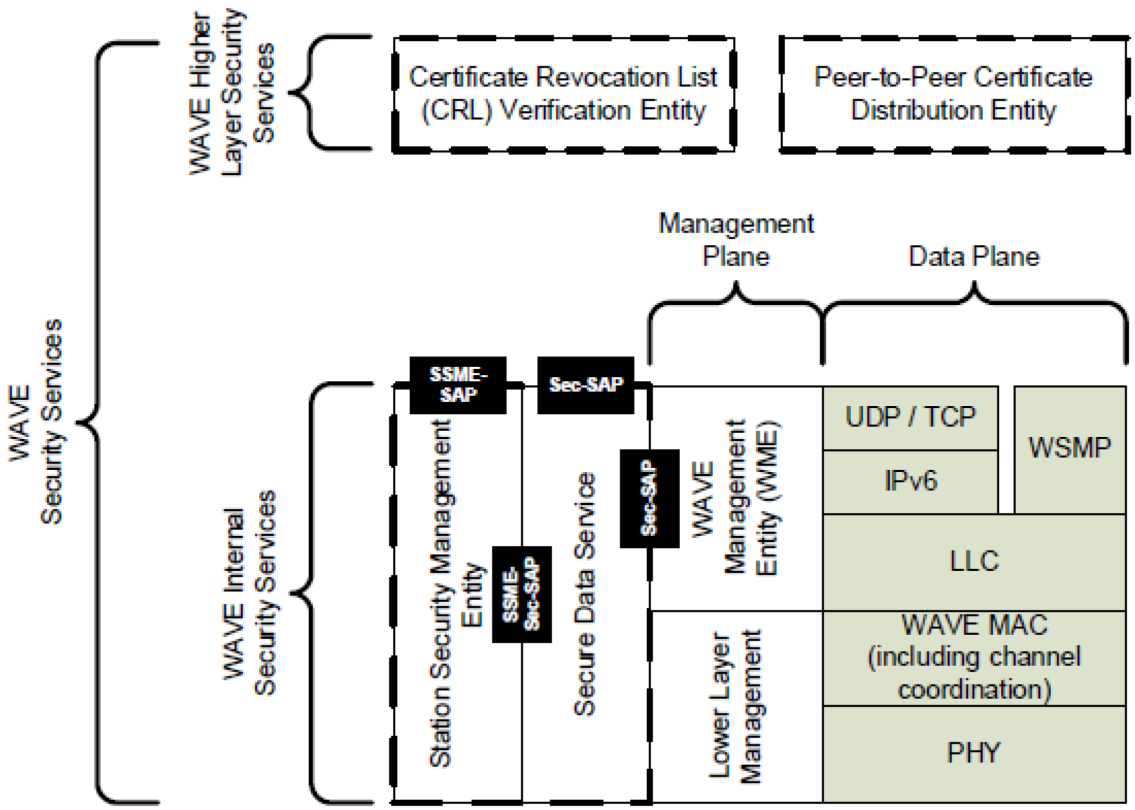

Figure 4. WAVE protocol stack showing detail of WAVE Security Services [IEEE 1609.2, p13].

WAVE Internal Security Services consists of secure data service (SDS) and security management. The SDS operations define the process for creating a security envelope by adding data to unsecured protocol data units (PDUs), transforming them into secured protocol data units (SPDUs). The SDS also describes processing received SPDUs and transforming them into PDUs. The transformation of the data units occurs between two secure data exchange entities (SDEEs). The process occurs by one SDEE invoking a request to process data and the resulting processed data is returned to the invoking SDEE. The security management service defines managing information about certificates using a security services management entity (SSME) to store information related to the certificate data being managed.

WAVE Higher Layer Security Services consists of certificate revocation list (CRL) verification entity (CRLVE) and peer-to-peer certificate distribution (P2PCD) entity (P2PCDE). The CRLVE is a service that validates incoming CRLs and updates local stores of certification revocation by invoking the SDS and SSME. Related revocation information is then passed to the SSME for storage. The P2PCDE enables peer-to-peer certificates. The latest version of the standard is 2016 and is a revision of the IEEE 1609.2-2013.

2.2.3 IEEE 1609.3 - Standard for WAVE - Networking Services

IEEE 1609.3 - Standard for WAVE - Networking Services defines the services, operating at the layer 3 (networking) and layer 4 (transport) of the OSI communications stack, in support of wireless connectivity among vehicle-based devices, and between fixed roadside devices and vehicle-based devices using the 5.9GHz WAVE mode in ITS architectures. This standard provides the addressing and routing services within a WAVE system, enabling multiple stacks of upper layers above WAVE Networking Services, and multiple lower layers beneath WAVE Networking Services. This standard supports wireless communications for all WAVE devices including mobile, portable, and stationary.

The WAVE Networking Services, shown in Figure 5, consists of network and transport layer services and the associated management plane entity, called the WAVE Management Entity (WME). The standard also defines a WAVE specific alternative to Internet Protocol version 6 (IPv6) called WAVE Short Message Protocol (WSMP) and the Management Information Base (MIB) for the WAVE protocol stack.

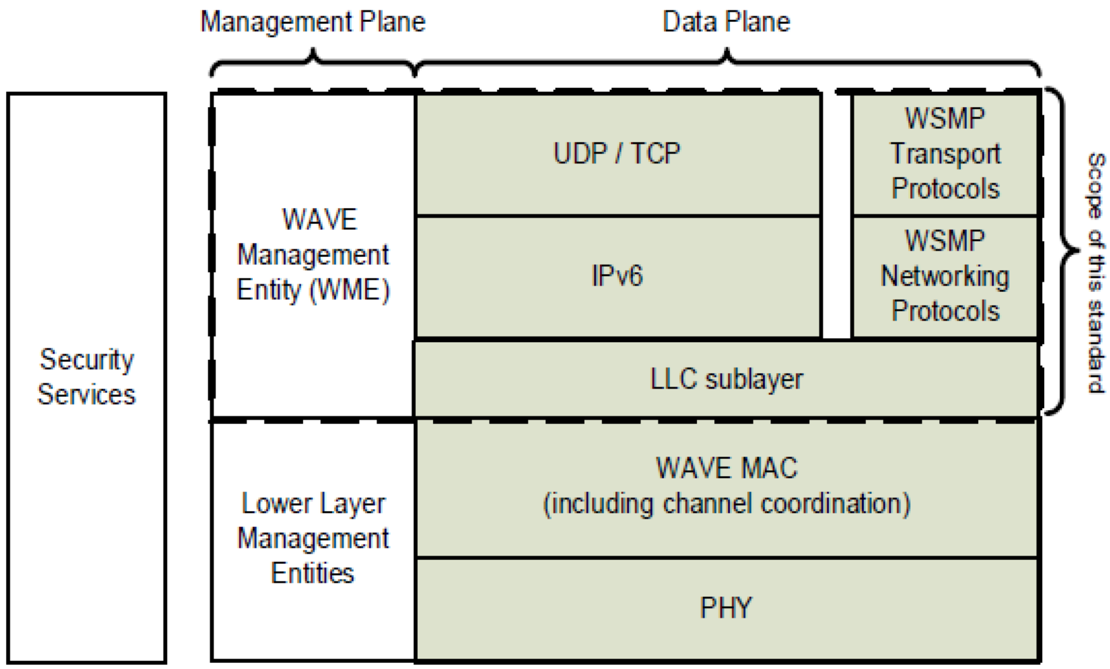

Figure 5. WAVE Network Services [IEEE 1609.3, p17].

The standard also specifies that a WAVE device must implement the following as a minimum:

- Logical Link Control (LLC) sublayer
- IPv6 or WSMP, or both
- Transmit or receive, or both

The standard is dated year 2016 and is a revision of IEEE 1609.3-2010.

2.2.4 IEEE 1609.4 - IEEE Standard for WAVE - Multi-Channel Operation

IEEE 1609.4 - IEEE Standard for WAVE - Multi-Channel Operation, shown in Figure 6, provides specifications regarding the MAC sublayer functions and services that support multi-channel wireless connectivity between WAVE devices without requiring knowledge of PHY parameters. This standard describes the channel coordination required for WAVE devices to operate over multiple wireless channels, using additional features for “OCBActivated” communication in the MAC sublayer, outside the context of basic service set, as specified by IEEE 802.11. The standard is dated year 2016 and is a revision of IEEE 1609.4-2010.

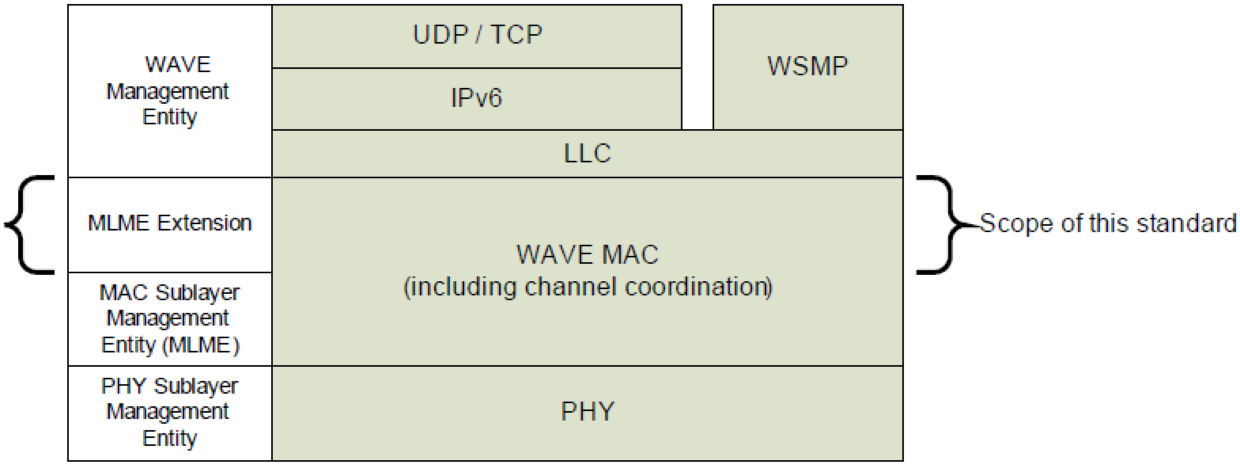

Figure 6. WAVE Multi-Channel Operation [IEEE 1609.4, p15].

The IEEE 802.11 MAC layer conceptually includes a management entity called MLME. This management entity invokes layer management functions using layer management service interfaces. This standard specifies MLME extensions to the IEEE 802.11 sublayer that include channel coordination features and additions to the primitives used for transmitting data to support MAC service data units (MSDU) delivery. The defined primitives are exchanged through services access point (SAP) interactions between the various entities.

For multi-channel operation, the 1609.4 standard specifies data plane services and management services. Data services consists of:

- Channel coordination
- Channel routing
- User priority

Channel coordination describes how the MAC sublayer coordinates device resources so that data packets are transmitted on the proper wireless channel in the correct time slot. Channel routing describes how the MAC sublayer handles inbound and outbound higher layer data, including the routing of data packets to and from a higher layer to the designated channel, and setting parameters (e.g., transmit power) for WAVE transmissions. User priority utilizes the IEEE 802.11 enhanced distributed channel access (EDCA) mechanism to define the use of user priority (UP) and related access category (AC) to support quality of service and accommodate a variety of safety and non-safety applications.

The IEEE 1609.4 management services uses the MLME and consists of:

- Multi-channel synchronization
- Channel access
- Other IEEE 802.11 services
- MIB maintenance
- Readdressing

Multi-channel synchronization defines how to use the MLME synchronization function to achieve the aligning time slots among communicating WAVE devices using the MLME using information that may be derived locally or received over the air. The MLME also provides the capability to generate and monitor Timing Advertisement (TA) frames for the distribution of system timing information. Channel access defines the MLME methods to control access to specific radio channel communication requests received from the WME. When considering other IEEE 802.11 services, the management services defines that the

IEEE 802.11 services may be invoked on a per-channel basis using the MLME. MIB maintenance describes how the MLME maintains an MIB containing configuration and status information. Readdressing supports pseudonymity, disguised identity, using the MLME to perform device MAC address changes.

The 1609.4 standard also stipulates that a WAVE device implements at least the following features that are specified in this standard:

- “OCBActivated” communication
- Transmit or receive, or both
- When transmitting, EDCA and user priority

2.2.5 IEEE 1609.11 - Over-the-Air Electronic Payment Data Exchange Protocol for ITS

IEEE 1609.11 - Over-the-Air Electronic Payment Data Exchange Protocol for ITS extends the IEEE 1602.2 standard and defines the services and security message formats required to support secure electronic payments.

2.2.6 IEEE 1609.12 - Standard for WAVE - Identifier Allocations

IEEE 1609.12 Standard for WAVE - Identifier Allocations is a recent standard that was released late 2016 and specifies the WAVE identifier allocation. It is a revision of the 1609.11-2010. The WAVE identifies the following:

- Provider Service Identifier (PSID)
- Object Identifier (OID)
- EtherType
- 36-bit Organizationally Unique Identifier (OUI-36)
- Management ID

The PSID has three use cases:

- Identify the permissions of the senders of some information
- Identify available advertised provider services
- Route messages, sent by advertised provider services, to the appropriate user applications

The PSID is represented by an integer with a value from 0 to 270,549,119 (0x10-20-40-7F, where “0x” indicates hexadecimal, or hex, notation). It is used twice in IEEE 1609.3 and shares characteristics and its numbering space with the ITS Application Identifier (ITS-AID) used in standards from other international standards organizations involved in Intelligent Transportation Systems including International Organization for Standardization (ISO), European Committee for Standardization (CEN), and European Telecommunications Standards Institute (ETSI).

The OID is used to uniquely identify an object and whose format is specified in ISO/IEC 8824-1 and ISO/IEC 8825-1 and is used to identify ASN.1 objects, including MIBs, objects within MIBs, and other data structures.

The EtherType identifier is a 2-octet field with values (i.e., networking protocols) assigned by the IEEE Registration Authority and is used to identify the networking protocol employed above the data link layer, such as IPv6 and WSMP.

The OUI-36 identifier is a 36-bit value used to identify the organization responsible for the definition of the content of “vendor-specific” information. This identifier has been replaced by the MAC Address Block

Small (MA-S) registry product name as of January 1, 2014; however, already assigned OUI-36 registry product may continue to use the assignment. [1]

The Management ID can be used by the WAVE devices to distinguish among different WAVE management functions (i.e., WME, expansion code) that may send or receive management information.

2.3 SAE J2735 – DSRC Message Set Dictionary

SAE J2735, DSRC Message Set Dictionary, is a surface vehicle standard whose purpose is to support interoperability among 5.9GHz DSRC applications. The standard specifies a message set, and its data frames and data elements in DSRC applications used by WAVE communication systems. This standard was developed with focus on DSRC; however, it can also be applied to applications deployed in conjunction with other wireless communication technologies as it was developed to be independent of the underlying lower layer protocols. The usage of the messages and performance requirements are specified in SAE J2945/X standards. The standard is quite mature and has undergone several updates, with the first version released in Dec 2006 and the latest version (v5) in March 2016.

SAE J2735 defines message sets and their corresponding data frames and data elements. A message set is a collection of messages based on the ITS functional area they pertain to. The collection of messages defined in this Standard is a message set and a data frame is a collection of two or more other data concepts in a known ordering [J2735_200911, p19]. These data concepts may be simple, such as data elements, or complex, such as data frames.

SAE J2735 also defines how the information gets encoded. In the March 2016 version, some changes to how information is encoded occurred. This update effects systems implementing older versions of the standard such that SPaT broadcasts using an older version of the standard may not be able to be received by vehicles using the 2016 standard.

The following message sets are covered in this standard:

- MessageFrame (FRAME)
- BasicSafetyMessage (BSM)
- CommonSafetyRequest (CSR)
- EmergencyVehicleAlert (EVA)
- IntersectionCollisionAvoidance (ICA)
- MapData (MAP)
- NMEAcorrections (NMEA)
- PersonalSafetyMessage (PSM)
- ProbeDataManagement (PDM)
- ProbeVehicleData (PVD)
- RoadSideAlert (RSA)
- RTCMcorrections (RTCM)
- SignalPhaseAndTiming Message (SPAT)
- SignalRequestMessage (SRM)
- SignalStatusMessage (SSM)
- TravelerInformation Message (TIM)
- TestMessages

[1] http://standards.ieee.org/faqs/regauth.html#21

The MessageFrame (FRAME) is the main message structure that encompassed all other message sets defined in this standard.

The BasicSafetyMessage (BSM) set describes messages used in a variety of applications to exchange safety data regarding vehicle state. The BSM is broadcast frequently to surrounding vehicles with data content as required by safety and other applications. BSM transmission rates are approximately sent at a rate of 10 times per second when congestion control algorithms do not prescribe a reduced rate.

The CommonSafetyRequest (CSR) message set provides a means for a vehicle participating in the exchange of the BSM can unicast requests to other vehicles for additional information required for the safety applications it is actively running. Responding vehicles will (or may) add the CSR information to the appropriate place in the basic safety message when they broadcast it.

The EmergencyVehicleAlert (EVA) message set is used to broadcast warning messages to surrounding vehicles that an emergency vehicle, such as an incident responder, is operating in the vicinity and that additional caution is required. The EVA message itself is built on the original Alliance for Telecommunications Industry Solutions (ATIS) roadside alert (RSA) message which in turn uses the common Integrated Taxonomic Information System (ITIS) phrase list to both describe the event and provide advice and recommendation for travelers. The EVA message appends some additional data elements regarding the overall type of vehicle involved and other useful data. This message set can be used by both private and public response vehicles, and that the relative priority and security certificates of each are determined in the application layer.

The IntersectionCollisionAvoidance (ICA) message set is intended to be used to broadcast a warning to other DSRC devices near a potential collision with a vehicle that is likely to be entering an intersection without the right of way. The sender of the ICA message may be either an equipped vehicle or another source such as the ITS infrastructure.

The MapData (MAP) message is used to convey many types of geographic road information and includes such items as complex intersection descriptions, road segment descriptions, high-speed curve outlines (used in curve safety messages), and segments of roadway (used in some safety applications). Currently, the MAP's primary use is to convey descriptions of one or more geographic areas or intersection lane geometry maps within a single message. The contents of this message involve defining the details of indexing systems that are in turn used by other messages to relate additional information to events at specific geographic locations on the roadway. An example of additional information may be the signal phase and timing via the SPAT message.

The NMEAcorrections (NMEA) message is used to encapsulate NMEA 183 style differential corrections for global positioning system (GPS)/ global navigation satellite system (GNSS) radio navigation signals as defined by the National Marine Electronics Association (NMEA) committee in its Protocol 0183 standard. For transport on the DSRC media, the NMEA 183 style differential corrections are encapsulated and can be re-constructed back into the final expected formats defined by the NMEA standard. Once re-constructed, the formatted message can be used directly by GNSS to increase the absolute and relative accuracy estimates produced.

The PersonalSafetyMessage (PSM) is used to broadcast safety data regarding the kinematic state of various types of Vulnerable Road Users (VRU), such as pedestrians, cyclists or road workers. Note that the message set is currently under development.

The ProbeDataManagement (PDM) message is used to control the type of data collected and sent by on-board units (OBUs) to the local Roadside Unit (RSU), also called a STA. The data is taken at a defined snapshot event to define RSU coverage patterns including the moment an OBU joins or becomes associated with an RSU and can send probe data.

The ProbeVehicleData (PVD) message is used to exchange status about a vehicle with other DSRC devices, such as the RSU, to allow the collection of information along a segment of road about typical vehicle traveling behaviors.

The Road Side Alert (RSA) message is used to send alerts for nearby hazards to travelers. Unlike many other messages which use the Location Referencing Message Specification (LRMS) profiles to describe the areas affected, this message likely applies to the receiver by the very fact that it is received. In other words, it does not use LRMS. Typically transmitted over the DSRC media, this message provides simple alerts to travelers (both in vehicle and with portable devices).

The RTCMcorrections (RTCM) message is used to encapsulate RTCM differential corrections for GPS and other radio navigation signals. The message set is defined by the Radio Technical Commission for Maritime Services (RTCM) special committee number 104 in its various standards. For transport on the DSRC media, the RTCM differential corrections are encapsulated and can be re-constructed back into the final expected formats defined by the RTCM standard. Once re-constructed, the formatted message can be used directly by various position systems to increase the absolute and relative accuracy estimates produced

The SignalPhaseAndTiming (SPAT) message is used to convey status of one or more signalized intersections. Along with the MapData message, that describes a full geometric layout of an intersection, the receiver of this message can determine the state of the signal phasing and when the next expected phase will occur. Note the latest 2016 standard affects how this message is encoded such that broadcast messages using older versions of encoding may not be received by vehicles implementing the 2016 standard.

The SignalRequestMessage (SRM) is a message sent by a DSRC equipped entity, such as a vehicle, to the RSU in a signalized intersection. Depending on the setting of the request, the SRM message is used for either a priority signal request or a preemption signal request. Each request defines a path through the intersection which is desired in terms of lanes and approaches to be used and can also contain the time of arrival and the expected duration of the service. The SRM supports multiple requests to multiple intersections. The outcome of all the pending requests to a signal can be found in the SignalStatusMessage (SSM), and may be reflected in the SPAT message contents if successful.

The SSM is sent by an RSU in a signalized intersection and is used to relate the status of the signal and the collection of pending or active preemption or priority requests acknowledged by the controller. The SSM is also used to send information about preemption or priority requests which were denied that in turn allows a dialog acknowledgment mechanism between any requester and the signal controller. The data contained in the SSM allows other users to determine their "ranking" for any request they have made as well as to see the currently active events. If there have been no recently received requests for service messages, then this message may not be sent. The outcome of all pending requests to a signal can be found in the SSM, the current active event, if any, will be reflected in the SPAT message contents.

TravelerInformationMessage (TIM) is used to send various types of information, such as advisory and road sign types, to equipped devices at a precise start and duration period. The TIM heavily depends on the ITIS encoding system to send well known phrases, but allows limited text for local place names. The supported message types specify several sub-dialects of ITIS phrase patterns to further reduce the number of octets to be sent.

TestMessages are expandable messages used to support the local and regional deployment development of new messages and their own information exchanges within the common framework of the overall DSRC Message set and this data dictionary. The TestMessage provides a few common elements for consistency and is anticipated that over time the concepts developed in these messages will migrate into the data dictionary and main message set. [

2.4 SAE J2945/X - DSRC Common Performance Requirements Family of Standards (WIP)

SAE J2945/X DSRC Common Performance Requirements Family of Standards define a range of standards that intend to provide guidance for the use of the Systems Engineering (SE) process and generic DSRC interface requirements content, including how to read and interpret the J2945/x family of documents to assist standards-based deployments and procurement processes. J2945/X is still under development and it along with several of its standards are considered a work in progress (WIP).

Currently the J2945/X standards suite consists of following standards:

- SAE J2945/1 - On-Board System Requirements for V2V Safety Communications
- SAE J2945/2 - DSRC Performance Requirements for V2V Safety Awareness (WIP)
- SAE J2945/3 - Requirements for V2I Weather Applications (WIP)
- SAE J2945/4 - DSRC Messages for Traveler Information and Basic Information Delivery (WIP)
- SAE J2945/6 - Performance Requirements for Cooperative Adaptive Cruise Control and Platooning (WIP)
- SAE J2945/9 - Vulnerable Road User Safety Message Minimum Performance Requirements (WIP)
- SAE J2945/10 - Recommended Practices for MAP/SPaT Message Development (WIP)

2.4.1 SAE J2945/1 - On-Board System Requirements for V2V Safety Communications

SAE J2945/1, On-Board System Requirements for V2V Safety Communications, standard was released in 2016 and specifies the system requirements for an on-board V2V safety communications system for light vehicles. The requirements include standards profiles, functional requirements, and performance requirements. This standard addresses the on-board system, shown in Figure 7, needs for ensuring that the exchange of BSMs provides the desired interoperability and data integrity in V2V safety communications while supporting the performance of the envisioned safety applications.

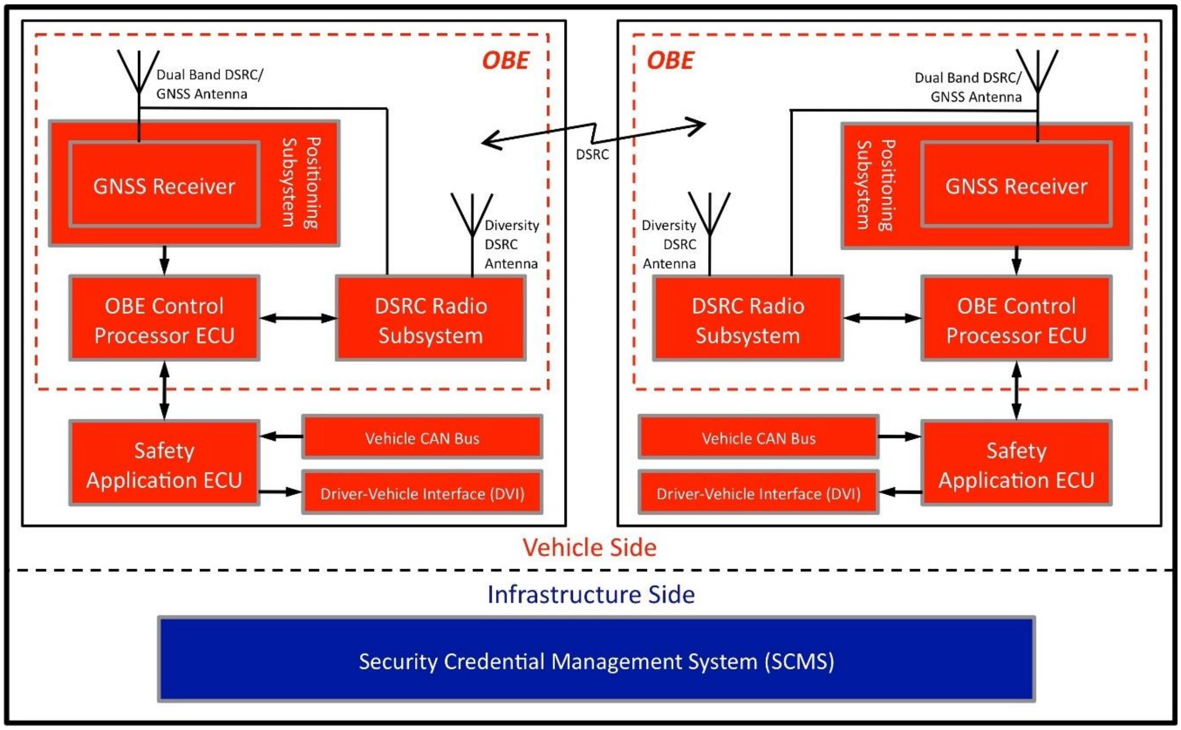

Figure 7. On-board V2V System [J2945/1, p12].

The V2V safety communications system can transmit and receive the SAE J2735-defined BSM over a DSRC wireless communications link as defined in the IEEE 1609 standards suite and IEEE 802.11 standards family.

2.4.2 SAE J2945/2 - DSRC Performance Requirements for V2V Safety Awareness (WIP)

SAE J2945/2, DSRC Performance Requirements for V2V Safety Awareness, standard will specify use cases and DSRC requirements for V2V safety awareness application, including detailed SE documentation. This standard aims to define the safety needs and requirements mapped to appropriate message exchanges. This standard is still under development and limited public information is available.

2.4.3 SAE J2945/3 - Requirements for V2I Weather Applications (WIP)

SAE J2945/3, Requirements for V2I Weather Applications, standard will define requirements to support V2I weather applications interface in a connected vehicle environment with the focus on information exchanges between the infrastructure and connected vehicles. USDOT has provided funding for this standard and has requested that the Technical Committee (TC) approve using the Systems Engineering Process (SEP) and initial works in the field of road weather applications have been conducted by stakeholders from both the public and private sector. USDOT has offered a high-level Concept of Operations for Road Weather Connected Vehicle and Automated Vehicle Applications to the TC as a basis for consideration to initiate the dialog for J2945/3. This Concept of Operations contains 8 Proposed Applications and 13 Operational Scenarios for the TC and V2I TF to consider. The TC also has material in SAE J3067 as a basis for its consideration.

Note this effort may result in identifying new messages, data frames and data elements in SAE J2735.

2.4.4 SAE J2945/4 - DSRC Messages for Traveler Information and Basic Information Delivery (WIP)

SAE J2945/4, DSRC Messages for Traveler Information and Basic Information Delivery, standard will serve to re-work and extend the existing SAE J2735 message elements to include additional travel and roadway information from the infrastructure to enhance safety awareness and promote the exchange and transfer of such messages types between V2I. This standard will outline the needs and detail the system requirements to support a variety of use cases linking to the SAE J2735 effort as other SAE J2945/x documents do.

2.4.5 SAE J2945/6 - Performance Requirements for Cooperative Adaptive Cruise Control and Platooning (WIP)

SAE J2945/6, Performance Requirements for Cooperative Adaptive Cruise Control (CACC) and Platooning, standard will define the data exchange necessary for coordinated maneuvers and categorization of that definition. The definition of the categories will begin with differentiating Platooning and CACC, then determine message sets and performance requirements to realize cooperative vehicles. This standard aims to realize the role of V2X communication with automated vehicles (AV). This standard is still under development and limited public information is available.

2.4.6 SAE J2945/9 - Vulnerable Road User Safety Message Minimum Performance Requirements (WIP)

SAE J2945/9, Vulnerable Road User (VRU Safety Message Minimum Performance Requirements, standard will determine VRU use cases and provide recommendations for performance levels between a VRU and a vehicle. This standard addresses the increasing proportion of US and European road fatalities associated with VRU crashes by providing driver and vehicle system awareness and potentially offer safety alerts to VRUs. This standard is still under development and limited public information is available.

2.4.7 SAE J2945/10 - Recommended Practices for MAP/SPaT Message Development (WIP)

SAE J2945/10, Recommended Practices for MAP/SPaT Message Development, will be a recommend best practices document outlining how to use the current MAP and SPAT message content found in the SAE J2735. The standard’s primary content will deal with better explaining and demonstrating by small working examples of how suitable messages are constructed and used to meet operational needs of user.

2.5 Other Various SAE Documents

- SAE J3101, Requirements for Hardware-Protected Security for Ground Vehicle Applications
- SAE J3016, Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems, is intended to provide a basis for standardization of terminology regarding the highest three SAE levels of vehicle automation and operation on public roadways
- SAE J3018, Guidelines for Safe On-Road Testing of SAE Levels 3, 4, and 5 Prototype Automated Driving Systems (ADS), provides safety guidelines for conducing AV testing
- SAE J3092, Dynamic Test Procedures for Verification and Validation of Automated Driving Systems (ADS), is intended to provide Verification and Validation (V&V) best practices and guidance for AVs. This standard is still under development and limited public information is available.
- SAE J3131, Automated Driving Reference Architecture, intends to provide a reference automated vehicle architecture. This standard is still under development and limited public information is available.

2.6 ISO/TS 19091:2017 - ITS - Co-operative ITS (C-ITS) - Using V2I and I2V communications for applications related to signalized intersections

ISO/TS 19091:2017, ITS - C-ITS - Using V2I and Infrastructure-to-Vehicle (I2V) communications for applications related to signalized intersections, standard is a new standard defines the messages, data structures, and data elements to support periodic CV information exchanges, such as BS or cooperative awareness message (CAM), between vehicles to other vehicles and vehicles to RSE. This standard considers its user needs and describes use cases, information needs, and requirements for several applications to address safety, mobility, sustainability, and priority. The information requirements are primarily focused on SPaT, MAP, SSM, and SRM.

The use cases, based on DSRC communications, utilize the functional model, shown in Figure 8, focuses on V2I and with some consideration about interactions with traffic and fleet management functions beyond the roadside.

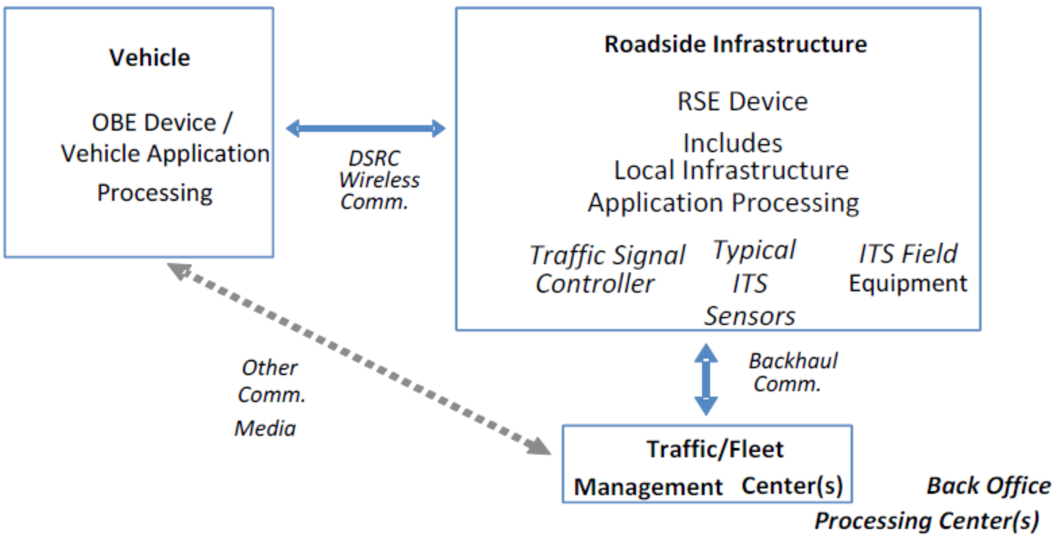

Figure 8. Working Model for Use Cases (Functional) [ISO/TS19091:2017, p23].

The use cases also use the conceptual architecture, shown in Figure 9, to generalize the overall distribution of management applications, RSE, and vehicle equipment.

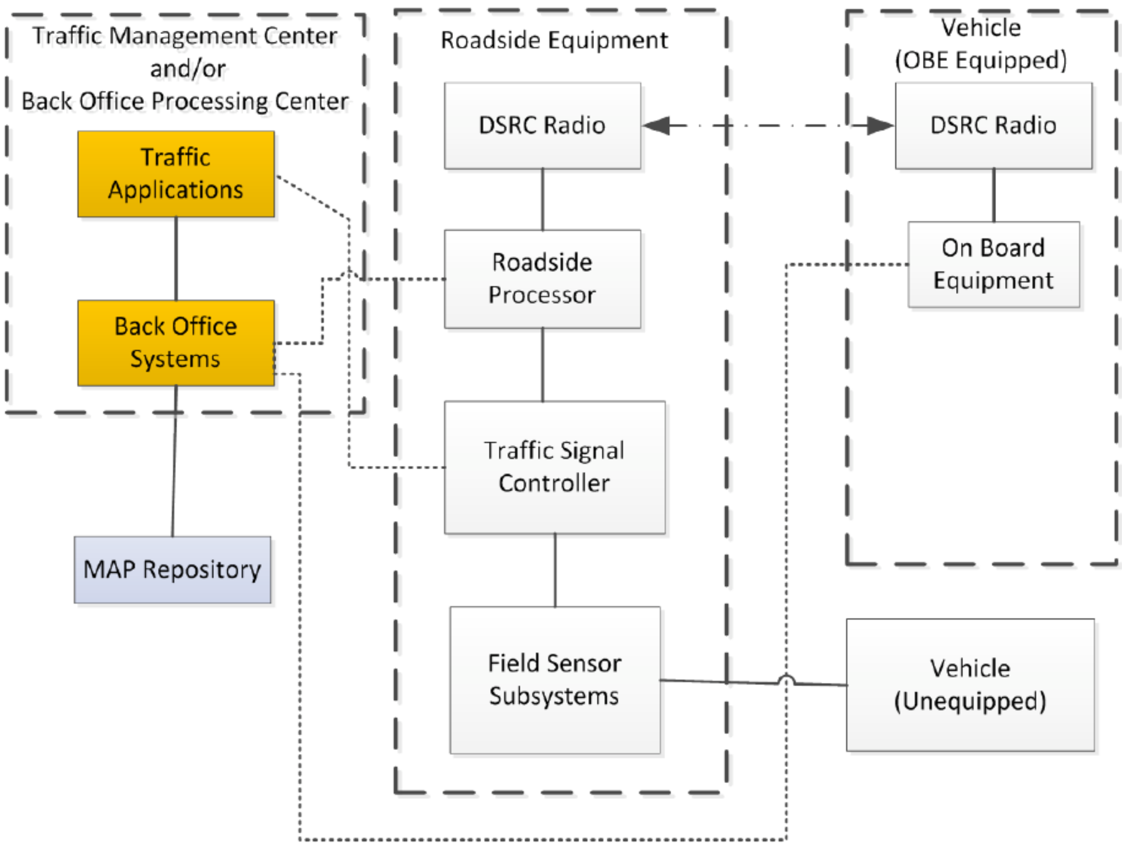

Figure 9. General Architecture for V21/I2V Communications [ISO/TS19091:2017, p26].

ISO/TS 19091 is made of a main document and several annexes. The main document defines the information requirements and references other standards, such as SAE J2735 DSRC Message Set Dictionary, for message definition. This standard follows the SE process, so the annexes contain use case descriptions, traceability matrices, a list of base requirements, and list application-oriented specific requirements that map to message and data concept to be implemented [ISO/TS 19091:2017, p13]. The traceability matrices relate uses cases to requirements and requirements to messages and data to ensure the defined messages will satisfy the applications. The base requirements and list application-oriented specific requirements map to message and data concept to be implemented such that each region or specific set of applications supported will be defined by the base plus their own extensions with in the ISO/TS19091 standard [ISO/TS 19091:2017, p13].

This standard compliments ISO 22951, Data Dictionary and Message Sets for Preemption and Prioritization Signal System for Emergency and Public Transport Vehicles (PRESTO). It does this by providing vehicle location and request information directly from CVs rather than the detection of the vehicles from other fixed sensing equipment [ISO/TS 19091:2017, p11]. ISO 22951 also considers its user needs through the implementation of a specific system architecture that includes traffic signals, message signs, routing systems, human machine interfaces (HMI), and fixed detection locations. ISO/TS 19091 does address the system architecture. Instead, ISO/TS 19091 examines the data needed to meet user needs, detailing data values and structures, that will be managed in the architecture.

2.7 ISO 22951:2009, Data Dictionary and Message Sets for PRESTO

ISO 22951, Data Dictionary and Message Sets for PRESTO standard describes communication messages sets and data dictionary related to priority signal control information used by emergency vehicles. This standard considers the following communications:

- between a roadside communication unit and each in-vehicle unit,
- between a roadside communication unit and other RSUs, and
- between in-vehicle units and RSUs.

ISO 22951 aims to promote system introduction through the standardization of messages and common infrastructure that result in more timely and efficient operation. The system is composed of a traffic management centers (TMC), in-vehicle units, roadside communication units, and RSUs, as shown in Figure 10. The standard does not depend on the medium used for communication or have information provisions, such as the situation at the emergency scene. This standard only focuses on information related to priority signal control, defining the PRESTO concept, architecture, and logical system architecture.

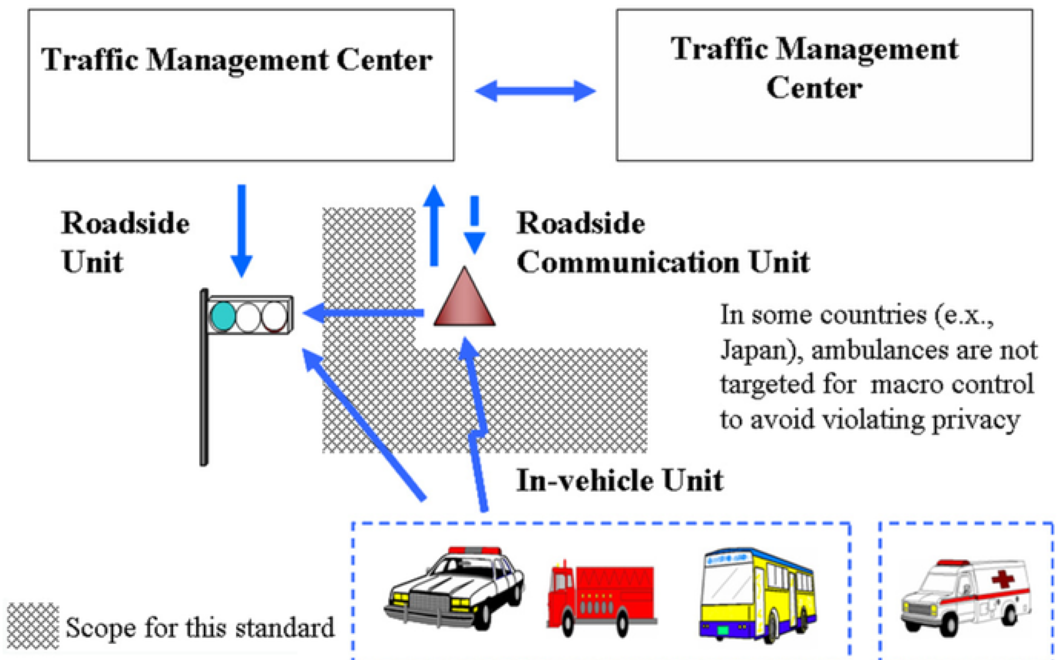

Figure 10. Scope of ISO 22951 [ISO 22951:2009].

2.8 ITE/AASHTO TMDD Standard v3.03 for the Center-to-Center (C2C) Communications

The joint standard of ITE/ American Association of State Highway and Transportation Officials (AASHTO) TMDD standard v3.03 for the C2C Communications is a two-volume standard. The TMDD Volume I standard provides the center-to-center concept of operations and requirements for an Advanced Traffic Management System (ATMS). The TMDD Volume II standard provides design content for an ATMS based on the requirements discussed in Volume I.

Volume I of the standard covers the following C2C communications information:

- A detailed description of the scope of this standard
- An explanation of what operations the C2C connections provide

- A starting point in the procurement process
- An understanding of the perspective of the designers of the standard

Volume II of the standard covers the following C2C communications information:

- Dialog Sequence
- TMDD Interface and dialog messages
- eXtensible Markup Language (XML) data concept definitions, including class dialogs, class messages, data frames, and data elements
- Requirements traceability matrix

The TMDD standard provides data descriptions of event information that can include incidents, obstructions, traffic conditions, weather conditions, evacuations, homeland security events and natural and man-made disasters. Data elements described in this standard that are relevant to the purpose of a BIM and can assist in its definition are related to event information such as incident data, construction lane closures, and special event data.

The following event information types described in this standard share the following information useful to the BIM's situational awareness needs:

- Traffic detector data [TMDDv3.03-Vol1, Section 2.3.5.1]
    - Contains measurements on traffic volume, occupancy and speed
    - Monitor the surface transportation system
    - Determine system performance
    - Quantitatively measure how well the ITS system helps to improve incident response
- Closed-circuit television (CCTV) Camera Status and Control [TMDDv3.03-Vol1, Section 2.3.5.2]
    - Verifies the existence of reported traffic congestion
    - Determine what assistance may be needed by the incident
    - Monitor the progress of incidents, construction and special events
    - Determine when the residual congestion from an incident is cleared
    - Provide visual images to the public as to the state of the roadway
    - Determine what type of emergency services need to be dispatched
- Ramp Meter Status [TMDDv3.03-Vol1, Section 2.3.5.9]
    - Manage traffic during an incident or event to alleviate congestion
- Traffic Signal Control and Status [TMDDv3.03-Vol1, Section 2.3.5.10]
    - Monitor signal system operations within an area
    - Improve traffic signal coordination to move traffic more efficiently
    - Manage traffic at specific areas or intersections based on congestion and/or accidents on the roadways
    - Execute mitigation plans for construction and special event congestion and reacting to traffic incidents

Several infrastructure data classes that may be a useful starting point for the design of a BIM are:

- TrafficConditions [TMDDv3.03-Vol2, Section 3.6.5.28, pg. 572] provides an enumerated list of 19 event category classifications of different types of traffic conditions including:
    - stopped-traffic
    - stop-and-go-traffic
    - slow-traffic
    - heavy-traffic
    - traffic-lighter-than-normal

- traffic-heavier-than-normal
- traffic-much-heavier-than-normal
- current-speed
- speed-limit
- travel-time
- merging-traffic
- traffic-returned-to-normal
- no-problems-to-report
- traffic-congestion-cleared

- AccidentsAndIncidents [TMDDv3.03-Vol2, Section 3.6.5.1, pg. 544] provides an enumerated list of 52 event category classifications concerning accidents and or incidents on the roadways, including, but not limited to:
  - accident
  - serious-accident
  - minor-accident
  - multi-vehicle-accident
  - numerous-accidents
  - secondary-accident
  - rescue-and-recovery-work-removed
  - stalled-vehicle
  - abandoned-vehicle
  - disabled-vehicle
  - vehicle-on-fire
  - vehicle-in-water
  - jackknifed-trailer
  - chemical-spill
  - hazardous-materials-spill
  - oil-spill
  - spilled-load
  - toxic-spill
  - overturned-vehicle
- Closures [TMDDv3.03-Vol2, Section 3.6.5.5, pg. 548] provides 18 different phrases describing types of closures including, but not limited to:
  - closed-to-traffic
  - closed
  - closed-ahead
  - closed-for-repairs
  - reduced-to-one-lane
  - reopened-to-traffic
  - clearing
- Roadwork [TMDDv3.03-Vol2, Section 3.6.5.22, pg. 567] provides 18 different phrases describing types of roadwork including, but not limited to:
  - major-road-construction
  - long-term-road-construction
  - construction-work
  - paving-operations
  - work-in-the-median

- Obstruction [TMDDv3.03-Vol2, Section 3.6.5.15, pg. 559-60] provides 40 different phrases describing types of roadwork including, but not limited to:
  - object-on-roadway
  - objects-falling-from-moving-vehicle
  - debris-on-roadway
  - storm-damage
  - downed-cables
  - road-surface-collapse
  - pavement-buckled
  - pothole
  - flooding
  - mudslide
  - avalanche
  - rockfall
  - landslide
- UnusualDriving [TMDDv3.03-Vol2, Section 3.6.5.32, pg. 575-6] provides a list of 8 different phrases describing types of unusual driving including:
  - vehicle-traveling-wrong-way
  - reckless-driver
  - prohibited-vehicle-on-roadway
  - emergency-vehicles-on-roadway
  - high-speed-emergency-vehicles
  - high-speed-chase
  - dangerous-vehicle-warning-cleared
  - emergency-vehicle-warning-cleared
- SpecialEvents [TMDDv3.03-Vol2, Section 3.6.5.23, pg. 568] provides 23 different phrases describing types of special events including, but not limited to:
  - airshow
  - concert
  - vip-visit
  - festival
  - carnival
  - fireworks-display
  - trade-expo
  - movie-filming
  - presidential-visit

Data elements:

- event-description-notes-and-comments
  - A textual description of a roadway event (incident, planned roadway closure, or special event). This data element is also used to describe any ancillary textual notes or comments supplemental to the description of a specific roadway event. [TMDDv3.03-Vol2, Section 3.4.8.10]
- event-description-priority-level
  - Number indicating the priority given an incident, where 1 is the Highest Priority and 10 the Lowest Priority. [TMDDv3.03-Vol2, Section 3.4.8.11]
- event-incident-status
  - A code which indicates a status of the incident. [TMDDv3.03-Vol2, Section 3.4.8.20]

- event-incident-humans-involved-count
  - The number of known injuries or fatalities present at an incident at the time of report. [TMDDv3.03-Vol2, Section 3.4.8.19]

2.9 ETSI Standards

The ETSI published two European Standards for ITS in 2014 regarding the specification of Cooperative Awareness Basic Service, EN 302 637-2, and the specification of Decentralized Environmental Notification Basic Service, EN 302 637-3. They share naming with their technical specifications, ETSI TS 102 637-2 and ETSI TS 102 637-3, respectively. These services define the messages used for I2V communications in Europe.

2.9.1 EN 302 637-2 Part 2: Specification of Cooperative Awareness (CA) Basic Service

The EN 302 637-2 Part 2: Specification of Cooperative Awareness Basic Service standard specifies the syntax and semantics of the CAM and provides detailed specifications on message handling in the V2X network as part of ITS. The standard covers the following information:

- CA Basic Service introduction and functional descriptions
- CAM dissemination concept and constraints
- CAM formats and specifications

The CA basic service is the facilities layer entity operating the CAM protocol within the ITS station (ITS-S), shown in Figure 11. The service provides two services, sending and receiving CAMs, and may interface with other entities to collect information relevant to CAM generation and forwarding it for further processing.

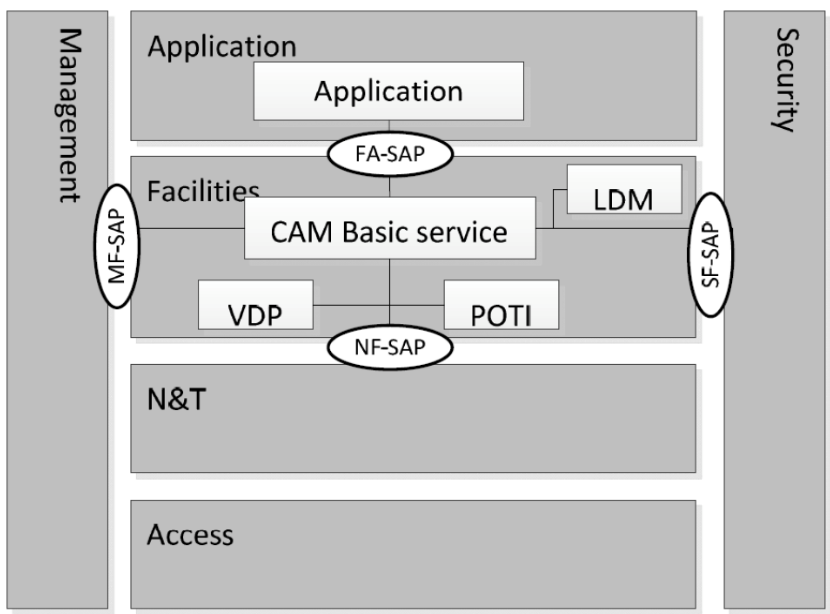

Figure 11. CA Basic Service within ITS-S Architecture [ETSI EN 302 637-2 V1.3.2 (2014-11), p12].

Within the standard, the CAM dissemination concept describes the point-to-multipoint communication that shall be used for transmitting CAMs and the frequency management performed by the CA basic service. Lastly, the standard defines the CAM structure, shown in Figure 12, formatting and coding rules.

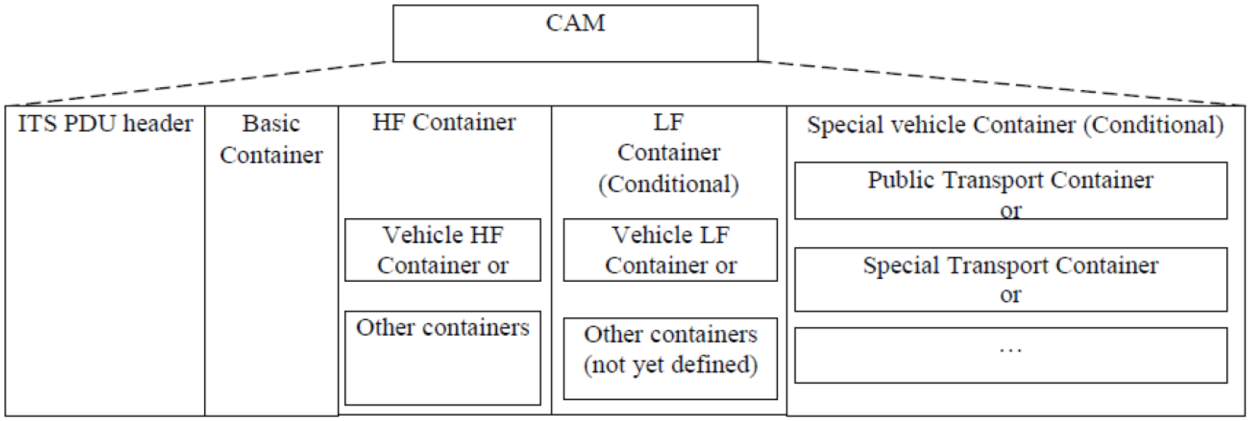

Figure 12. General Structure of a CAM [ETSI EN 302 637-2 V1.3.2 (2014-11), p21].

CAMs contain a header and a basic container that includes [ETSI EN 302 637-2 V1.3.2 (2014-11), p21]:

- type of the originating ITS-S;
- the latest geographic position of the originating ITS-S as obtained by the CA basic service at the CAM generation.

The standard also includes provisions in the CAM structure for special vehicle containers according the vehicle's role in road traffic. These special containers include public transport, transport containing heavy loads, dangerous goods transport, road work, rescue, emergency, and safety.

2.9.2 EN 302 637-3 Part 3: Specifications of Decentralized Environmental Notification (DEN) Basic Service

The EN 302 637-3 Part 3: Specifications of DEN Basic Service standard defines the DEN Basic Service that supports road hazard warning. The standard also includes the DEN Message (DENM) that contains information related to a road hazard or an abnormal traffic condition, including its type and position. The standard covers the following information:

- DEN basic service introduction and functional descriptions
- DENM dissemination concept and constraints
- DENM formats and specifications
- Protocol operation of the DEN basic service

EN 302 637-2 describes the DEN basic service, shown in Figure 13, as a facilities layer message implementing the DENM protocol that is mainly used by ITS to alert road users of a detected event. The DEN basic service performs construction, transmission, forwarding and reception of DENMs and may exchange information with other facilities to perform these tasks. A DENM, disseminated by the DEN basic service, contains information related to an event that has potential impact on road safety or traffic condition. These events are characterized by an event type, an event position, a detection time, and a time duration that may change over time and space.

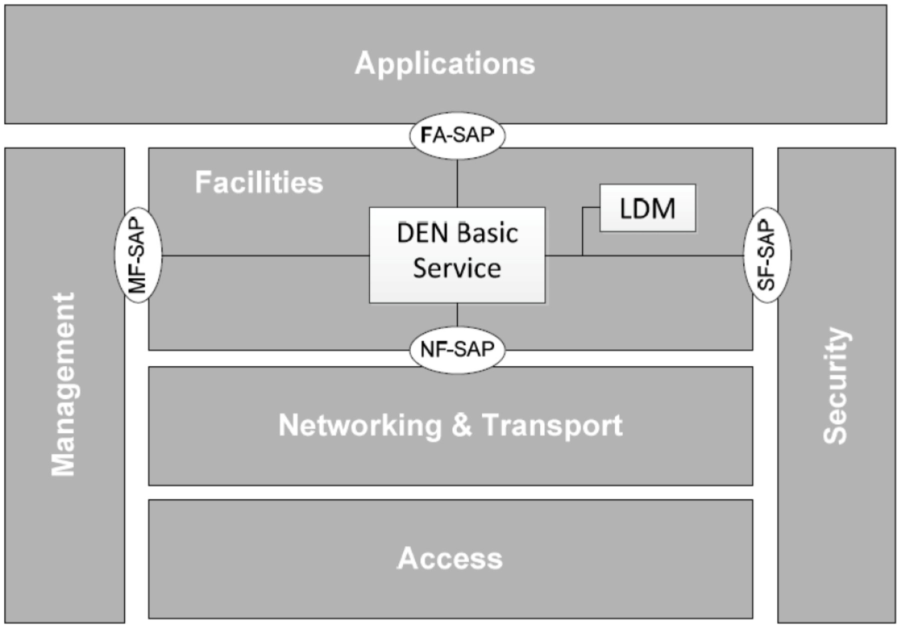

Figure 13. DEN Basic Services and Interfaces [ETSI EN 302 637-3 V1.2.2 (2014-11), p16].

The standard defines the DENM format structure, shown in Figure 14, as having a header, a management container, and three optional containers: situation, location, and à la carte.

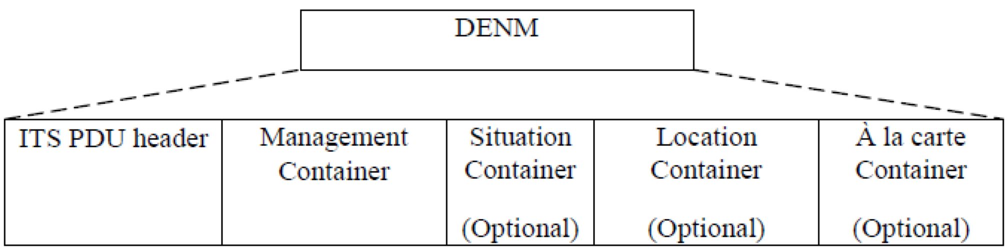

Figure 14. General Structure of a DENM [ETSI EN 302 637-3 V1.2.2 (2014-11), p31].

The management container provides information related to DENM management and the DENM protocol. The situation container provides information related to the type of the detected event. The location container provides information of the event location and the location referencing. The à la carte container provides required information that is not included in the three previous containers.

Finally, the EN 302 637-2 specifies a detected event's required message fields within each DENM container, a common data dictionary, and data presentation.

2.10 NTCIP Standards

The National Transportation Communications for ITS Protocol (NTCIP) describes a family of standards that define data definitions and proprietary communication interfaces and protocols utilized as part of ITS.

2.10.1 NTCIP 1202 - Object Definitions for Actuated Traffic Signal Controller (ASC) Units

NTCIPs 1202, Object Definitions for ASC Units, standard is a mature standard circa 2005 that identifies and defines the data object definitions for the messaging between Transportation Management and Actuated Signal Controller units. Messaging is done using a NTCIP Application Layer services, such as Simple Network Management Protocol (SNMP), to convey requests to access or modify objects stored in each device.

NTCIP 1202 standard defines the requirements that involve actuated traffic signal controls in an NTCIP environment. The standard describes the data dictionary, containing a MIB header and parameters, to configure, monitor, and control actuated controller units. The following types of parameters are included in the standard:

- Phase Parameters
  - This contains objects that configure, monitor, or control phase functions for this device.
- Detector Parameters
  - Defines supporting detector objects.
- Unit Parameters
  - Defines supporting unit objects.
- Coordination Parameters
  - This contains objects that support coordination configuration, status and control functions for the device.
- Time Base Parameters
  - This object is an identifier used to group all objects for support of time base functions. If a device implements time base functions, then these objects shall be supported.
- Preempt Parameters
  - This contains objects that support preempt input functions for the device.
- Ring Parameters
  - This contains objects that support ring configuration, status, and control functions in the device.
- Channel Parameters
  - Defines a node for supporting channel objects.
- Overlap Parameters
  - This contain objects that configure, monitor, and control overlap functions
- TS2 Port 1 Parameters
  - Used to group all objects for support of National Electric Manufacturers Association (NEMA) TS 2 (Clause 3.3.1) Port 1 activities.
- ASC Block Objects
  - Used to group all objects for support of ASC Block Upload and Download activities.

This standard also provides block object definitions that contain block data block types defining the data type and data ID for each type of block.

Currently, the NTCIP 1202 working group is working on Version 3 of the standard which will standardize the communications between the signal controller and an RSU, between the TMC and the RSU, and between the TMC and the signal controller for configuring and operating SPaT. This upcoming revision should be very valuable to agencies deploying SPaT.

2.10.2 NTCIP 1203 V03 - Object Definitions for Dynamic Message Signs (DMS)

NTCIP 1203, Object Definitions for DMS, standard describes the logical interface between the DMS and the central systems that control them. This standard defines the typical physical architecture, shown in Figure 15, along with the concept of operations, functional requirements, and standardized procedures and interface specifications applicable to DMS systems. The latest version, V3, is dated May 2011.

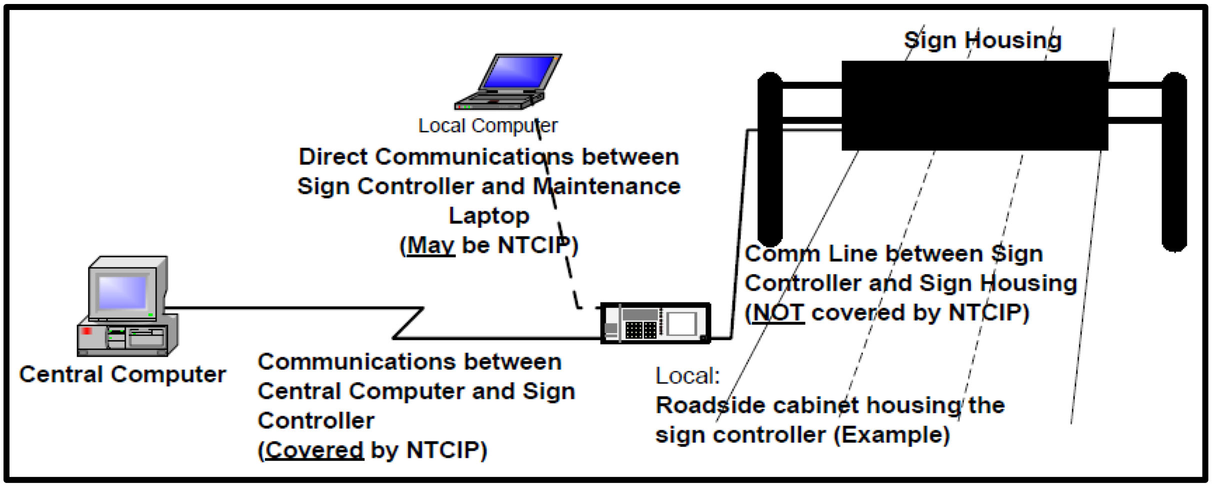

Figure 15. View of a Typical DMS System Architecture [NTCIP 1203 V03, p45].

The NTCIP 1203 also includes:

- Protocols Requirements List (PRL) table defining conformance requirements
- Standardized procedures to manage a sign
- Operations allowed by a DMS, including controlling the DMS and how to define and prioritize displayed messages
- Data elements exchanged and how they are inter-related
- MIB object definitions exchanged during communications
- Mark-Up Language for Transportation Information (MULTI) concerning how a message is to be displayed
- Test procedures
- A Requirements Traceability Matrix that traces each requirement to a dialog, one or more interfaces, and associated list of objects

2.10.3 NTCIP 1204 V03 - Environmental Sensor Station (ESS) Interface Protocol

NTCIP 1204 V03, ESS Interface Protocol, standard defines how a transportation management station may wish to interface with a field device to control and monitor an ESS related to the monitoring of and response to environmental conditions. An ESS consists of a remote processor unit (RPU) and a suite of sensors that are frequently co-located or share a controller with a pavement treatment system (PTS). A reference architecture depicting the relationship between a management station, a controller, and other logical components can be seen in Figure 16. The sensor data is typically exchanged between a management station and a field device using an application layer such as SNMP. The latest version is dated 2014.

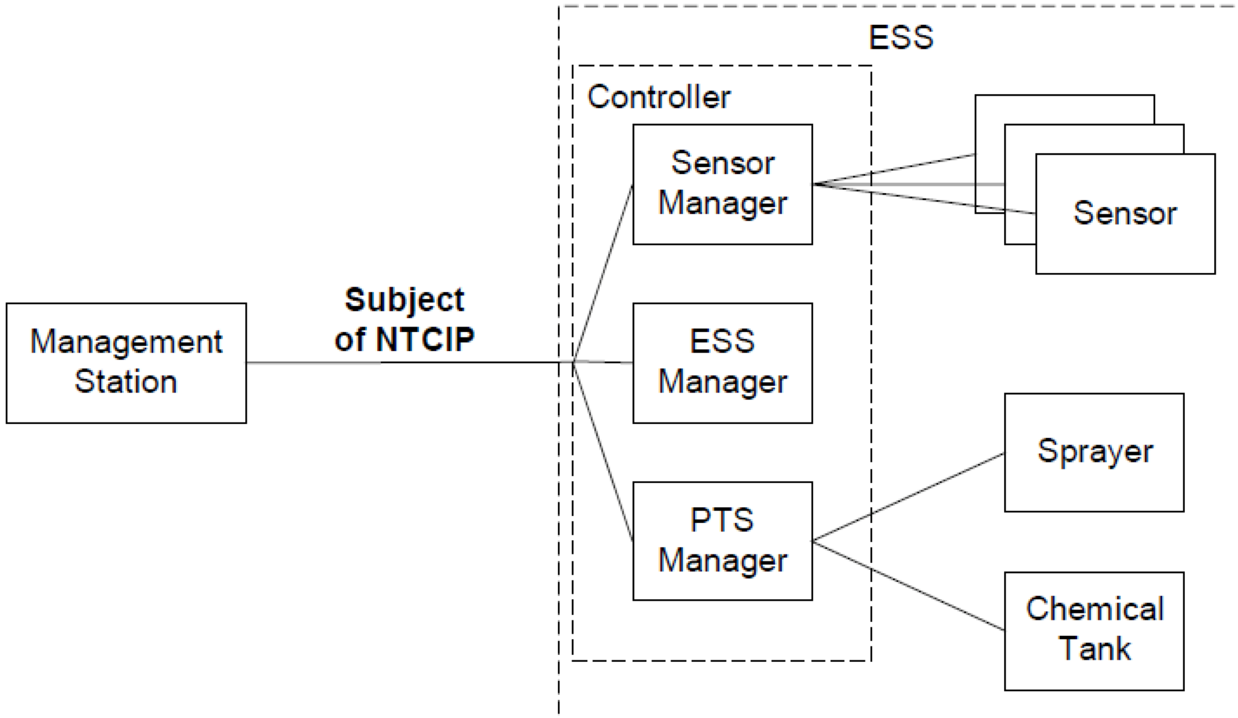

Figure 16. ESS Reference Physical Architecture [NTCIP 1204 V03, p56].

Object definitions of data elements for the environmental sensor data are provided within this standard and include weather data, roadway surface or pavement condition data, water level data, and air quality data. NTCIP 1204 V03 standardizes the communications interfaces and, while not addressing sensor performance, covers a subset of requirements for sensor procurement. The standard provides the following additional information:

- Referenced physical architectures for a remote weather station, a sprayer combined with a pavement sensor, and pavement treatment station
- Functional requirements covering the PRL, architectural requirements, data exchange requirements, and supplemental requirements for additional sensor types
- Dialogs describing standardized procedures to manage an ESS, a state transition diagram, and class diagrams for types of sensor data
- MIB object definitions for each type of ESS data communication exchange
- MULTI concerning how a message is to be displayed
- Requirements Traceability Matrix tracing each requirement to a dialog, one or more interfaces, and associated list of objects
- Test procedures

2.10.4 NTCIP 1209 V02 - Object Definitions for Transportation Sensor Systems (TSS)

NTCIP 1209 V02, Object Definitions for TSS, standard defines the TSS data elements that include any system capable of sensing and communicating near real-time traffic parameters. The most current update of Version 2 was approved in 2011 after several revisions. This standard describes the user needs related to the operational environment, the functional requirements, and the dialogs that define the procedures for a central system to manage a sensor. To assist in understanding the key components related to TSS and how one or more management systems may communicate with a single TSS, a typical physical architecture is depicted within the standard and shown in Figure 17.

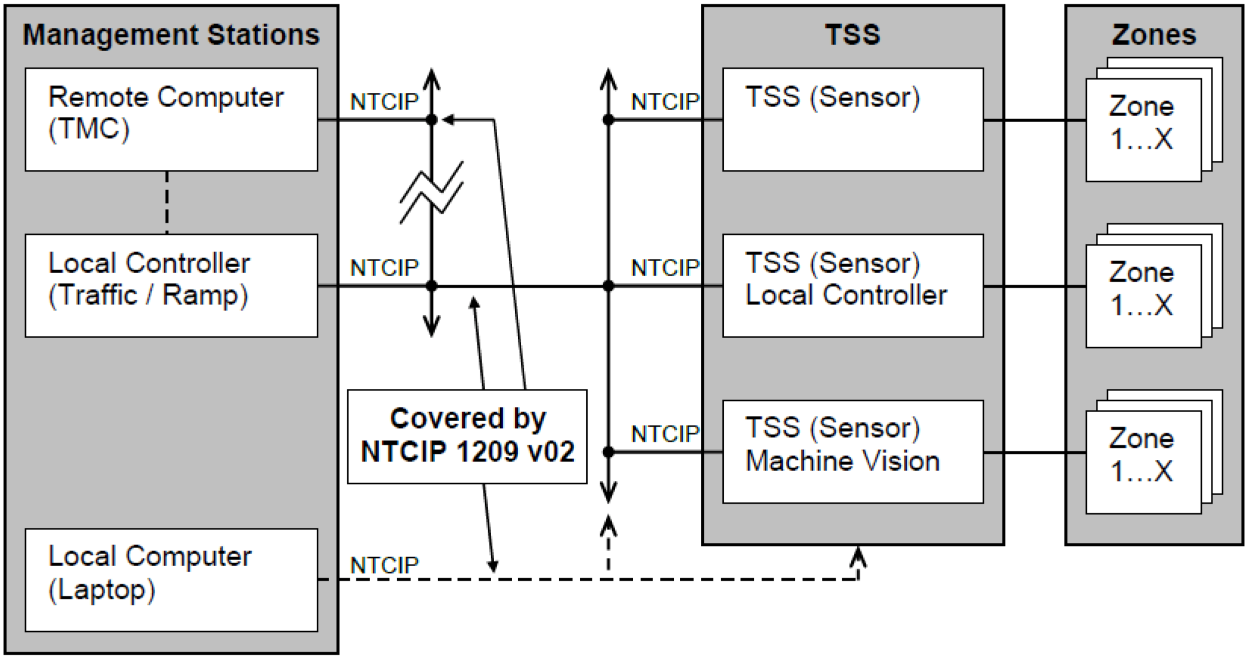

Figure 17. Typical Physical Architecture of Key Components Related to a TSS [NTCIP 1209 V02, p23].

The NTCIP 1209 V02 standard also defines the following:

- MIB object definitions for TSS data exchanged during communications
- Requirements Traceability Matrix tracing each requirement to a dialog, one or more interfaces, and associated list of objects
- Object Tree that provides users with a high-level orientation tool to navigate TSS data elements
- Test procedures placeholder that hopes to later address TSS needs and requirements

2.10.5 NTCIP 1210 - Field Management Stations – Part 1: Object Definitions for SSM

NTCIP 1210, Field Management Stations Part 1: Object Definitions for SSM, standard defines the management information related to a SSM, using the standardized definition of the communications interface between the SSM and a Signal System Local (SSL) from NTCIP 1202. This standard defines the requirements that involve the control of traffic signal controls in an NTCIP environment. Version 1 is dated Feb 2002.

An SSM is a system that may be a physical or logical device and includes traffic signal controllers and office, computer-based traffic management center software. NTCIP 1210 describes the SSM management information of a SSM system which includes individual parameters that represent the configuration, status, and control information of these devices.

NTCIP 1210 defines the requirements related to the Information Level communications interface between a management station and an SSM. These requirements are supported through the description of user needs for such an interface, detailed functional requirements, and a summary of the conformance requirements using a traceability matrix.

2.11 Mobile Broadband Standards – 3GPP[2]

The 3rd Generation Partnership Project (3GPP) unites [Seven] telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, and TTC), known as "Organizational Partners" and provides their members with a stable environment to produce the Reports and Specifications that define 3GPP technologies.

The project covers cellular telecommunications network technologies, including radio access, the core transport network, and service capabilities - including work on codecs, security, quality of service - and thus provides complete system specifications. The specifications also provide hooks for non-radio access to the core network, and for interworking with Wi-Fi networks.

3GPP specifications and studies are contribution-driven, by member companies, in Working Groups and at the Technical Specification Group (TSG) level.

The three TSGs in 3GPP are;

- Radio Access Networks (RAN)
- Services and Systems Aspects (SA)
- Core Network and Terminals (CT)

The Working Groups, within the TSGs, meet regularly and come together for their quarterly TSG Plenary meeting, where their work is presented for information, discussion and approval.

Each TSG has an area of responsibility for the Reports and Specifications within its own Terms of Reference (Details available in the Specification Groups pages).

The last meeting of the cycle of Plenary meetings is TSG SA, which also has responsibility for the overall coordination of work and for the monitoring of its progress.

[2] http://www.3gpp.org/about-3gpp/about-3gpp

3. UNITED STATES DEPARTMENT OF TRANSPORTATION (USDOT) RELATED PROGRAMS AND ARTIFACTS

The following sections summarize programs that are being conducted by the USDOT or at a minimum involve USDOT and other state Department of Transportations (DOTs).

3.1.1 Safety Pilot Model Deployment (SPMD)[3]

CV Safety Pilot is a research program that demonstrates the readiness of DSRC-based CV safety applications for nationwide deployment. The vision of the CV Safety Pilot program is to test connected vehicle safety applications in real-world driving scenarios to determine their effectiveness at reducing crashes and to ensure that the devices are safe and do not unnecessarily distract motorists or cause unintended consequences.

In 2012, University of Michigan Transportation Research Institute (UMTRI) and the USDOT established a test environment (SPMD) located in the northeast quadrant of the city of Ann Arbor and equipped it with the latest connected vehicle and connected infrastructure technology including: 73 lane miles, 25 roadside equipment, and roughly 2,800 vehicles (including cars, trucks, etc.) Results from this deployment were significant. They demonstrated the viability of DSRC communication in a live-traffic environment and indicated that 81 percent of unimpaired vehicle crashes could be mitigated with these technologies[4][5]. This information provided the basis for NHTSA to move forward with rulemaking to require DSRC equipment in light vehicles.

3.2 Southeast Michigan CV Testbed[6]

A roughly 125-mile sensor installation near I-96 near General Motors Co.'s Milford Proving Grounds, I-94 from Ann Arbor to metro Detroit, US 23 from Ann Arbor to Brighton, and elsewhere. The sensors connect vehicles to infrastructure, such as traffic lights, to help alleviate traffic congestion.

In that area are many sensors and other wireless equipment on roadsides to broadcast signals to and from CVs equipment with receivers. About 115 of these sensors exist in the test area, including:

- 17 within the Detroit city limits
- 25 within the Ann Arbor city limits
- 17 along I-96 from Milford Road to M-5, and at M-5 and 12 Mile Road
- the rest along I-696 between I-275 and Telegraph Road, and along Telegraph Road in Oakland County

3.3 CV Pilot Deployments

3.3.1 New York City DOT (NYCDOT) Pilot[7]

NYCDOT's planned deployment provides an ideal opportunity to evaluate CV technology and applications in tightly-spaced intersections typical in a dense urban transportation system and is anticipated to be the largest CV technology deployment to date (see Table 1). The NYDOT CV Pilot Deployment project is one of three USDOT-funded Pilot Deployments initiated in 2016. The deployment area encompasses three distinct areas in the boroughs of Manhattan and Brooklyn. The first area includes a 4-mile segment of

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[3] https://www.its.dot.gov/research_archives/safety/aacvte.htm
[4] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/readiness-of-v2v-technology-for-application-812014.pdf
[5] https://ntl.bts.gov/lib/60000/60200/60240/FHWA-JPO-16-4201.pdf
[6] http://www.gomobilemichigan.org/planetm/southeast-michigan-connected-vehicle-test-bed.html
[7] https://www.its.dot.gov/pilots/pilots_nycdot.htm

Franklin D. Roosevelt (FDR) Drive in the Upper East Side and East Harlem neighborhoods of Manhattan. The second area includes four one-way corridors in Manhattan. The third area covers a 1.6-mile segment of Flatbush Avenue in Brooklyn. As shown in Table 2, approximately 5,800 cabs, 1,250 MTA buses, 400 commercial fleet delivery trucks, and 500 City vehicles that frequent these areas will be fit with the CV technology. Using DSRC, the deployment will include approximately 310 signalized intersections for V2I technology. In addition, NYCDOT will deploy proximately 8 RSUs along the higher-speed FDR Drive to address challenges such as short-radius curves, a weight limit and a minimum bridge clearance and 36 RSUs at other strategic locations throughout the City to support system management functions. As a city bustling with pedestrians, the pilot will also focus on reducing vehicle-pedestrian conflicts through in-vehicle pedestrian warnings and an additional V2I/I2V project component that will equip approximately 100 pedestrians with personal devices that assist them in safely crossing the street. To learn more about the NYCDOT Pilot, please visit the NYCDOT Pilot website and the Phase 1 documents.

Table 1. NYCDOT Pilot Site Proposed CV Applications.

ID	Category	NYCDOT – CV Application
1	V2I/I2V Safety	Speed Compliance
2		Curve Speed Compliance
3		Speed Compliance/Work Zone
4		Red Light Violation Warning
5		Oversize Vehicle Compliance
6		Emergency Communications and Evacuation Information
7	V2V Safety	Forward Crash Warning (FCW)
8		Emergency Electronics Brake Lights (EEBL)
9		Blind Spot Warning (BSW)
10		Lane Change Warning/Assist (LCA)
11		Intersection Movement Assist (IMA)
12		Vehicle Turning Right in Front of Bus Warning
13	V2I/I2V Pedestrian	Pedestrian in Signalized Crosswalk
14		Mobile Accessible Pedestrian Signal System (PED-SIG)
15	Mobility	Intelligent Traffic Signal System (I-SIGCVDATA)

Table 2. NYCDOT Pilot Site Proposed CV Devices.

NYCDOT – Devices	Estimated Number
Roadside Unit (RSU) at Manhattan and Brooklyn Intersections and FDR Drive	353
Taxi Equipped with Aftermarket Safety Device (ASD)*	5,850
MTA Fleet Equipped with ASD*	1,250
UPS Truck Equipped with ASD*	400
NYCDOT Fleet Equipped with ASD*	250
DSNY Fleet Equipped with ASD*	250
Vulnerable Road User (Pedestrians/Bicyclists) Device	100
PED Detection System	10 + 1 spare
Total Equipped Vehicles	8,000

3.3.2 Tampa Hillsborough Expressway Authority (THEA) CV Pilot Deployment[8]

The THEA CV pilot is one of three USDOT-funded Pilot Deployments initiated in 2016. The pilot will deploy a variety of V2V and V2I applications (see Table 3) to relieve congestion, reduce collisions, and prevent wrong way entry at the reversible express lanes (REL) exit. THEA also plans to use CV technology to enhance pedestrian safety, speed bus operations and reduce conflicts between street cars, pedestrians and passenger cars at locations with high volumes of mixed traffic. To accomplish this, the THEA CV Pilot will employ DRSC to enable transmissions among approximately 1,500 cars, 10 buses, 10 trolleys, 500 pedestrians with smartphone applications, and approximately 40 RSUs along city streets (see Table 4). To support this initiative, THEA will be working with their primary partners, The City of Tampa (COT), Florida DOT (FDOT) and Hillsborough Area Regional Transit (HART) to create a region-wide CV Task Force. The primary mission of this Task Force is to support the deployment of CV infrastructure in the region in a uniform manner to ensure interoperability and interagency coordination as these deployments transition from concept to planning to operations. While THEA plans to initiate this process, the intent is to work with the other partner agencies to ultimately host this task force, including funding the studies and administrative activities. To learn more about the THEA CV Pilot, please visit the THEA Pilot website and the Phase 1 documents.

The THEA CV Pilot will employ innovative V2V and V2I communication technology to improve safety and traffic conditions in downtown Tampa.

[8] https://www.its.dot.gov/pilots/pilots_thea.htm

Table 3. THEA Pilot Site Proposed CV Applications.

ID	Category	THEA - CV Application
1	V2I Safety	Curve Speed Warning (CSW)
2		Pedestrian in Signalized Crosswalk Warning (PED-X)
3		Red Light Violation Warning (RLVW)
4	V2V Safety	Emergency Electronic Brake Lights (EEBL)
5		Forward Collision Warning (FCW)
6		Intersection Movement Assist (IMA)
7		Vehicle Turning Right in Front of a Transit Vehicle (VTRFTV)
8	Mobility	Mobile Accessible Pedestrian Signal System (PED-SIG)
9		Intelligent Traffic Signal System (I-SIG)
10		Transit Signal Priority (TSP)
11	Agency Data	Probe-enabled Data Monitoring (PeDM)

Table 4. THEA Pilot Site Proposed CV Devices.

THEA – Devices	Estimated Number
Roadside Unit (RSU) at Intersection	40
Vehicle Equipped with On-Board Unit (OBU)	1,500
Pedestrian Equipped with App in Smartphone	500
HART Transit Bus Equipped with OBU	10
TECO Line Street Car Equipped with OBU	10
Total Equipped Vehicles	1,520

3.3.3 Wyoming DOT (WYDOT) Pilot Deployment

The WYDOT CV Pilot site focuses on the needs of the commercial vehicle operator in the State of Wyoming and will develop applications (see Table 5) that use V2I and V2V connectivity to support a flexible range of services from advisories including RSAs, parking notifications and dynamic travel guidance. WYDOT connected vehicle pilot is one of three USDOT-funded Pilot Deployments initiated in 2016. The pilot will develop systems that support the use of CV Technology along the 402 miles of I-80 in Wyoming. As listed in Table 6, approximately 75 RSUs that can receive and broadcast message using DSRC will be deployed along various sections of I-80. WYDOT will equip around 400 vehicles, a combination of fleet vehicles and commercial trucks with OBUs. Of the 400 vehicles, at least 150 would be heavy trucks that are expected to be regular users of I-80. In addition, of the 400 equipped-vehicles, 100 WYDOT fleet vehicles, snowplows and highway patrol vehicles, will be equipped with OBUs and mobile weather sensors. To learn more about the WYDOT Pilot, please visit the WYDOT Pilot website and the Phase 1 documents.

Table 5. WYDOT Pilot Site Proposed CV Applications.

ID	Category	ICF/WYDOT – CV Application
1	V2V Safety	Forward Collision Warning (FCW)
2	V2I/I2V Safety	I2V Situational Awareness*
3		Work Zone Warnings (WZW)*
4		Spot Weather Impact Warning (SWIW)*
5	V2I and V2V Safety	Distress Notification (DN)

Table 6. WYDOT Pilot Site Proposed CV Devices.

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

3.3.4 Minnesota Integrated Mobile Observation (IMO) program[9]

The Minnesota IMO program was a USDOT Research and Innovative Technology Administration (RITA) and Federal Highway Administration (FHWA) sponsored project that consisted of state DOT maintenance vehicles providing mobile (vehicle-based) observations of road weather related and other data. This program was conducted in collaboration with the Nevada and Minnesota State Departments of Transportation (NDOT and MNDOT, respectively) as well as the National Center for Atmospheric Research (NCAR). The purpose of the program was to demonstrate how weather, road condition, and other related vehicle data might be collected, transmitted, processed, and used for decision support applications and activities. Using the data collected, NCAR developed a Vehicle Data Translator (VDT) software system, later called Pikalert®, that incorporate vehicle-based measurements of the road and surrounding atmosphere with other weather data sources as show in Figure 18.

[9] https://ntl.bts.gov/lib/48000/48300/48314/Final_Report_Task_5b_5-31-131.pdf

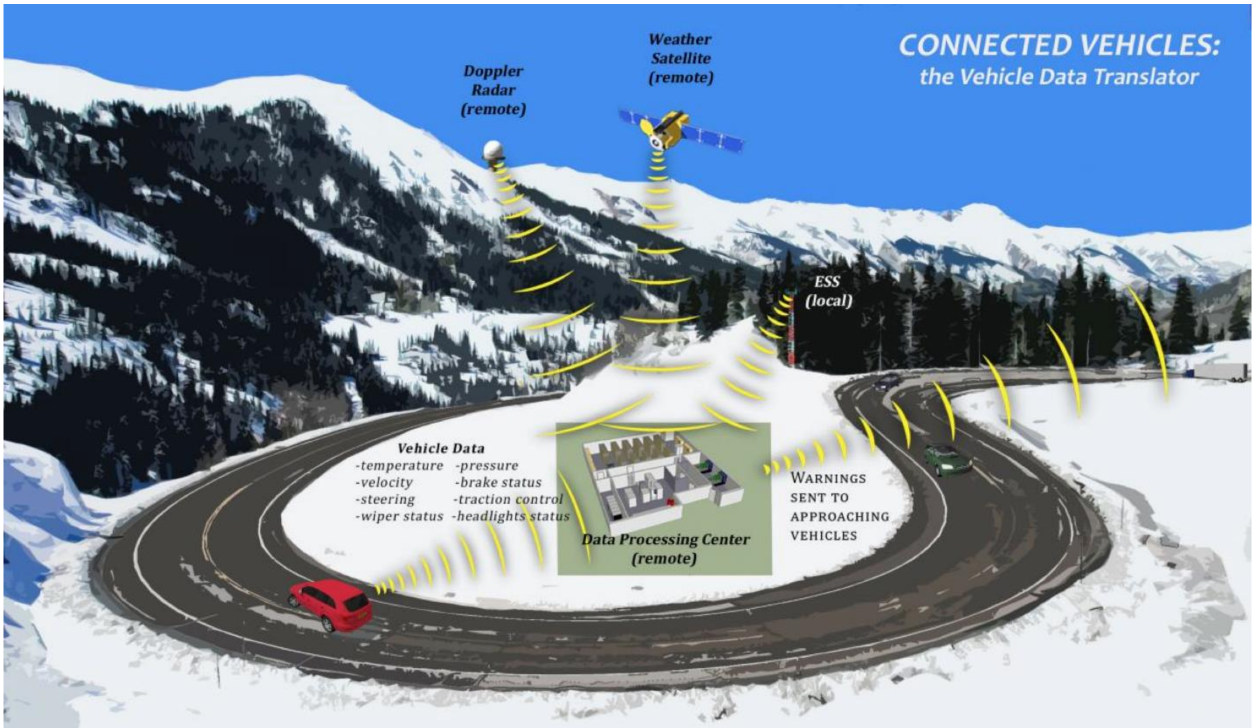

Figure 18. Schematic of the CVs Concept[10].

This program included using DSRC to obtain road weather conditions from the moving maintenance vehicles and explored using vehicles as weather and road condition sensors. Like the infrastructure information needs when adding CV applications, this program sought to collect data regarding vehicle parameters including wheel speed, cruise control, vehicle speed, and ambient conditions.

3.4 CV Certification[11]

CV Certification is a key research program of the ITS Joint Program Office (ITS JPO), a program office within the USDOT's RITA. Certification is the process of ensuring that system components, manufactured according to program requirements, perform as intended. Certification will ensure that users can trust that the components will work within the system.

The vision for the USDOT CV Certification research program is to work in close cooperation with public and private partners to establish appropriate certification requirements for equipment.

The ITS CV program deployment strategy will address the inherent risks to consumer safety, security, and privacy associated with a system breakdown. The system will have national interoperability so national standards and criteria for certification of individual products that have access to the system, system processes, and operational procedures need to be established. Since this is a new high-risk industry without an established consumer base, ITS JPO will work with industry to develop certification processes and procedures independently.

The ultimate form that a certifying entity would take, and the potential role of the federal government in oversight and enforcement of certification requirements is yet to be determined. Those two questions

[10] https://ral.ucar.edu/solutions/products/pikalert%C2%AE
[11] https://www.its.dot.gov/factsheets/pdf/JPO-028_CERTIFICATION_V5.5.1_F.pdf

will be investigated as part of both the technical research program as well as the Policy and Institutional Issues research program.

Certification research will primarily be focused on understanding the needs for device compliance, system security, and privacy requirements.

3.5 Connected Vehicle Reference Implementation Architecture (CVRIA)[12]

The CVRIA Team, led by the ITS Joint Program Office, is comprised of the National ITS Architecture Team (led by Iteris), the Standards Program Technical Support Services Team (led by Booz Allen Hamilton) and the Policy Team (ITS JPO Policy Program and the Volpe National Transportation Systems Center). The CVRIA development includes stakeholder engagement and development of an integrated standards strategy and action plan. Outputs of the project include a set of system architecture viewpoints that describe the functions, physical and logical interfaces, enterprise relationships, and application dependencies within the CV environment. This effort will produce a prioritized list of interfaces to be considered for standardization, and a CV standardization plan for the development, modification, and/or harmonization of the defined interfaces.

The project was completed in 2014, and the CVRIA development team has established a website that hosts the architecture viewpoints for 88 CV safety, mobility, environmental, and support applications. The site (http://www.iteris.com/cvria) includes the complete set of drawings and detailed descriptions that make up the physical, functional, enterprise, and communications views of the CVRIA. To ask questions or provide comments on the viewpoints, please use the feedback links.

The CVRIA team has conducted the following four public workshops:

- April 2013 (view summary report, view documents and presentations)
- February 2014 (view summary report)
- August 2014 (view workshop presentation)
- June 2015 (view summary report, view workshop presentation)

The CVRIA has now been incorporated into the new USDOT National ITS Architecture version 8, which is now called Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) (http://local.iteris.com/arc-it/). CVRIA will not likely remain separate from ARC-IT in the future.

3.6 Dynamic Mobility Applications[13]

The objective of the Dynamic Mobility Applications program is to foster the development of open source applications that utilize multi-source ITS data to transform surface transportation management and information. The research conducted in this program will identify high-value applications for research and develop the tools, metrics, and concepts that form the foundation for future application development.

The applications that have been and will be evaluated are those that enable public sector, multimodal system management, and:

- Use vehicle and infrastructure connectivity and data to enable dynamic decision making.

[12] https://www.standards.its.dot.gov/DevelopmentActivities/CVReference
[13] https://www.its.dot.gov/factsheets/dma_factsheet.htm

- Allow traffic managers to anticipate problems, be proactive in addressing issues, and rapidly monitor impacts on and across multimodal transportation networks.
- Support emerging work in decision support systems, systems that can assimilate and analyze large volumes of detailed real-time and historic data to provide recommendations in formats that are most valuable to traffic managers or travelers.

Dynamic Mobility Applications:

- Enable Advanced Traveler Information System (EnableATIS)
- Freight Advanced Traveler Information Systems (FRATIS)
- Integrated Dynamic Transit Operation (IDTO)
- Intelligent Network Flow Optimization (INFLO)
- Multi-Modal Intelligent Traffic Signal Systems (MMITSS)
- Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E)

3.7 Data Capture and Management (DCM)[14]

DCM is the creation and expansion of access to high-quality, real-time, multimodal transportation data, captured from CVs, mobile devices, and infrastructure. DCM technologies collect real-time data from a variety of sources and modes and integrate the data across modes and sources or make it available for users to incorporate according to their needs.

The vision of the DCM program is to enhance current operational practices and transform future transportation-systems management and traveler information through the active acquisition of integrated multi-source data from vehicles, travelers, mobile devices, and fixed sensors, and the systematic provision of this data to researchers, application developers, and system operators.

The objectives of the DCM program are to:

- Enable systematic data capture from CVs (automobiles, transit, and trucks), mobile devices, and infrastructure)
- Develop data environments that enable integration of high-quality data from multiple sources for transportation management and performance measurement.
- Reduce costs of data management, and eliminate technical and institutional barriers to the capture, management, and sharing of data.
- Determine required infrastructure for transformative applications implementation, along with associated costs and benefits.

Applications that use real-time data have the potential to increase highway safety and operational efficiency nationwide while minimizing the impact on the environment, and enabling travelers to make better-informed travel decisions. Real-time data sets also have the potential to support a range of multimodal mobility applications. For example, real-time information on parking availability and transit schedules can enable smarter mode- choice decisions and yield time and fuel efficiencies for travelers. Updated freight-movement data helps commercial freight operators to optimize operations.

[14] https://www.its.dot.gov/research_archives/data_capture/index.htm

3.8 V2I Hub[15]

In order to bring infrastructure components into the CV architecture, you need software that will facilitate the exchange of data in a format that can be understood by both vehicles and infrastructure devices The Integrated V2I Prototype (IVP), called V2I Hub, takes in data from vehicles via BSM in a Society of Automotive Engineers (SAE) standard format and translates the data to a National Transportation Communications for ITS Protocol (NTCIP) that infrastructure components can understand, and vice versa. It translates SPaT data from NTCIP to SAE and sends it to the RSU for broadcast to mobile devices, including vehicles.

V2I Hub is a message handler that acts as a translator and data aggregator/disseminator for infrastructure components of a CV deployment.

V2I Hub was developed to support jurisdictions in deploying V2I technology by reducing integration efforts and issues.

- V2I Hub is a software platform that enables CVs to talk to existing traffic management hardware and systems, such as traffic signal controllers, Transportation Management Centers, pedestrian and vehicle detection systems, road weather sensors, and dynamic message signs.
- V2I Hub simplifies integration by translating communication between different standards and protocols.
- Using a modular design, software plugins enable efficient connections to new hardware, custom connections to Transportation Management Centers, and CV Safety Apps to run on roadside equipment.

3.9 AERIS[16]

The Applications for the Environment: Real-Time Information Synthesis (AERIS) Research Program defined five Operational Scenarios and eighteen unique CV applications that sought to reduce fuel consumption and vehicle emissions. AERIS Operational Scenarios include: Eco-Signal Operations, Eco-Lanes, Low Emissions Zones, Eco-Traveler Information, and Eco-Integrated Corridor Management (Eco-ICM). Each Operational Scenario encompassed a set of applications which individually achieved environmental benefits. However, by strategically bundling the applications, the AERIS Program saw that the Operational Scenarios could achieve additional environment benefits above those of the individual applications. Many of these first-of-their-kind applications were innovative and transformative. The AERIS team created Concept of Operations (ConOps) documents for each of the five Operational Scenarios to guide analysis, modeling, simulation, and prototyping. Learn more about the AERIS Operational Scenarios and Applications.

3.10 Saxton Transportation Operations Laboratory

The Saxton Transportation Operations Laboratory (Saxton Laboratory) shown in Figure 19 is a state-of-the-art facility for conducting transportation operations research. The laboratory is located at FHWA's Turner-Fairbank Highway Research Center (TFHRC) in McLean, VA. The laboratory enables FHWA to validate and refine new transportation services and technologies before committing to larger scale research, development, testing, and deployment phases, and

[15] https://www.itsforge.net/index.php/component/ars/repository/roadway-operations-and-maintenance/V2I%20Hub%20v2.3
[16] https://www.its.dot.gov/research_archives/aeris/index.htm

serves as a gateway where Federal staff, contractors, and academia collaborate on cutting-edge research. The Saxton Laboratory also supports professional development and technology transfer of innovative service concepts and technologies through knowledgeable onsite staff, physical prototype systems, and advanced simulation capabilities.

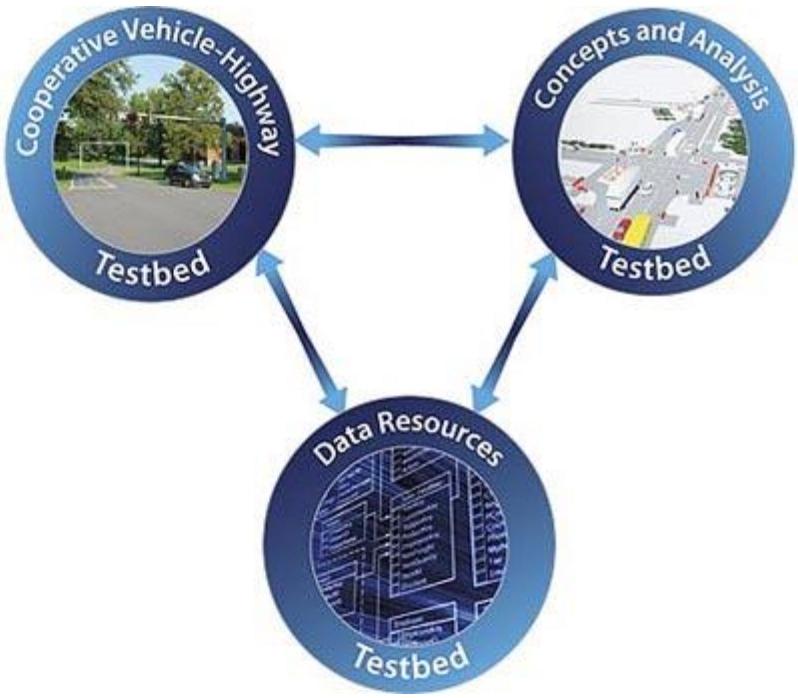

Figure 19. Illustration of the Saxton Laboratory testbeds and how they are interconnected[17].

The Saxton Laboratory comprises three testbeds:

- **Data Resources Testbed (DRT)** – Provides researchers with access to live and archived multisource transportation data to support transportation system performance measurement and transportation system management applications. The testbed assembles and archives data, hosts traffic datasets, analyzes operations and performance, provides advanced visualization tools to improve situational awareness, and aids strategic program and tactical operations decision making.
- **Concepts and Analysis Testbed (CAT)** – Incorporates a repository of macroscopic, mesoscopic, and microscopic transportation models to allow simulation runs and visualizations of representative traffic networks and experimental strategies to improve safety (to some extent), mobility, and environmental performance. The testbed allows FHWA research staff to refine the experimental strategies through direct interaction with the models and to determine the potential value of potential strategies to various stakeholders.
- **Cooperative Vehicle-Highway Testbed (CVHT)** – Enables FHWA to explore enabling technologies for CVs and to assess the potential of new transportation services based upon cooperative communication. The facilities, equipment, staff support, and other resources of this testbed

[17] https://www.fhwa.dot.gov/research/tfhrc/labs/operations/

enable FHWA researchers to develop prototypes, install systems in the roadside infrastructure and on vehicles, and conduct tests directed to investigate and answer key research questions needed to further CV research efforts.

3.11 CAMP V2I Activities[18]

The following subsections discuss V2I activities conducted by the Crash Avoidance Metrics Partners (CAMP) LLC, a consortium of automakers. Most of these activities were conducted under a cooperative agreement with USDOT.

3.11.1 V2I Safety Applications (V2I-SA)

The objective of the V2I-SA Project is to develop and initially test V2I safety applications for which performance requirements have been completed and sufficient information exists to initiate development. The safety applications considered in the project include:

- RLVW
- Emergency Vehicle Priority Warning (EVPW)
- CSW
- SWIW
- Reduced Speed/Work Zone Warning (RS/WZW)
- Stop Sign Gap Assist (SSGA)

CAMP only moved forward with three (3) of the listed applications; RLVW, CSW and RS/WZW. They have also developed and demonstrated operational prototypes of these three (3) applications.

3.11.2 Road Weather Management Program CV-Infrastructure Research Project

This project is directed towards CV-Infrastructure (CVI) research focused on demonstrating how weather, road condition, and related vehicle data may be collected, transmitted, processed, and used in road weather applications and services. This project is a joint effort between the Crash Avoidance Metrics Partnership (CAMP) V2I Consortium and the Virginia Tech Transportation Institute (VTTI).

3.11.3 Advanced Messaging Concept Development (AMCD)

The overall objective of the AMCD project was to evaluate the ability of CVs to generate and infrastructure to collect BSM, PDM, and Basic Mobility Message (BMM) alternatives using cellular and DSRC communications under simulated data message control schemes, including emulating elements of Dynamic Interrogative Data Collection (DIDC) control where applicable, in real world driving conditions for non-safety critical applications.

Research Topics:

- Characterize Dual Mode Communication
  - DSRC
  - Cellular
- Evaluate message control schemes
  - DIDC
  - PMM
- Message Type Characterization
  - BSM

[18] https://ntl.bts.gov/lib/56000/56800/56823/V2I_1st_Annual_Report__508_compliant_12_14_15.pdf

- PDM
- BMM

3.11.4 SCMS Proof-of-Concept Development[19]

The Security Credential Management System (SCMS) Proof-of-Concept (POC) Implementation Project (SCMS POC Project) is being conducted by the CAMP Vehicle Safety Communications 5 (VSC5) Consortium. Members of the consortium are Ford Motor Company, General Motors LLC., Honda R&D Americas, Inc., Hyundai-Kia America Technical Center, Inc., Mazda, Nissan Technical Center North America, Inc., and Volkswagen Group of America. The goal of the SCMS POC design is to provide security services to support V2V and V2I communications at current production levels of passenger vehicles (up to 17 million annually) for the first year of deployment. An important goal of the SCMS POC system is to provide a flexible architecture that is capable of scaling to support larger numbers of V2V and V2I devices in the years following initial deployment. It is also anticipated that the SCMS POC design will provide both a stable platform and a research platform to support the USDOT and industry research needs prior to deployment. The work is sponsored by the National Highway Traffic Safety Administration (NHTSA) through Cooperative Agreement DTNH22-14-H-00449/0003.

Work in Task 4 of the project focuses on the design of the SCMS core components and protocols. Four software releases are planned during the project. These consist of an initial release followed by three maintenance releases that will take place later in the project. This document presents the requirements and specifications for the SCMS POC system that are needed to support the first of the four software releases from the perspective of an end entity (EE). This document is an output of the efforts in Task 4 and was produced to fulfill Task 4, Milestone 2 titled "Completion of POC System Requirements and Specifications (including ASN.1)." This document is a work-in-progress. Future refinements and revisions to the requirements and specifications are anticipated as work in the project continues, new information becomes available, and the lessons learned from system testing can be incorporated into the SCMS design. This document is being provided to mark the progress in Task 4 to date and, potentially, to facilitate the information exchange with other related USDOT programs and stakeholders.

With respect to the BIM, it is intended that SCMS will be used in a manner consistent with other infrastructure messages, such as MAP and SPaT.

3.12 RSE Specification Update[20]

The ITS Program definition of CVs includes both 5.9GHz DSRC and non-DSRC technologies as means of facilitating communication for V2V and V2I applications. Non-DSRC technologies [e.g., Radio Frequency Identification (RFID), Worldwide Interoperability for Microwave Access (WiMAX), Wi-Fi, Bluetooth and cellular communication] enable use of existing commercial infrastructure for additional capacity support, but may not meet the low-latency needs of transmitting safety-critical information.

DSRC is a two-way wireless communications protocol suite that integrates the IEEE 802.11, 1609.x standards, SAE J2735, and SAE J2945. The USDOT is pursuing DSRC because of its low-latency and high-reliability performance that can be used to reduce fatalities through active safety applications, including collision avoidance, incident reporting and management, emergency response, and pedestrian safety. Furthermore, DSRC supports the close-range communication requirements to distribute Traffic SPaT information for intersection-based applications and localized roadway warnings.

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[19] https://www.its.dot.gov/pilots/pdf/SCMS_POC_EE_Requirements.pdf

[20] https://transportationops.org//publications/dedicated-short-range-communications-roadside-unit-specifications

The latest specification, version 4.1, will set the minimum requirements for roadside units capable of acting as a network edge device for 5.9GHz DSRC infrastructure.

It is important to note that many deployments still utilize the 3.0 specification yet the 4.0 specification included specifications necessary for the security hardware module, which will be necessary to implement to use the SCMS.

3.13 International Harmonization[21]

Technology harmonization is a process for establishing common architectures, standards, policies, and other critical processes that benefit from being as similar as practical across regions. The USDOT collaborates with other governments, industry associations, experts, and standards development organizations (SDOs) when in the public interest to enable:

- Shared research, leading to a broader base of expertise to inform research, a larger and more detailed set of results, and leveraged/reduced research costs;
- Common hardware and software across regions, leading to reduced development and manufacturing costs;
- Improved interoperability across borders, leading to enhanced safety and commerce; and
- Facilitation of a global marketplace, leading to accelerated deployment of new technologies.

Due to differences in policy and regulatory regimes across regions, harmonization may not always result in identical outcomes. However, substantial benefits are still possible if architectures and standards can be made sufficiently similar and allow, for example, commonalities in hardware and software and/or comparable policies.

The USDOT collaborates with multiple SDOs working on ITS and related standards to facilitate harmonization when in the public interest. USDOT cooperates with the ISO as well as domestic SDOs, including IEEE, SAE, the AASHTO, and the NEMA. The basis of these relationships is to fund experts and State and local participants to identify requirements in standards working groups, as appropriate. USDOT also strategically cooperates with two European SDOs, maintaining a Memorandum of Cooperation with the ETSI and observer status with CEN.

SDO participation allows the USDOT to:

- Support consistent and rigorous development of standards;
- Influence development on the issues that result in key benefits to the Nation (such as interoperability), as well as support consistent deployments across the Nation; and
- Keep abreast of other developments that might affect US standards (such as development of the next generation of technology protocols) or present critical opportunities for harmonization.

In addition to relationships with SDOs, the USDOT maintains important cooperative agreements with other countries in support of harmonization efforts. The Implementing Arrangement with the European Union (EU) has formed the basis of much of the USDOT's work in international harmonization, and has provided additional means for multilateral efforts with other nations. Agreements and informal cooperation between the USDOT and Australia, Japan, and Korea permit information exchanges and research collaborations on select standards working group activities. The USDOT also collaborates with Canada on various standards activities related to border interoperability under a long-standing agreement.

[21] https://www.standards.its.dot.gov/DevelopmentActivities/IntlHarmonization

3.14 CV Affiliated Testbeds[22]

Affiliation will help ensure that all future CV applications are based on common implementations of the communications technology, while harnessing the collective abilities of the membership. Benefits include:

- Exchanging information
- Sharing of deployment lessons learned
- Developing a common technical platform
- Expanding test bed options for users

The Office of the Secretary of Transportation (OST-R) has entered into 87 Memorandums of Agreement (MOA) with public, private, and academic organizations involved in the Affiliation of Test Beds.

In addition to the collaborators who have signed the MOA, several organizations have expressed interest in becoming an Affiliated Test Bed collaborator. Any organization that signs the MOA has an equal opportunity to participate in the affiliation.

The purpose of the agreements and similar memoranda is to create a non-binding, precompetitive affiliation among those using devices and installations related to V-I communications. The affiliation will facilitate information exchanges, share USDOT tools and resources, and encourage the consistent development and deployment of infrastructure components.

This directly supports the ITS JPO CV program goal of ensuring a successful deployment of 5.9GHz DSRC and other communication media in Research Test Beds.

3.15 Digital Infrastructure[23]

The following definition summaries the concept of Digital Infrastructure: “static and dynamic digital representation of the physical world with which the automated vehicle will interact to operate. This includes sourcing, processing and information”.

The motivations of a Digital Infrastructure are mainly related to:

- The need of a digital representation of the road infrastructure along with the investment needed on the physical road infrastructure
- The need of cooperation from the vehicles and the infrastructure operators to collect, update and correct eventual changes made on the physical infrastructure

The roles of the Digital Infrastructure for Automation should include the following aspects (from a static to a dynamic representation information):

- Provide accurate map data (e.g. HD Maps)
- Provide apriori knowledge along the road (Electronic Horizon)
- Enable high relative position accuracy (landmarks)
- Reproduce human like driving (driving patterns)
- Allow or not automated functions on specific roads (e.g. managed lanes)
- Notify the vehicle about situations ahead that may require human attention or even intervention (L4→L3→L2…) s
- Provide dynamic information around the vehicle (LDM)

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[22] https://www.its.dot.gov/pilots/pdf/ITSA2016_affiliatedTestbeds_Gay.pdf
[23] http://cordis.europa.eu/docs/projects/cnect/7/610737/080/deliverables/001-D361DigitalInfrastructure.pdf

3.16 Smart Cities – Columbus, OH[24]

The City of Columbus won the USDOT $40 million Smart City Challenge in June 2016 after competing against 77 cities nationwide to implement a holistic vision for how technology can help all residents to move more easily and to access opportunity. Columbus was also awarded a $10 million grant from the Paul G. Allen Family Foundation to reduce greenhouse gas emissions through the de-carbonization of the electric supply and transportation sectors.

The vision of smart Columbus is to:

- Improve access to jobs through expanded mobility options in major job centers
- Compete globally through smart logistics
- Connect Columbus residents to safe, reliable transportation that can be accessed by all
- Better connect our visitors to transportation options
- Develop a more environmentally-sustainable transportation system

The anticipated outcome is for Columbus to become the nation's epicenter for intelligent transportation systems research to improve safety, enhance mobility, create ladders of opportunity for those who may have been left behind in the past, and address climate change by reducing greenhouse gas emissions.

3.17 Traditional ITS Standards

The following standards have been used in many ITS deployments over the last 20 years. Some are more active than others. Some of them have not had activity within the last 10 years but still contain useful data.

1. NTCIP [C2C and Center-to-Field (C2F)] Standards
   a. https://www.ntcip.org/
2. TMDD
   a. http://www.ite.org/standards/tmdd/
3. Commercial Vehicle Information Systems and Networks (CVISN)
   a. https://www.its.dot.gov/research_archives/cvisn/index.htm
4. Incident Management (IEEE 1512)
   a. http://standards.ieee.org/email/2014_04_1512_web.html
5. Transit Communications Interface Profiles (TCIP)
   a. http://www.aptatcip.com/
6. Advanced Traveler Information Systems
   a. https://saemobilus.sae.org/content/j2354_199911

[24] https://www.columbus.gov/smartcolumbus/

4. STATE AND LOCAL RELATED PROGRAMS AND ARTIFACTS

The following sections summarize activities that have been performed in State and Local CV deployments that are of potential interest to the development of the BIM.

4.1 USDOT Multi-Modal Intelligent Traffic Signal System (MMITSS)

The USDOT's Multi-Modal Intelligent Traffic Signal System (MMITSS) is a traffic management system that seeks to provide a comprehensive traffic information framework to service all modes of transportation, including general vehicles, transit, emergency vehicles, freight fleets, and pedestrians and bicyclists in a CV environment. Utilizing CVs technologies and using messaging from SAE Standards J2735-2009, the MMITSS incorporates the following traffic signal applications:

- ITS System (ISIG): Using high-fidelity data collected from vehicles through V2V and V2I wireless communications as well as pedestrian and non-motorized travelers, this proposed application seeks to control signals and maximize flows in real time. The ISIG application also plays the role of an overarching system optimization application, accommodating transit or freight signal priority, preemption, and pedestrian movements to maximize overall network performance.
- TSP: This proposed application allows transit agencies to manage bus service by adding the capability to grant buses priority based on many factors. The proposed application provides the ability for transit vehicles to communicate passenger count data, service type, scheduled and actual arrival time, and heading information to roadside equipment via an on-board device.
- Mobile Accessible PED-SIG: This application integrates information from roadside or intersection sensors and new forms of data from pedestrian-carried mobile devices. Such systems will be used to inform visually impaired pedestrians when to cross and how to remain aligned with the crosswalk. This application may also support the accommodation of safe and efficient pedestrian movement of a more general nature.
- Emergency Vehicle Preemption (PREEMPT): This proposed application, while like existing technologies, will integrate with V2V and V2I communication systems. The application would account for non-linear effects of multiple emergency responses through the same traffic network.
- Freight Signal Priority (FSP): This application provides signal priority near freight facilities based on current and projected freight movements. The goal is to reduce delays and increase travel time reliability for freight traffic, while enhancing safety at key intersections.

The MMITSS is available to DOTs across the country to help them build and establish their own CV programs. To learn more, please visit the MMITSS website.

4.2 Arizona[25]

4.2.1 Maricopa County DOT (MCDOT) SMARTDrive℠ Program

Arizona's CV Program was initiated in 2007 by MCDOT, the Arizona DOT (ADOT) and the University of Arizona (U of A). It began as a research project to identify how new technology applications could enhance traffic signal operations, incident management and traveler information. During this time, MCDOT developed the concept of vehicle prioritization and used this concept to develop applications to improve safety for emergency responders. This concept, now known as the MCDOT SMARTDrive℠ Program, prevents emergency vehicles from colliding with one another at signalized intersections while responding to emergencies. The MCDOT SMARTDrive℠ Program simultaneously communicates with multiple

[25] https://www.maricopa.gov/640/Connected-Vehicles-Program

emergency vehicles arriving at the same intersection at the same time and relates back which vehicle has the right-of-way.

4.2.2 Anthem Test Bed[26]

MCDOT constructed a test bed in Anthem, Arizona to test the MCDOT SMARTDrive^SM Program's vehicle prioritization technology in 2011. It was one of the first seven test beds in the country. Currently in phase two of the pilot, the Anthem Test Bed leverages V2X sensors based on DSRC technology, using RSUs fixed to light poles in conjunction with aftermarket OBUs mounted in buses and emergency vehicles.[27] The Arizona CV program has now expanded its testing to include new applications such as a pedestrian traffic signal crosswalk application, transit priority application and a trucking priority application. In the future, the AZ CV Consortium hopes to expand its program even further by testing these applications in "real world" scenarios where residents and businesses in Maricopa County can participate.

4.2.3 MCDOT Future Developments

MCDOT plans to develop partnerships with local universities to test the pedestrian crosswalk application, which will allow pedestrians to request extended crossing times. MCDOT also plans to work with the warehouse and shipping industry along MC85 to provide trucks with equipment to help reduce shipping times and therefore provide a regional economic benefit to companies. CV technology will reduce wear and tear on the roadway from the constant starting and stopping of trucks. It also reduces emissions as the trucks will be idling less, thus helping to improve the environment.

4.2.4 National Leadership

The technology developed by Arizona's CV Program contributed to the development of the USDOT's Multi-Modal Intelligent Traffic Signal System (MMITSS). MMITSS is now available to other DOTs across the country to help them build and establish their own CV programs. MCDOT's Anthem CV Test Bed was officially recognized as a Nationally Affiliated Test Bed in 2012.

4.3 California

4.4 Contra Costa Transportation Authority (CCTA) – GoMentum Station[28]

GoMentum Station in Concord, California is where Contra Costa Transportation Authority (CCTA) leads and facilitates a collaborative partnership amongst multiple Automobile Manufacturers; OEMs and Tier-1 suppliers; communications companies; technology companies; researchers and academia; public agencies and other partners that converge in research, development, testing, validation and commercialization of CV applications and AV technologies to define the next generation of transportation network infrastructure. This 5000 –acre former Navy Weapons Station is one of the largest CV/AV test facilities in the world.

Designated in January 2017 as one of ten USDOT Automated Vehicle Proving Grounds, several automobile manufacturers will test and validate their CV/AV technologies at the GoMentum Station Testbed to advance their research and accelerate commercialization.

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[26] http://www.aztech.org/projects/connected-vehicles-research.htm

[27] http://iotdesign.embedded-computing.com/articles/v2x-test-beds-for-faster-cleaner-safer-transportation/

[28] www.ccta.net/about/download/Website_one_pager.pdf

4.4.1 Palo Alto Test Bed[29]

Established in 2005, the Palo Alto Test Bed is California's main CV test bed is a federally funded resource available to developers to test how CV technologies perform under real-world conditions. The test bed spans 11 consecutive intersections along a 2-mile stretch of the highly traveled arterial of El Camino Real SR-82 in Palo Alto. Operated by University of California, Berkley's Partners for Advanced Transportation Technology (PATH), in partnership with Caltrans, Palo Alto provides an operational environment where intersections, roadways, and vehicles can communicate through wireless connectivity. This test bed is used to assess wireless communication standards designed specifically for automotive use and CV applications and technologies.

Currently, PATH and Caltrans are upgrading the Palo Alto Test Bed so that it can become a key element in the national network of DSRC test beds. This comes as the USDOT is encouraging the development of DSRC, which has been rapidly improving in recent years, for the exchange of safety-critical and time-critical information between roadway infrastructure and vehicles. The Palo Alto location is also considered especially crucial as several major international vehicle manufacturers have built research facilities in the area.

4.5 Canada

4.5.1 2017 World Congress in Montréal

The City of Montréal is planning a deployment of 5G and DSRC around the Convention and exhibition Centre for the upcoming 2017 ITS World Congress to support the various demonstrations.

4.5.2 Montréal Smart Mobility[30]

As part of the Smart and Digital City 2015-2017 Action Plan currently being researched by the city of Montréal, the Smart Mobility phase is planning to:

- Provide all transit data in real time
- Set up smart, intermodal and integrated transportation systems
- Support deployment of solutions for providing information to travelers

There are plans to work with existing transportation systems (e.g. taxis and buses) to gather data to develop the following:

- GeoTraffic – A Montréal real-time urban transit database that will provide:
    - Real-time data collection (traffic jams, congestion, public transit status, etc.)
    - Formulation of mechanisms for communicating, processing and sharing data with partners
- Open Montréal 511 – An application program interface (API) for interacting with GeoTraffic, under open 511 standards, to create a vast range of applications, including a Web portal and mobile app
- iBus - Launch of real-time bus locating service (service/disruption status) and make data available as open data and to application program interfaces (API)
- Smart Parking – A mobility app that will provide:
    - Real-time displays of available parking spots

[29] http://www.path.berkeley.edu/research/modal-applications/palo-alto-test-bed

[30] http://villeintelligente.montreal.ca/sites/villeintelligente.montreal.ca/files/plan-action-bvin-ce-6-mai-2015-eng.pdf

- Nav/parking spot prediction app
- Real-time parking data capture

4.5.3 ACTIVE-AURORA Research Initiative[31]

Alberta Cooperative Transportation Infrastructure and Vehicular Environment (ACTIVE)- AUtomotive test bed for Reconfigurable and Optimized Radio Access (AURORA) represents a unique partnership among three orders of government (Transport Canada, Alberta Transportation, and the City of Edmonton), the University of Alberta (U of A), the University of British Columbia (UBC), and several industry partners.

4.5.3.1 ACTIVE CV Test Bed[32]

In Alberta, three on-road ACTIVE test bed sites are in the greater Edmonton area. The three test bed sites currently equipped include Whitemud Drive, Anthony Henday Drive and 23 Avenue, allowing for testing on both highway and arterial corridors. These ACTIVE test beds will enhance the U of A's capacity to partner with government, industry and academic stakeholders to develop, test, demonstrate and commercialize innovations with emphasis on data for the active traffic management.

4.5.3.2 AURORA CV Test Bed[33]

In British Columbia, the on-road AURORA CV test bed covers up to 10km along both two and four-lane roadway within and adjacent to the UBC's campus. AURORA is being funded by Transport Canada and is a USDOT affiliated test bed with industry collaboration currently from Moovee Innovations, Novax Industries, and FP Innovations. The test bed is anticipated to advance the use of wireless technology for freight security and efficiency and establish best practices for use of wireless technology in Canada's ITS Architecture.

AURORA incorporates a range of wireless technologies such as Long-Term Evolution (LTE), and 5.9 GHz DSRC, and permits a variety of radio and network configurations. The Roadside portion of the testbed is comprised both enhanced RSUs that include interfaces to the traffic signal controller, IP cameras, software defined radio (SDR) modules, as well as conventional RSUs and WiMAX CPEs, and nine basic RSUs that include only conventional RSUs and WiMAX CPEs.

The test bed aligns with the UBC "campus as a living lab" initiative, enhancing UBC's capacity to partner with industry, government and academic stakeholders to develop, test, demonstrate and commercialize innovations with emphasis on wireless communications for freight security and efficiency.

4.6 Colorado

4.6.1 I-70 Mountain Corridor[34]

Interstate 70 intends to be the testing ground for the Colorado DOT's (CDOT's) CV Pilot Program. This program is a collaborative effort with Panasonic and is part of an initiative to use new technology to improve safety and traffic. This program aims to leverage DSRC to facilitate communication between cars and traffic lights or other smart objects on the road. It is anticipated that the protocol will manage data

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31 http://www.engineering.ualberta.ca/en/NewsEvents/Engineering%20News/2016/September/Wirelessconnectedvehicletechnologymarksamilestone.aspx s

32 http://transportation.ualberta.ca/News%20and%20Events/2013/December/TheCSTandtheFirstConnectedVehicleTestBedinCanada.aspx

33 http://rsl.ece.ubc.ca/aurora/

34 http://www.summitdaily.com/news/regional/when-cars-talk-the-future-of-colorados-i-70-mountain-corridor/

in real-time and may also be used to send timely information to moving vehicles. This type of communications and reporting could provide early warning notifications related to icy roads, obstructions and car accidents.

The program will equip more than 700 CDOT first responder, ski shuttle and commercial vehicles on I-70 with DSRC devices that use radio waves to transmit information on road conditions, traffic and closures. The devices will also be installed on roadside infrastructure to collect data on vehicle speeds and incidents. Vehicles installed with DSRC will function as "data collectors" for the pilot program, automatically sending information to CDOT that can be sent out to drivers along the corridor in a timely fashion. The project will stretch between C-470 in Denver and Edwards.

Additionally, CDOT vehicles, such as snowplows, installed with friction sensors could send information on icy or snow packed road conditions to this database. Sensors installed on highway infrastructure tracking traffic volume, travel speeds and accidents could also feed this data into the system for real-time traffic updates.

4.6.2 Smart Truck Parking (Pre-Pass, Cellular, and DSRC)[35]

Using detection and cloud-based software that understands and can report available parking spots to truckers will improve:

- Truckers' time and fuel consumption
- Excess wear and tear on Colorado's roadways
- Excess pollution

The first phase of this project will integrate six existing parking facilities into the Smart Truck Parking System.

4.7 Delaware[36]

Delaware DOT (DelDOT) will be participating in the 2017 SPaT challenge in Smyrna by connecting DelDOT vehicles to signals along Route 1 and Route 13 by making it into a loop.

Delaware is also working with Turner Fairbanks to implement artificial intelligence into its TMC for better management along the I-95 corridor and surrounding area.

4.8 Florida

4.8.1 2011 World Congress Deployment[37]

Roadside infrastructure was deployed for the demonstrations that took place at the ITS World Congress in the fall. Five units were installed along John Young Parkway, 11 units were installed along I-4, and 11 units were installed along International Drive/Universal Boulevard.

4.8.2 Utilization of CV Data to Support Traffic Management Decisions

This project is examining the utilization of detailed data provided by CVs to support off-line planning and real-time operation decisions of TMC operations.

[35] https://www.codot.gov/programs/roadx/projects-in-motion
[36] http://www.wilmapco.org/OurTown/GeneDonaldson.pdf
[37] https://www.michigan.gov/documents/mdot/09-12-2013_International_Survey_of_Best_Practices_in_ITS_434162_7.pdf

4.9 Idaho[38]

In collaboration with the Idaho Transportation Department (ITD), the Idaho National Laboratory (INL) is implementing CV research in two phases:

- Phase 1 2015-2016
  - Mobile road weather data collection
    - First installation: INL scout vehicle, May 2015
    - Three additional units installed 2016
    - One unit pending repair return
  - Snow plow controller data uploads to Vaisala Navigator website
  - Scout vehicle V2V safety (DSRC)
    - Forward collision warning
    - Electronic brake light warnings
    - Intersection moment assist
    - Blind spot and lane change warning
- Phase 2 2016-2017 (pending funding)
  - SPaT broadcasts along US 20, 14 intersections
  - Bus and snow plow V2I
  - Dashboard camera images
  - 511 CV modules
  - Two animal detection zones

Idaho's program provides an example of weather and safety related use cases that the BIM should consider as it is being developed.

4.10 Maryland

Current Maryland DOT (MDOT) plans are centered on responding to the National SPaT Challenge[39], to achieve deployment of DSRC infrastructure with SPaT broadcasts in at least one corridor or network by January 2020. MDOT is implementing DSRC at many signalized intersections in pursuit of broadcasting SPaT and MAP data. The current focus on V2I applications such as TSP, Eco-Approach, Red Light Warning, Curve-Speed Warning, and Work Zone Warning are of interest as well in this deployment and potentially others.

4.11 Michigan

4.11.1 Ann Arbor CV Test Environment[40]

The Ann Arbor CV Test Environment (AACVTE) aims to be the largest operational, real-world deployment of CVs and infrastructure in the world. The UMTRI and its partners will build upon an existing model deployment to become the standard for a national implementation.

The test bed is federally funded, (Federal Highway) state funded (Michigan Economic Development Corporation.) as well as funded by academia [Michigan Mobility Transformation Center (MTC) the City of Ann Arbor and additional partners].

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[38] http://www.westernstatesforum.org/Documents/2016/presentations/Idaho_KoeberleinPray_FINAL_CV_CRADA.pdf

[39] https://transportationops.org/spatchallenge

[40] https://www.its.dot.gov/research_archives/safety/aacvte.htm

This contract will expand the current CV test environment, known as CV Safety Pilot Model Deployment (SPMD) and will increase the number of vehicles, roadside equipment and will facilitate additional applications (pedestrians, etc.).

The larger deployment will include:

- 45 street locations
- 12 freeway sites
- 27 square miles (the City of Ann Arbor)
- Up to 5,000 equipped vehicles

4.11.2 Michigan's Smart Corridor - Southeast Michigan CV Testbed[41]

A roughly 125-mile sensor installation near I-96 near General Motors Co.'s Milford Proving Grounds, I-94 from Ann Arbor to metro Detroit, U.S. 23 from Ann Arbor to Brighton, and elsewhere. The sensors connect vehicles to infrastructure, such as traffic lights, to help alleviate traffic congestion.

In that area are many sensors and other wireless equipment on roadsides to broadcast signals to and from CVs equipment with receivers. About 115 of these sensors exist in the test area, including:

- 17 within the Detroit city limits
- 25 within the Ann Arbor city limits
- 17 along I-96 from Milford Road to M-5, and at M-5 and 12 Mile Road
- the rest along I-696 between I-275 and Telegraph Road, and along Telegraph Road in Oakland County

4.11.3 Vehicle Infrastructure Integration (VII) Proof-of-Concept[42]

In 2005, the USDOT initiated a program to develop and test a 5.9GHz based VII POC, in support of a nationwide deployment decision. The USDOT and its private-sector partner the VII Consortium (VIIC)—an organization consisting of several light-duty OEM) and industry participants—executed the POC test. The USDOT has engaged Booz Allen Hamilton to design the national VII network architecture, act as system integrator, and implement the POC.

The POC Development Test Environment (DTE) was implemented in the northwest suburbs of Detroit, Michigan. Fifty-five RSEs were installed within 45 square miles, 27 vehicles were configured with OBEs, and a communications network was established. Further, a limited number of public- and private-sector applications were developed, primarily as a means of testing the end-to-end functionality and performance of the VII system.

4.12 Minnesota

4.12.1 University of Minnesota CVs Research Lab

The CVs Research Lab (CVRL) is in the electrical engineering (EE) department of the University of Minnesota Duluth (UMD). The CVRL is involved in the state of the art research to improve driver safety and traffic mobility using V2V or V2) wireless communication which is commonly known as the CVs technology. The CVRL has previously worked on projects funded by the Northland Advanced Transportation Systems Research Laboratory (NATSRL), the Intelligent Transportation Systems (ITS) Institute, and the Center for Transportation Studies (CTS) of the University of Minnesota. Currently, CVRL

[41] http://www.gomobilemichigan.org/planetm/southeast-michigan-connected-vehicle-test-bed.html
[42] https://ntl.bts.gov/lib/31000/31000/31078/14481.pdf

is working in collaboration with Roadway Safety Institute (RSI) of CTS, and Savari Networks on two different projects funded by USDOT. The CVRL is also working on a work zone safety project funded by Minnesota DOT.

4.12.2 University of Minnesota Center for Transportation Studies[43]

Safety and traffic operations concepts based on V2V and V2I communication have been in development for some time. The USDOT is now actively promoting speed harmonization (SPD-HARM) and queue warning (Q-WARN) as the first two most-implementable V2I technologies and has a request for proposals regarding the establishment of CV pilots around the country.

With the assistance of MNDOT, the Minnesota Traffic Observatory at the University of Minnesota has studied and experimented with infrastructure-based Q-WARN systems. A permanent field lab has been established at the high-crash area of westbound I-94 in Minneapolis, Minn., capturing detailed data on hundreds of crashes. This area experiences upwards of 100 crashes annually, the majority being rear-end crashes due to failure to stop or too little headway. This research aims to capitalize on the already extensive instrumentation available at the I-94 Field Lab to develop a CV testbed specifically for the implementation and testing of SPD-HARM and Q-WARN systems.

The project is following a phased approach, where first an infrastructure-based Q-WARN system will be implemented and expanded to a V2I SPD-HARM and Q-WARN demonstration. The current site will be enhanced to support fully developed CV safety systems as well as the research and evaluation of the underlying human factors of such systems. The final product of this project will be a fully functional CV testbed uniquely situated to attract freeway safety-oriented V2I and V2V safety application development, implementation, and evaluation projects.

The use case for creating the SPD-HARM and Q-WARN systems is being considered within the BIM as part of the safety elements.

4.13 Nevada

Various companies showcased DSRC and LTE technologies at the CES 2017 in Las Vegas. No permanent infrastructure has been deployed.

4.14 New Jersey

Currently working on two non-DSRC pilots at four pilot sites however information is currently limited on their implementation and application.

4.15 New York

4.15.1 Commercial VII (CVII) Program[44]

The CVII program, coined by New York State DOT (NYSDOT), refers to the development, adaptation and application of IntelliDrive[SM] technology using 5.9 GHz DSRC with a focus on commercial vehicles. Throughout this program are several use cases relevant to BIM development including Driver Identification, Wireless Vehicle Safety Inspection, and Commercial Vehicle Advisory.

The CVII Program develops and tests the exchange of real time information between IntelliDrive[SM] compliant roadside infrastructure and vehicles to improve safety, security, mobility, and transportation system asset management. This project has the potential to improve future safety through crash

[43] http://www.roadwaysafety.umn.edu/research/search/projectdetail.html?id=2015037
[44] http://i95coalition.org/projects/commercial-vehicle-infrastructure-integration-project-library/

avoidance technology. The technology used in this project will focus on commercial vehicles, but is applicable to any IntelliDrive^{SM} compliant vehicle.

The test vehicles in the project are equipped with a Human-Vehicle Interface (HVI) that provides visual and audible information to the driver. In the main test truck, the HVI is a Volvo product which is modified for the CVII application and integrated into the dashboard. In other project vehicles, an aftermarket display is used.

Minimizing the risk for driver distraction is a key objective for the CVII project. Volvo's human factors experts have been engaged in this aspect of the project. While the vehicle is not moving, the HVI allows information to be input by the driver (e.g., driver authentication) This Driver Identification Feature verifies and authenticates the commercial vehicle driver's license and medical certificate to ensure that they have not expired or been revoked prior to allowing the vehicle to be started. In the future, this feature could be enhanced to verify the driver's hours of service as well as their endorsements for the vehicle type and cargo. The HVI also allows presentation of information to the driver (e.g. dynamic travel information, electronic roadside signage, truck parking availability, etc.).

The Commercial Vehicle Advisory Feature allows hazardous commercial vehicles, such as a snow plow, to communicate their location and the type of hazard directly to near-by vehicles to provide a warning to the drivers of approaching vehicles. In all cases, driver distraction will be minimized by managing the information load presented to drivers. The Wireless Vehicle Safety Inspection Feature is capable of transmitting vehicle safety status while the vehicle is moving down the highway. This feature can support fixed inspection station bypass and temporary inspection stations. In the future, this feature could be enhanced to support on-demand wireless inspection by enforcement officers or un-manned, virtual inspection stations.

4.15.2 2008 ITS World Congress Deployment[45]

VII Testbed in NY in New York City and Long Island for demonstration at 2008 ITS World Congress and CVII program:

- Demonstrated 20+ applications in New York city and Long Island
- 40+ RSEs installed
- Installation and integration took 6 months to complete

Commercial vehicle applications demonstrated:

- Weight in motion
- Height warnings
- Construction alerts
- Road camera images

Traffic information:

- Travel time based on probe data
- Traffic cameras
- Incident alerts
- Maps

Road Signage:

[45] http://i95coalition.org/wp-content/uploads/2015/03/NYS-Existing-VII-May2009.pdf?fe2c99

- Bike lanes
- Exit information
- Points of interests

Localized intersection safety and transit services:

- SPaT
- Transit priority
- Emergency Preemption

Multi-modal travel:

- Schedules for ferry
- Commuter buses
- Airport flight information
- City parking
- Airport parking information

Additionally, local e-commerce services information, advertisements were shown. This 2008 demonstration provides many of the notable situations that the BIM should consider as it is being developed.

4.15.3 Screening Sites[46]

Under an earlier NYSERDA Agreement (17420) Intelligent Imaging Systems (IIS) supplied and installed Smart Roadside network software and integrated new CV roadside devices into the Schodack Smart Roadside system. The Smart Roadside Inspection System (SRIS) Enterprise software platform was integrated with NYSDOT's existing backend information systems including the NYS CVIEW and NYS' CV / CVII Program. The added roadside devices included an automated USDOT Number reader (AUR), and an Overview Camera System (OVC) at the NYSDOT Schodack Commercial Vehicle (CV) electronic screening (e-screening) site. The initial existing NYSDOT inspection systems included Weigh-In-Motion (WIM), Automated License Plate Recognition (ALPR), 915MHz North American Preclearance and Safety System (NORPASS) and 5.9GHz DSRC as part of Automated Vehicle Identification (AVI) and legacy software components system. Under this NYSERDA Agreement IIS added trailer/rear ALPR, vehicle Over Height Detection (OHD), and a Hazardous Material placard reader (HAZMAT) to the existing suite of e-screening tools. Enforcement personnel, utilizing the automated mainline electronic screening system, are now automatically and in real-time identifying and providing notifications on vehicles.

Aside from the commercial vehicle information exchange mentioned before in other programs, both the OHD and the HAZMAT information are additional use cases of information that could be transmitted under the BIM.

4.16 Pennsylvania[47]

4.16.1 CMU Cranberry Township and Pittsburgh Test Bed

Through a collaboration between Carnegie Mellon University (CMU), Cranberry Township, the City of Pittsburgh, the Pennsylvania DOT (PennDOT), and the Southwestern Pennsylvania Commission (SPC), 11 traffic signals in Cranberry Township and 24 traffic signals in Pittsburgh were equipped with DSRC radios.

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[46] https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/C-10-19%20Schodack%20Smart%20Roadside%20Inspection%20System%20Enhancement%20Final%20Report.pdf

[47] http://www.itspennsylvania.com/wp-content/uploads/2015/05/ITSA-App-Connected-Automated-Section.pdf

In January 2015, CMU entered into a Memorandum of Agreement with the US Department of Transportation (DOT) Intelligent Transportation Systems Joint Program Office as a member of the Affiliated Test Bed Program.

Cranberry Township, which is a suburb located in Butler County, 20 miles North of Downtown Pittsburgh. With a population of 30,000 it is the fastest growing area of the Pittsburgh Metro and hosts almost 24,000 commuters daily, who are employed at companies such as Westinghouse International Nuclear Engineering and Mine Safety Appliances, MSA. Population is expected to top out near 50,000 residents by 2030. This area is also directly at the intersection of the East-West traveling Pennsylvania Turnpike and the North-South traveling Interstate 79. As a major employment hub and its proximity to the Turnpike and I-79 the area experiences significant commuter and freight congestion.

The CV environment is located at the intersection of Routes 19 and 228 which is a rapidly growing retail and commercial district. PennDOT reports that over 100,000 vehicles routinely pass through the Intersection of Routes 19 228. This is just 1 of 48 signalized intersections maintained by township staff. The traffic light infrastructure has been updated and 11 of the intersections have been equipped with DSRC radios. In addition, there is backhaul support at each of the intersections connecting to a state of the art municipal traffic management center. Cranberry Township is willing to work with us to set up a larger DSRC radio presence at their intersections and for CV applications.

4.16.2 Harrisburg

The deployment here is part of the SPaT Challenge: Walnut Creek, Third Street, Seventh Street and Forster Street are all equipped with SPaT deployment.

4.16.3 Ross Township

In 2014, PennDOT was awarded a FHWA Accelerated Innovations Deployment (AID) grant. PennDOT plans to use the grant to deploy innovative technologies, including adaptive traffic control signals and DSRC along McKnight Road (SR 4003) from I-279 to Perrymont Rd/Babcock Blvd. in Ross and McCandless Townships. This corridor consists of 11 traffic signals, is roughly 4.8 miles and serves 30,000 ADT. McKnight Road is one of the most heavily traveled arterials in PennDOT District 11-0. It consists of three through lanes in each direction divided by a concrete median with one or more turning lanes at the signalized intersections. This corridor is a classic example of urban sprawl as it is a heavy commuting corridor from the northern suburbs to Downtown Pittsburgh, but it also is very densely populated with both residential and commercial developments. This corridor is densely developed with little to no opportunity for additional capacity improvements.

While installing adaptive system equipment, crews will install (DSRC) technology into the traffic signal controllers. The DSRC equipped signals will be used to assist Carnegie Mellon University's research on V2I and AV technology. PennDOT will also be working with CMU.

4.17 SPaT Challenge[48]

A challenge to state and local public-sector transportation infrastructure owners and operators to cooperate to achieve deployment of DSRC infrastructure with SPaT broadcasts in at least one corridor or network (approximately 20 signalized intersections) in each of the 50 states by January 2020. SPaT broadcasts are expected to be accompanied by MAP and RTCM broadcasts.

[48] http://www.transportationops.org/spatchallenge

4.18 Texas[49]

4.18.1 I-35 Connected Work Zone

Expand existing I-35 traveler information during construction

- In-vehicle messaging for commercial vehicles
- Communications
  - 1st Phase: Cellular
  - 2nd Phase: DSRC
- Enhancement to the Texas component of the USDOT's Freight Advanced Traveler Information System (FRATIS) project
  - Corridor optimization for freight

4.18.2 Texas CV Research

The following programs have been implemented by Texas, each of which provide some insight into the type of use case or a use case of a data element that may be beneficial for the BIM to handle:

- TxDOT 0-6836: Commercial Truck Platooning
- TxDOT 0-6837: Assessment of Innovative and Automated Freight Systems and Development of Evaluation Tools
- TxDOT 0-6838: Bringing Smart Transport to Texans: Ensuring the Benefits of a Connected and Autonomous Transport System in Texas
- TxDOT 0-6845: CV Problems, Challenges and Major Technologies
- TxDOT 0-6847: An Assessment of Autonomous Vehicles: Traffic Impacts and Infrastructure Needs
- TxDOT 0-6848: Transportation Planning Implications of Automated/CVs on Texas Highways
- TxDOT 0-6849: Implications of Automated Vehicles on Safety, Design and Operation of the Texas Highway System
- TxDOT 0-6851: Strategies for Managing Freight Traffic Through Urban Areas
- TxDOT 0-6867: Wrong-Way Driving CV Demonstration
- TxDOT 0-6875: Autonomous and CV Test Bed to Improve Transit, Bicycle, and Pedestrian Safety
- TxDOT 0-6877: Communications and Radar-Supported Transportation Operations and Planning (CAR-STOP)

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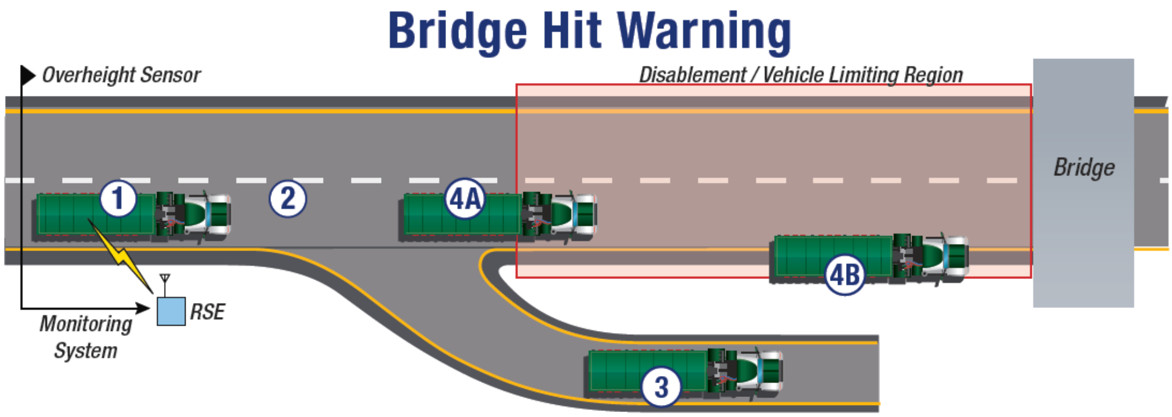
[49] http://static.tti.tamu.edu/conferences/tsc16/presentations/traffic-ops-1/ma.pdf

4.18.3 Over Height Detection (OHD) and Warning



1: Infrastructure OH sensor detects OH vehicle
2: RSE identifies specific vehicle and warning is displayed to the driver
3: Vehicle exits and uses bypass –Warning is removed from driver display
4A: Vehicle does not exit – Additional warnings presented. Vehicle automatically slows if available.
4B: Vehicle is disabled or speed limited prior to hitting the bridge, if available. Emergency responders automatically notified.

Figure 20. OHD and Warning Program – Bridge Hit Warning Scenario.

4.18.4 In-Vehicle Static Signage

Shown below in Figure 21 is an example of a portable onboard device (POD) that can send and receive messages, displaying in-vehicle static signage determined from the vehicle's BSM providing the location, direction, and speed of the vehicle.

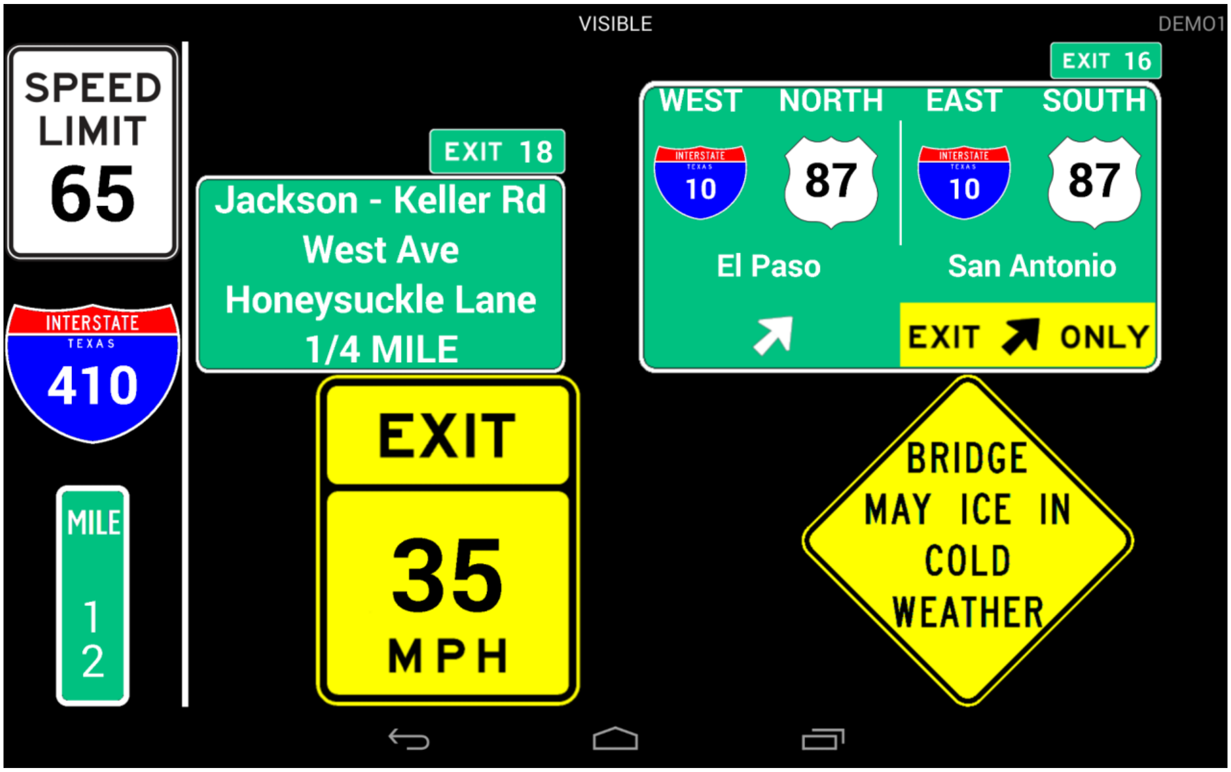


Figure 21. Tablet Display of In-Vehicle Static Signage.

4.18.5 Enhancing Work Zone safety with Connected Automation[50]

This program replaced a manned work zone vehicle with a fully-autonomous vehicle, capable of communicating with other vehicles in the work crew, traffic management systems, and, using visual recognition techniques, to follow other vehicles in the crew or even respond to arm gestures by a member of the work crew to improve work zone safety and reduce injuries and fatalities (see Figure 22 and Figure 23).

[50] http://ieeexplore.ieee.org/document/7297701/

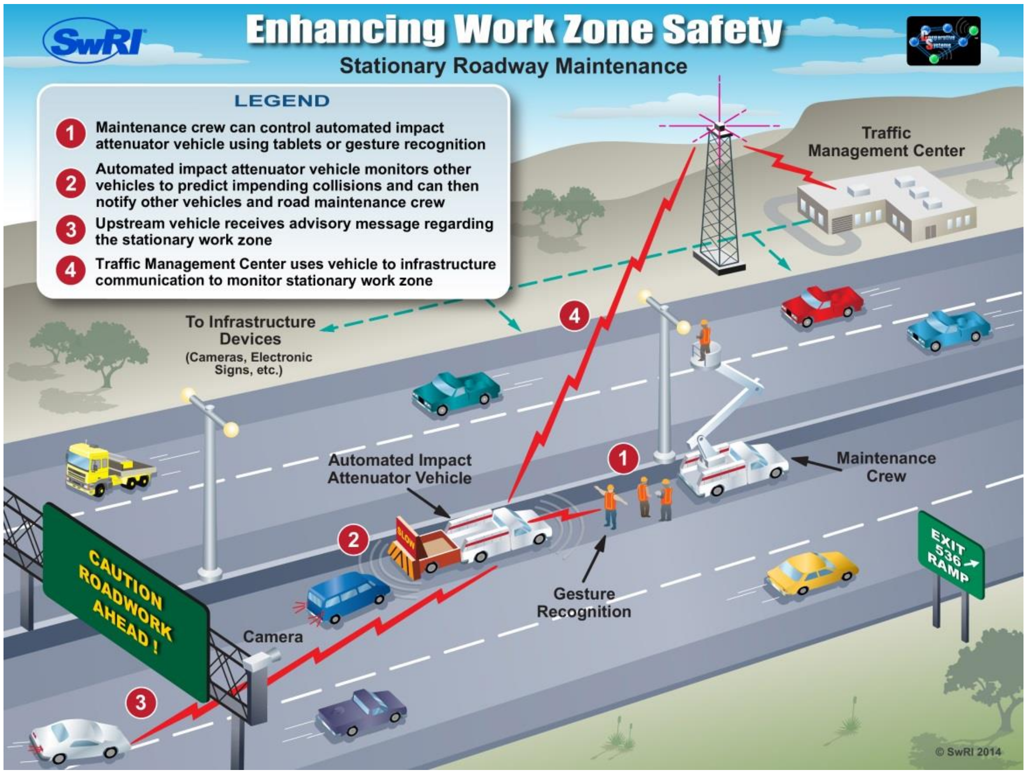


Figure 22. Stationary Roadway Maintenance Program.

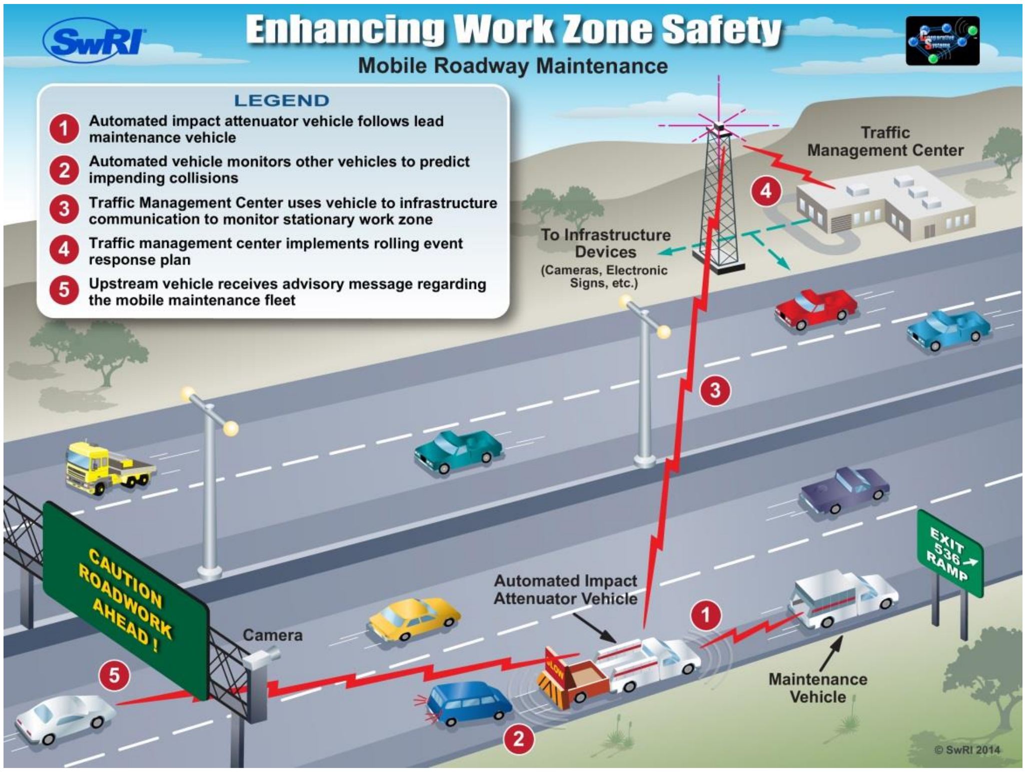


Figure 23. Mobile Roadway Maintenance Program.

4.18.6 Wrong-Way Driving Detection and Alert

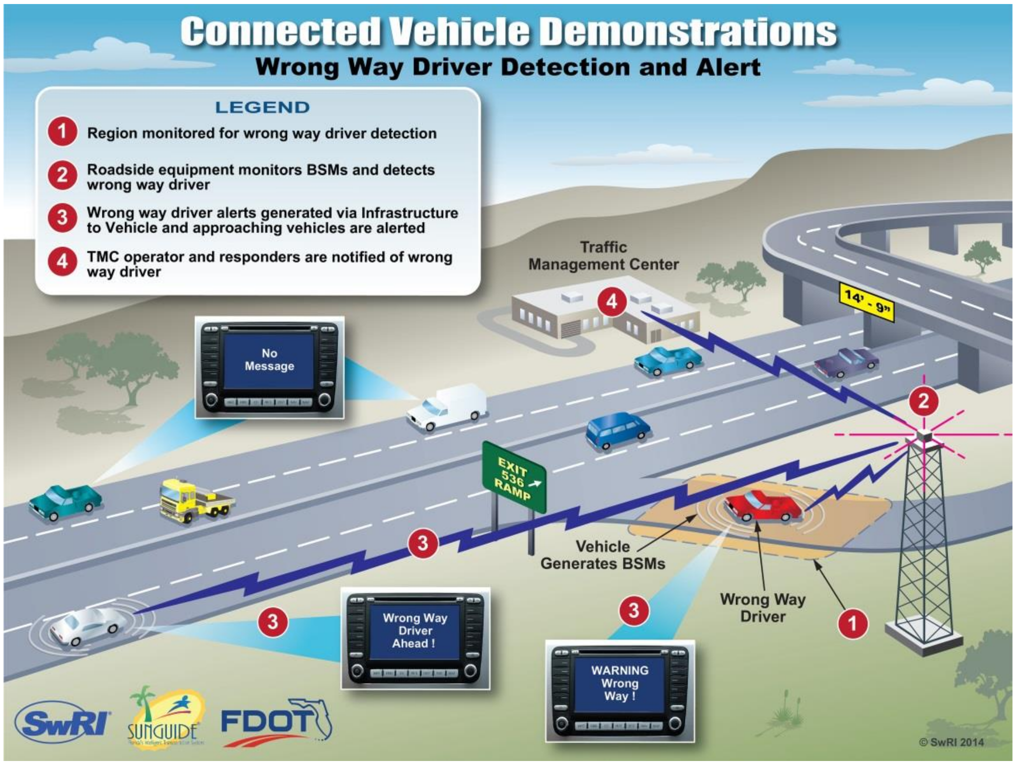


Figure 24. Wrong Way Driver Detection and Alert.

4.18.7 Road Condition Monitoring

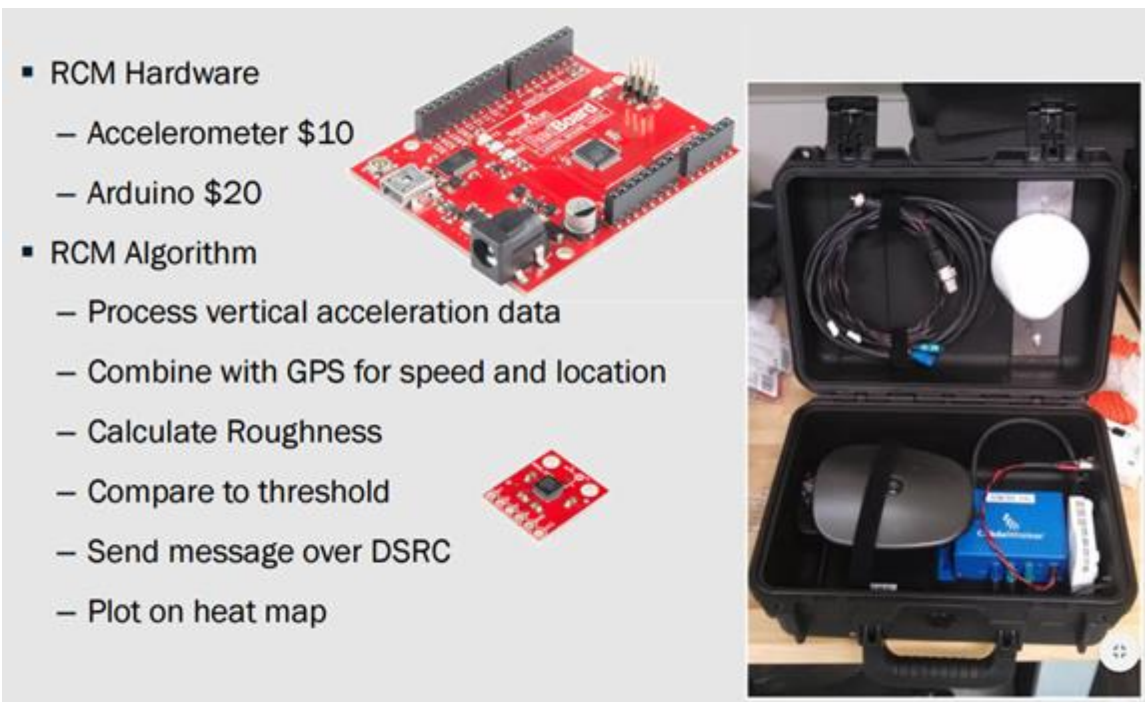


Figure 25. Road Condition Monitoring Program Hardware and Algorithm.

4.19 Utah

The Utah Connected Vehicle deployment is using DSRC to provide smart transit signal priority to Utah Transit Authority (UTA) buses along Redwood Road, a significant arterial in Salt Lake County. The instrumented corridor is 11 miles long and crosses through 35 signalized intersections. Thirty of those intersections have DSRC equipment, with three different DSRC vendors included. Two brands of signal controller are also involved in the project. DSRC units on the UTA buses allow the bus to request signal priority when the bus is behind schedule and meets an occupancy threshold. UDOT modified the Multi-Modal Intelligent Transit Signal Software (MMITSS) developed at the University of Arizona for the CV Pooled Fund Study for this project. This DSRC-based transit signal priority system will be operational on daily bus service beginning in October 2017 and plans are underway for this system to be used on a new Bus Rapid Transit line in Utah County in 2018.

The Redwood Road DSRC corridor will also be used to test and deploy other connected vehicle applications. Having three brands of DSRC installed will facilitate testing of hardware and software interoperability.

4.20 Virginia

The following programs have been implemented by Virginia DOT (VDOT).

4.20.1 Northern Virginia Test Bed[51]

The Northern Virginia Test bed is a part of Virginia's connect vehicle program whose mission is to provide an open CV environment where concepts can be developed, tested, deployed, and evaluated in real world operating environments. In Fairfax County, Virginia (VA), the test bed is looking to deploy connect solutions and evaluate their effectiveness, focusing on:

- Heavily Congested Arterials and Freeways
- Interface to VDOT Northern Region TOC
- ATM, VDMS, HOVs, Toll Lanes, Ramp Meters
- 49 RSUs

4.20.2 Virginia Connected Corridors[52]

The Virginia Connected Corridors (VCC) is an initiative developed by VTTI in partnership with the). The VCC encompasses both the Virginia Smart Road and the Northern Virginia Connected-vehicle Test Bed, which is located along one of the most congested corridors in the United States. The VCC is facilitating the real-world development and deployment of CV technology using more than 60 roadside equipment units.

VTTI, VDOT, and researchers from across Virginia are already implementing connected applications using the VCC, including traveler information, enhanced transit operations, lane closure alerts, and work zone and incident management. Implementation of the VCC and the information being transmitted ties closely with the efforts and use cases of the BIM, especially in cases of congestion and providing information on braking vehicles before they can be seen, and infrastructure data.

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[51] https://www.tiaonline.org/sites/default/files/2016/2/TIA%20Vehicle%20Connectivity%20Workshop%20112916_Vehicle%20Testbeds_Mike%20Mollenhauer%20VTTI.pdf
[52] http://www.vtti.vt.edu/facilities/vcc.html

4.20.3 Virginia Smart Road[53]

The Virginia Smart Road is a full-scale, closed test-bed research facility managed by VTTI and owned and maintained by VDOT. The Smart Road is FAA approved as a testing facility for flight and continues to play an important role in the overall success of the institute and its research endeavors. The test bed offers weather-making capabilities, one of the tallest bridges in Virginia, and about 400 acres of aerial space for Unmanned Aerial Vehicle (UAV) testing. Transportation scientists and product developers have spent more than 20,000 hours conducting research on this high-tech highway since its opening.

4.21 Washington DC

Seven DSRC RSUs were deployed along 7th Street and Independence Ave for testing during the Washington DC Auto Show. They are mostly for sending Traveler Information Messages but are envisioned to support SPaT also. There are tentative plans to deploy 20 units on New York Ave and Pennsylvania Avenue in the future.

[53] http://www.vtti.vt.edu/facilities/virginia-smart-road.html

5. INFRASTRUCTURE RELATED ELEMENTS IN THE EXISTING STANDARDS

The SAE J2735 standards contains the following data elements that may be useful to the BIM:

- BasicSafetyMessage (BSM)
- CommonSafetyRequest (CSR)
- EmergencyVehicleAlert (EVA)
- IntersectionCollisionAvoidance (ICA)
- MapData (MAP)
- NMEAcorrections (NMEA)
- PersonalSafetyMessage (PSM)
- ProbeDataManagement (PDM)
- ProbeVehicleData (PVD)
- RoadSideAlert (RSA)
- RTCMcorrections (RTCM)
- SignalPhaseAndTiming Message (SPAT)
- SignalRequestMessage (SRM)
- SignalStatusMessage (SSM)
- TravelerInformation Message (TIM)
- TestMessages

These data elements will be useful in creating the BIM. New data elements will be created for any specific cases or scenarios that are insufficiently handled by these data elements.

Below is a list of elements that may be useful in the creation of the BIM message.

An example of how the SAE J2735 messages would be called out is shown in the table below:

Existing Data Element	Type	Specific Type	Standard	Description
TravelerInformation	Message	Message	SAE J2735	
msgCnt	MsgCount	Integer		The MsgCount data element is used to provide a sequence number within a stream of messages with the same DSRCmsgID and from the same sender.
timestamp	MinuteOfTheYear	Integer		The MinuteOfTheYear data element expresses the number of elapsed minutes of the current year in the time system being used (typically UTC time). It is typically used to provide a longer-range time stamp indicating when a message was created.
packetID	UniqueMSGID	Octet String (Size 9)		The UniqueMSG_ID data element provides a relatively unique value which can be used to connect to (link to) other supporting messages in other formats.
urlB	URL-Base	IA5String (SIZE(1..45))		A valid internet style URI / URL in the form of a text string which will form the base of a compound string which, when combined with the URL-Short data element, will link to the designated resource. The string is to be interpreted as case-insensitive. Lower case is recommended. The protocol to be used (such as http) should be given in the string. The very last character of the string may be used to differentiate multiple URL-Base values in a single system. This allows for a total of up to 26+10= 36 such base addresses to exist. This last character is then used to differentiate which base a given short value is to be used with (a matching first character in the URL-Short value is also used). These characters are stripped from both the base and short data elements before combining to create the final URL / URI value.
dataFrames	TravelerDataFrameList	Data Element Sequence		The TravelerDataFrame is used to send a single "message" in a TIM message. The data frame allows sending various advisory and road sign types of information to equipped devices. It uses the ITIS encoding system to send well- known phrases, but allows limited text for local place names. The supported message types specify several sub-dialects of ITIS phrase patterns to further reduce the number of octets to be sent. The expressed messages are active at a precise start and duration period, which can be specified to a resolution of a minute. The affected local area (or set of areas) can be expressed using either a radius system or one of the two systems of short defined regions. This expression is similar to the way roadway geometry is defined in the map fragment messages. The ability to

Existing Data Element	Type	Specific Type	Standard	Description
				send this message is controlled by the SSPIndex which links back to the sender's CERT
RoadSideAlert (RSA)			SAE J2735	
msgCnt	MsgCount	Integer		The MsgCount data element is used to provide a sequence number within a stream of messages with the same DSRCmsgID and from the same sender.
timestamp	MinuteOfTheYear	Integer		The MinuteOfTheYear data element expresses the number of elapsed minutes of the current year in the time system being used (typically UTC time). It is typically used to provide a longer-range time stamp indicating when a message was created.
typeEvent	ITIS.ITIScodes	Integer		This element describes a category and an item from that category all ITS stds use the same types here to explain the type of the alert / danger / hazard involved. Refer to SAE J2540-2 for the complete code list.
description	Sequence of ITIS.ITIScodes	Integer		Up to eight ITIS code set entries to further describe the event, give advice, or any other ITIS codes – Note these IT IS codes are not very clear and sometimes limiting. When applying BIM it may be deemed that a better type of event should be used or field created.
priority	Priority	Octet String (Size 1)		A priority for the alert message, giving urgency of this message. A relative degree of merit compared with other similar messages for this type (not other messages being sent by the device, nor a priority of display urgency at the receiver).
heading	HeadingSlice	Bit String		Applicable headings/direction. The HeadingSlice data element is used to define a set of sixteen 22.5 degree slices of a unit circle (defined as 0~360 degrees of heading) which, when a given slice is set to one, indicates that travel, or motion, or message applicability along that slice of angles is allowed. Typically used to indicate a gross range of the direction to which the enclosing message or data frame applies. For example, in a use case indicating what directions of travel are to be considered, a value of 0x8181 would indicate travel in the direction of either due East or due West with a 45 degree cone about each of the cardinal axis.

Existing Data Element	Type	Specific Type	Standard	Description
extent	Extent	Enumerated (0-15)		The spatial distance over which this message applies and should be presented to the driver. Under certain conditions some messages may never be shown to the driver of a vehicle if they are short in duration and other conflicting needs supersede access to the display until such time as the subject message is no longer relevant.
position	FullPositionVector	Data Element Sequence		A complete report of the vehicle's position, speed, and heading at an instant in time. Used in the probe vehicle message (and elsewhere) as the initial position information. Often followed by other data frames that may provide offset path data.
furtherInfoID	FurtherInfoID	Octet String (Size 2)		An index link to any other incident information data that may be available in the normal ATIS incident description or other messages 1~2 octets in length. Use zero when unknown or not present.
regional	RegionalExtension	Data Element Sequence		
IntersectionCollisionAvoidance (ICA)			SAE J2735	
msgCnt	MsgCount	Integer		The MsgCount data element is used to provide a sequence number within a stream of messages with the same DSRCmsgID and from the same sender.
id	TemporaryID,	Octet String (Size 4)		This is the 4 octet random device identifier, called the TemporaryID. When used for a mobile OBU device, this value will change periodically to ensure the overall anonymity of the vehicle, unlike a typical wireless or wired 802 device ID. Because this value is used as a means to identify the local vehicles that are interacting during an encounter, it is used in the message set. Other devices, such as infrastructure (RSUs), may have a fixed value for the temporary ID value. See also DE_StationID which is used in other deployment regions.
timeStamp	MinuteOfTheYear	Integer		The MinuteOfTheYear data element expresses the number of elapsed minutes of the current year in the time system being used (typically UTC time). It is typically used to provide a longer range time stamp indicating when a message was created.
partOne	BSMcoreData	Data Element Sequence		The BSMcoreData data frame contains the critical core data elements deemed to be needed with every BSM issued. This data frame’s contents are often referred to as the "BSM Part One", although it is reused in other places as well.

Existing Data Element	Type	Specific Type	Standard	Description
path	PathHistory	Data Element Sequence		A set of recent path points forming a history. The PathHistory data frame defines a geometric path reflecting time-tagged vehicle movement over some period of time and/or distance. A sequence of Path History Points is used along with an initial position (and the GNSS status at that time) to create a set of straight line segments representing the path.
pathPrediction	PathPrediction	Data Element Sequence		The PathHistory data frame defines a geometric path reflecting time-tagged vehicle movement over some period of time and/or distance. A sequence of Path History Points is used along with an initial position (and the GNSS status at that time) to create a set of straight line segments representing the path.
intersectionID	IntersectionRefernceID	Data Element Sequence		The IntersectionReferenceID data frame conveys the combination of an optional RoadRegulatorID and of an IntersectionID that is unique within that region. When the RoadRegulatorID is present the IntersectionReferenceID is guaranteed to be globally unique.
laneNumber	ApproachOrLane	Choice (Approach, Lane)		The ApproachOrLane data frame is used to indicate a single approach or lane of interest. A typical use case would be to relate where a vehicle was located with respect to the indexing system used in a DSRC map. Under many operational conditions the precise lane may be unknown, and it is typical to then indicate the approach. [The relationship between lane indexes and approach indexes is defined in the map.] A value of zero is used when the lane or approach is unknown. See the entries for each data concept for further details.
eventFlag	VehicleEventFlags	Bit String		The Vehicle Event Flags data element conveys the sender's state with regard to a set of events. Used to convey vehicle Panic Events, set to indicate "Intersection Violation"
regional	RegionalExtension	Data Element Sequence		

The TMDD also contains the following event information types described in this standard share the following information useful to the BIM's situational awareness needs:

- Traffic detector data [TMDDv3.03-Vol1, Section 2.3.5.1]
  - Contains measurements on traffic volume, occupancy and speed
  - Monitor the surface transportation system;
  - Determine system performance; and
  - Quantitatively measure how well an ITS system helps to improve incident response.
- CCTV Camera Status and Control [TMDDv3.03-Vol1, Section 2.3.5.2]
  - Verifies the existence of reported traffic congestion;
  - Determine what assistance may be needed by the incident;
  - Monitor the progress of incidents, construction and special events;
  - Determine when the residual congestion from an incident is cleared;
  - Provide visual images to the public as to the state of the roadway; and
  - Determine what type of emergency services need to be dispatched.
- Ramp Meter Status [TMDDv3.03-Vol1, Section 2.3.5.9]
  - Manage traffic during an incident or event to alleviate congestion.
- Traffic Signal Control and Status [TMDDv3.03-Vol1, Section 2.3.5.10]
  - Monitor signal system operations within an area;
  - Improve traffic signal coordination to move traffic more efficiently;
  - Manage traffic at specific areas or intersections based on congestion and/or accidents on the roadways; and
  - Execute mitigation plans for construction and special event congestion and reacting to traffic incidents.

Several infrastructure data classes that may be a useful starting point for the design of a BIM are:

- TrafficConditions [TMDDv3.03-Vol2, Section 3.6.5.28, pg.572] provides an enumerated list of 19 event category classifications of different types of traffic conditions including:
  - stopped-traffic
  - stop-and-go-traffic
  - slow-traffic
  - heavy-traffic
  - traffic-lighter-than-normal
  - traffic-heavier-than-normal
  - traffic-much-heavier-than-normal
  - current-speed
  - speed-limit
  - travel-time
  - merging-traffic
  - traffic-returned-to-normal
  - no-problems-to-report
  - traffic-congestion-cleared
- AccidentsAndIncidents [TMDDv3.03-Vol2, Section 3.6.5.1, pg.544] provides an enumerated list of 52 event category classifications concerning accidents and or incidents on the roadways, including, but not limited to:
  - accident
  - serious-accident
  - minor-accident

  - multi-vehicle-accident
  - numerous-accidents
  - secondary-accident
  - rescue-and-recovery-work-removed
  - stalled-vehicle
  - abandoned-vehicle
  - disabled-vehicle
  - vehicle-on-fire
  - vehicle-in-water
  - jackknifed-trailer
  - chemical-spill
  - hazardous-materials-spill
  - oil-spill
  - spilled-load
  - toxic-spill
  - overturned-vehicle
- Closures [TMDDv3.03-Vol2, Section 3.6.5.5, pg.548] provides 18 different phrases describing types of closures including, but not limited to:
  - closed-to-traffic
  - closed
  - closed-ahead
  - closed-for-repairs
  - reduced-to-one-lane
  - reopened-to-traffic
  - clearing
- Roadwork [TMDDv3.03-Vol2, Section 3.6.5.22, pg.567] provides 18 different phrases describing types of roadwork including, but not limited to:
  - major-road-construction
  - long-term-road-construction
  - construction-work
  - paving-operations
  - work-in-the-median
- Obstruction [TMDDv3.03-Vol2, Section 3.6.5.15, pg.559-60] provides 40 different phrases describing types of roadwork including, but not limited to:
  - object-on-roadway
  - objects-falling-from-moving-vehicle
  - debris-on-roadway
  - storm-damage
  - downed-cables
  - road-surface-collapse
  - pavement-buckled
  - pothole
  - flooding
  - mudslide
  - avalanche
  - rockfall
  - landslide

- UnusualDriving [TMDDv3.03-Vol2, Section 3.6.5.32, pg.575-6] provides a list of 8 different phrases describing types of unusual driving including:
    - vehicle-traveling-wrong-way
    - reckless-driver
    - prohibited-vehicle-on-roadway
    - emergency-vehicles-on-roadway
    - high-speed-emergency-vehicles
    - high-speed-chase
    - dangerous-vehicle-warning-cleared
    - emergency-vehicle-warning-cleared
- SpecialEvents [TMDDv3.03-Vol2, Section 3.6.5.23, pg.568] provides 23 different phrases describing types of special events including, but not limited to:
    - airshow
    - concert
    - vip-visit
    - festival
    - carnival
    - fireworks-display
    - trade-expo
    - movie-filming
    - presidential-visit

Data elements:

- event-description-notes-and-comments
    - A textual description of a roadway event (incident, planned roadway closure, or special event). This data element is also used to describe any ancillary textual notes or comments supplemental to the description of a specific roadway event. [TMDDv3.03-Vol2, Section 3.4.8.10]
- event-description-priority-level
    - Number indicating the priority given an incident, where 1 is the Highest Priority and 10 the Lowest Priority. [TMDDv3.03-Vol2, Section 3.4.8.11]
- event-incident-status
    - A code which indicates a status of the incident. [TMDDv3.03-Vol2, Section 3.4.8.20]
- event-incident-humans-involved-count

6. CONCLUSION

The Task 3 is intended to capture information regarding the current CV standards and the various programs in which they are being used. As such, this document covers existing CV standards including IEEE 1609, SAE J2735 and J2945/X, Security Credential Management System (SCMS), Traffic Management Data Dictionary (TMDD), National Transportation Communications for ITS Protocol (NTCIP), and ISO TS 19091 standards. From these standards, a comprehensive list of infrastructure related messages from relevant standards was derived and included for use in BIM development.

Pilot programs and test bed developments that are being conducted state-wide, as well as in Canada, were noted to assist in gaining breadth of involvement and understanding of the types of deployments and their uses. This information assists other tasks in the development and justification of BIM use cases. It was observed that many of the programs use cases concern heavy congestion and traffic flow, driver identification and safety, wireless vehicle safety inspection, and commercial vehicle information exchanges.

The information in this document will be used in subsequent tasks including, Task 4 – Development of the BIM.