SAE INTERNATIONAL

SURFACE VEHICLE STANDARD

J2945™/C | JUN2022

Issued 2022-06

Requirements for Probe Data Collection Applications

RATIONALE

This standard provides a mechanism for vehicles to communicate environmental and sensor data to central repository. Anticipated data and situations include mobility data (understanding delays), roadway condition monitoring, adaptive signal control monitoring, local map development (including work zones), fleet vehicle maintenance, and third-party data. This proposed standard defines requirements to support V2I probe data messaging in a connected vehicle environment. The focus is on information exchanges between the infrastructure and connected vehicles.

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1. GENERAL

1.1 Scope

Connected vehicles can provide data from multiple sensors that monitor both the vehicle and the environment through which the vehicle is passing. The data, when shared, can be used to enhance and optimize transportation operations and management—specifically, traffic flow and infrastructure maintenance.

This document describes an interface between vehicle and infrastructure for collecting vehicle/probe data. That data may represent a single point in time or may be accumulated over defined periods of time or distance, or may be triggered based on circumstance. The purpose of this document is to define an interoperable means of collecting the vehicle/probe data in support of the use cases defined herein. There are many additional use cases that may be realized based on the interface defined in this document.

Note that vehicle diagnostics are not included within the scope of this document, but diagnostics-related features may be added to probe data in a future supplemental document.

1.2 References

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

1.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J2540-2	ITIS Phrase Lists (International Traveler Information Systems)
SAE J2735	V2X Communications Message Set Dictionary
SAE J2945	Dedicated Short Range Communication (DSRC) Systems Engineering Process Guidance for SAE J2945/X Documents and Common Design Concepts™
SAE J2945/3	Requirements for Road Weather Applications
SAE J2945/5	Service Specific Permissions and Security Guidelines for Connected Vehicle Applications
SAE J3161	LTE Vehicle-to-Everything (LTE-V2X) Deployment Profiles and Radio Parameters for Single Radio Channel JXXXX/x Coexistence

1.2.2 IEEE Publications

Available from IEEE Operations Center, 445 and 501 Hoes Lane, Piscataway, NJ 08854-4141, Tel: 732-981-0060, www.ieee.org.

IEEE Std 1233-1998 (R2002)	IEEE Guide for Developing System Requirements Specifications (Replaced by ISO/IEC/IEEE 29148:2011, https://www.iso.org/obp/ui/#iso:std:iso-iec-ieee:29148:ed-1:v1:en)
IEEE Std 1471-2000	IEEE Recommended Practice for Architectural Description for Software-Intensive Systems
IEEE Std 1609.2-2016	IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Security Services for Applications and Management Messages (As amended by IEEE Std 1609.2aTM-2017 and IEEE Std 1609.2bTM-2019)

IEEE Std 1609.3-2020 IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Networking Services

IEEE Std 1609.12-2019 IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Identifiers

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.

1.2.3 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/IEC 8824-2:1998 Information Technology - Abstract Syntax Notation One (ASN.1): Information Object Specification

ISO/IEC 8824-3:1998 Information Technology - Abstract Syntax Notation One (ASN.1): Constraint Specification

ISO/IEC 8824-4:1998 Information Technology - Abstract Syntax Notation One (ASN.1): Parameterization of ASN.1 Specifications

ISO/TS 19091 Intelligent Transport Systems - Cooperative ITS - Using V2I and I2V Communications for Applications Related to Signalized Intersections

ISO/TS 21177 Intelligent Transport Systems - ITS Station Security Services for Secure Session Establishment and Authentication Between Trusted Devices

1.2.4 Other Publications

Xu, J., Yang, K., Shao, Y.M., and Lu, G.Y. “An Experimental Study on Lateral Acceleration of Cars in Different Environments in Sichuan, Southwest China,” March 23, 2015.

NTCIP 1204 v04 National Transportation Communications for ITS Protocol, Environmental Sensor Station (ESS) Interface Protocol, Version 4

1.2.5 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

1.2.5.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J3067 Candidate Improvements to Dedicated Short Range Communications (DSRC) Message Set Dictionary [SAE J2735] Using Systems Engineering Methods

1.2.5.2 NIST Publications

Available from NIST, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070, Tel: 301-975-6478, www.nist.gov.

NIST SP800-122 Guide to Protecting the Confidentiality of Personally Identifiable Information (PII)

1.2.5.3 Other Publications

Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT), U.S. DOT ITS JPO, 1200 New Jersey Avenue, SE, Washington, DC 20590, http://local.iteris.com/arc-it/.

Specification of the Bluetooth® System (Bluetooth Core Specification), Bluetooth SIG.

INCOSE Systems Engineering Handbook v4, available from INCOSE publications, http://www.incose.org.

FCC 412172 D01, “Guidelines for Determining the Effective Radiated Power (ERP) and Equivalent Isotropically Radiated Power (EIRP) of an RF Transmitting System,” August 2015.

NTCIP 8002, “National Transportation Communications for ITS Protocol Content Outline for NTCIP 1200-Series Documents (for Standards Engineering Process (SEP) Content),” Annex B1 version v01, American Association of State Highway and Transportation Officials (AASHTO), 444 North Capitol Street, N.W., Suite 249, Washington, D.C. 20001, September 2016.

U.S. DOT, “Privacy Impact Assessment,” National Highway Traffic Safety Administration Notice of Proposed Rulemaking (NPRM) on V2V Communications, December 2016.

U.S. DOT, FHWA, Manual on Uniform Traffic Control Devices for Streets and Highways, 2009 Edition.

1.3 General Statements

The format of this document differs from the typical SAE document template for technical specifications in order to comply with NTCIP format.[1]

1.4 Terms and Definitions

1.4.1 AVERAGED RECORD

A probe data record that corresponds to a value that is derived by averaging multiple measurements (unweighted) over a time period or distance.

1.4.2 CONFIGURATION

The instructions provided by an entity in the infrastructure to vehicles that determine how probe data records are collected.

1.4.3 INSTANTANEOUS RECORD

A probe data record that corresponds to a measurement taken at an identified location and time. All records always include time, location, and velocity at the time of measurement. Multiple instantaneous records may be included in a probe data report (see 2.5.2.4).

1.4.4 PROBE DATA REPORT

A set of probe data provided by a vehicle or device consisting of one or more probe data records (see 2.5.2 and 1.4.3).

1.4.5 TRIGGER

A trigger is an event that causes a probe data recording to start (see 2.5.1.6).

[1] “NTCIP format” is used throughout this document to refer to the document structure defined in NTCIP 8002 Annex B1 version v01.

1.5 Abbreviations

The additional abbreviations and acronyms cited below are terms related to this standard (and of the other companion volumes and guides), unless specifically cited otherwise.

ABS	Anti-Lock Braking System
ARC-IT	Architecture Reference for Cooperative and Intelligent Transportation
BSM	Basic Safety Message
FHWA	The Federal Highway Administration
FR	Functional Requirement
GNSS	Global Navigation Satellite System
GSV	GNSS Satellites Visible
HDOP	Horizontal Dilution of Precision
IP	Internet Protocol
NRTM	Needs to Requirements Traceability Matrix
OBU	On-Board Unit
PoR	Percentage of Respondents
PDC	Probe Data Configuration
PDMS	Probe Data Management Subsystem
PDR	Probe Data Report
PPPP	ProSe Per-Packet Priority
RSM	Roadway Safety Message
RSU	Roadside Unit
SCMS	Security Credential Management System
TMC	Traffic Management Center
TSP	Transit Signal Priority
V2X	Vehicle-to-Everything Equipped Object
WSM	WAVE Short Message

2. CONCEPT OF OPERATIONS

2.1 Tutorial

A concept of operations describes a proposed system from the users' perspective. Typically, a concept of operations is used on a project to ensure that the system developers understand the users' needs. Within the application standards, the concept of operations documents the purpose of each feature for which an application standard supports an application. The concept of operations also serves as the starting point for users to select those features that may be appropriate for a specific application.

The concept of operations starts with a discussion of the current situation and issues that have led to the need to deploy systems within the scope of a standard and to the development of the standard itself. This discussion permits both potential users and system developers to understand the situation.

The concept of operations then documents key aspects of the proposed system, including:

a. Reference physical architecture: The reference physical architecture defines the overall context of the proposed system and defines which specific interfaces are addressed.

b. Architectural needs: The architectural needs discuss issues and needs relative to the system architecture.

c. Features: The features identify and describe the various functions that users may want probe data collection applications of a system to perform. These features are derived from the high-level user needs identified in the problem statement but are refined and organized into a more manageable structure that forms the basis of the traceability tables contained in 3.3.

Architectural needs and features are collectively called user needs. In 2.4 and 2.5, these user needs lead to the definition of the various functional requirements of a system with probe data collection applications. Basic systems engineering requires that:

a. Each user need traces to one or more functional requirement(s), and

b. Each functional requirement derives from at least one user need.

This traceability is shown in the needs to requirements traceability matrix (NRTM) in 3.3.2.6.

SAE J2945/C is intended for use in a broad range of prospective implementations involving probe data collection applications. Within the NRTM, each user need and requirement is identified as mandatory, optional, or conditional, and users may complete the NRTM to clearly define unique aspects of their implementation. Within SAE J2945/C, items marked mandatory are those that relate to the most basic functionality for a probe data collection application. For specific implementations, the user identifies those optional or conditional needs appropriate for a specific implementation.

Each requirement is presented in the requirements traceability matrix (RTM) in APPENDIX A, which defines how the requirement is fulfilled through the standardized dialogs and data entities defined in Sections 4, 5, and 6.

A conformant system may support additional features, as long as it is conformant with the requirements of SAE J2945/C.

2.2 Current Situation and Problem Statement

Based on the availability of probe data, numerous applications are contemplated by transportation management, each requiring a subset of the available information and each having their own set or requirements. Vehicles and devices can provide access to a diverse set of data including vehicle information such as wiper speed, stability control activation, and traction control loss. They can report on traffic signal encounters such as arrival on green, and track RF conditions detected by the radios. Information can be utilized by probe data applications to perform the following:

- Traffic signal performance reporting
- Highway system performance reporting

- Transit operation
- Road maintenance
- Road planning
- Environmental monitoring
- Communications performance monitoring
- Road weather monitoring
- Work zone detection and mapping
- Mobility assessment
- Infrastructure asset management

To make the necessary data available to these applications as well as many future services, SAE J2945/C sets the requirements for information exchanges between the infrastructure and connected vehicles/devices.

2.3 Reference Physical Architecture

Figure 1 represents an overview of what the overall system may consist of, and what information may be applicable for each interface. Within the system, a source for data may be any vehicle, including fleet, commercial, and personal vehicles or devices.

The major components of the architecture include:

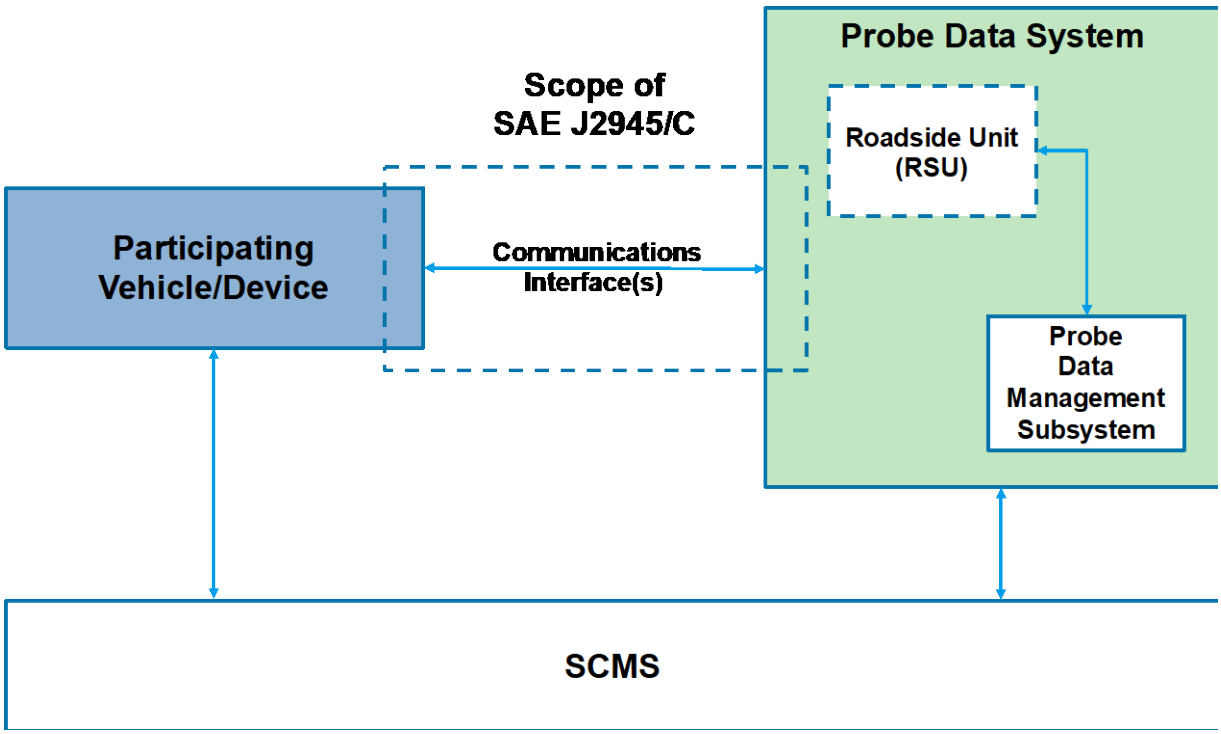


Figure 1 - Reference physical architecture

For this document, the probe data system encompasses RSUs and the probe data management subsystem (PDMS), hereon referred to as “the system.” The probe data system may also be accessed via other mediums such as cellular or other internet protocol-based interfaces.

- Roadside unit (RSU): A subsystem installed along the roadway used to exchange data with vehicles. RSUs are optional in the system and alternative interfaces may be used in place of an RSU-based interface. Note that an RSU may support additional functionality beyond probe data collection, such as monitoring basic safety messages and providing other mobility and safety information services to vehicles, which is outside the scope of this document.

- Probe data management subsystem (PDMS): A subsystem used to process and manage the probe data. The PDMS may be attached to or integrated within a traffic management center (TMC) or other types of central systems used to collect, process, and distribute surface transportation system information.

- Vehicle/device: A connected vehicle, on-board unit (OBU) or other mobile device that interacts with the System, hereon referred to as vehicle. Participation in the system is optional.

- Communications interface(s): The communications interface(s) is between the vehicle and the system. The interface to the PDMS may be via an RSU or other alternatives, such as a cellular network.

- Security credential management system (SCMS): The system interfaces to an SCMS to obtain certificates used to ensure the security of the data exchanged over the communications interfaces.

The probe data configuration and reporting concept is illustrated in Figure 2. The probe data configuration is sent to the vehicle by the system, either via RSU (4.2.1.1) or query from a connected vehicle (4.2.1.2) that is a participating vehicle/device. Data is uploaded at the end of a temporal or geographical boundary as specified in the configuration.

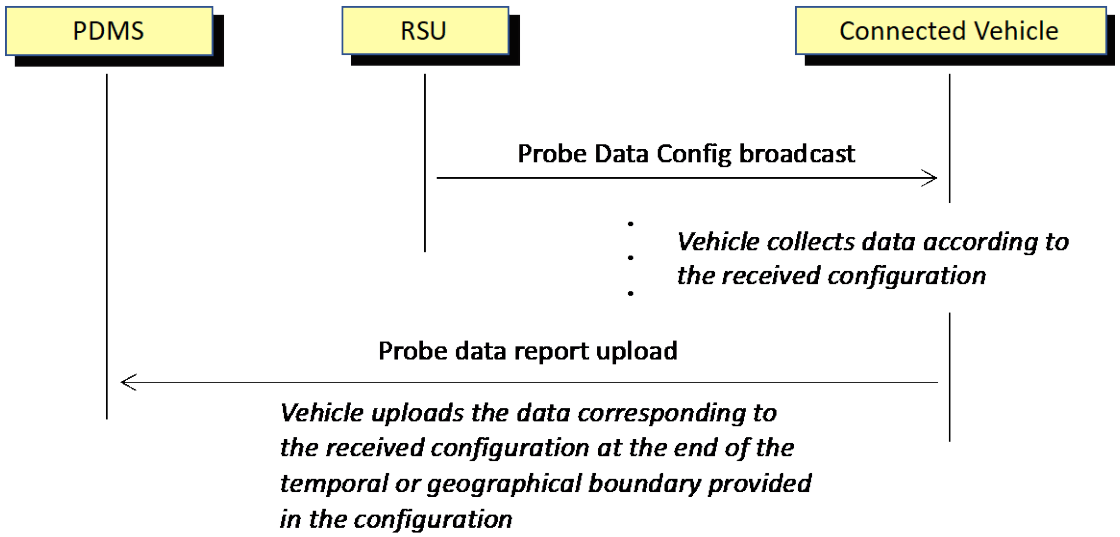


Figure 2 - Probe data configuration and reporting data flow

Note that probe data configuration may also be retrieved by the vehicle using a query to the PDMS. This approach is useful when using a traditional cellular interface (see 4.2.1.2).

Figure 3 illustrates the geographic nature of the probe data collection. The probe data configuration includes a configuration boundary that defines the direction of travel and area over which the data is collected. Data may be collected periodically using intervals of time or distance. The configuration is received by the vehicle as it approaches the boundary, and after crossing the boundary, the vehicle begins collecting data (e.g., speed). The vehicle collects data according to the configuration interval, and after exiting the boundary, the vehicle uploads its corresponding data to the PDMS. If a RSU is not available to upload the data after exiting the boundary, a traditional cellular interface can be used.

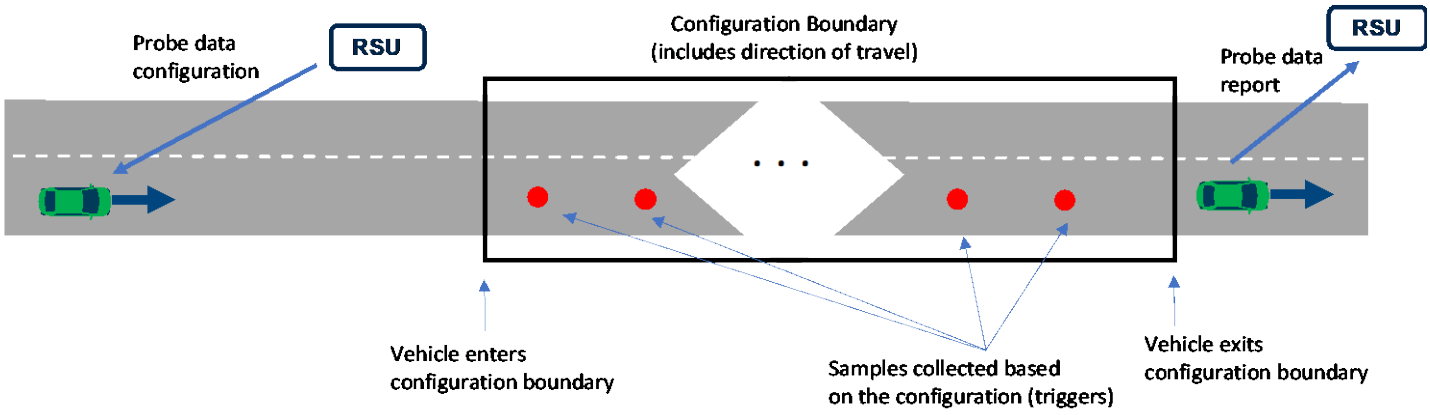


Figure 3 - Geographical illustration of probe data configuration and reporting

2.4 Architectural Needs

SAE J2945/C addresses the interfaces between connected vehicles or mobile devices and transportation management centers. An RSU may broadcast configuration data to vehicles, however the communications system also enables a direct connection between a vehicle and the probe data management subsystem using an IP-based interface.

2.4.1 Communications Interfaces

2.4.1.1 Configuration Interface

The PDMS needs to periodically provide the probe data configuration to vehicles, as determined by the transportation system operator.

2.4.1.2 Data Collection Interface

The PDMS needs to receive probe data reports from vehicles. The data collection interface and configuration interface may use the same functional lower-layer interface. The entity that receives the probe data need not be the same as the entity providing the configuration.

2.5 Features

A PDM may be the central source of information for a diverse set of services and applications. These services may each have their unique set of requirements and may need to gather data from vehicles and/or probes. To assure that the needed information is captured and transferred, various features are to be supported by a probe data collection application. These features are divided as follows:

a. Configure probe data recording features

b. Receive probe data features

2.5.1 Configure Probe Data Recording

The probe data collection management subsystem is able to configure the probe data records to be collected by the vehicle. Multiple configurations may be concurrently processed by vehicles. Note that the features specified in this document are optional for vehicles; vehicles may not collect as much data as requested by the transportation system operator. A transportation system operator may request a configuration that covers a large time frame (e.g., several months), but in order to support privacy, different durations may be supported by different types of vehicles.

2.5.1.1 Configuration Descriptor

A transportation system operator needs to be able to set a configuration identifier for the probe data collection configuration including the destination for the data (how a vehicle reaches the PDMS or publishes a probe data report). This enables a vehicle to include the identifier when it provides the collected data, so the system knows which configuration the received probe data corresponds to and the destination (e.g., a host IP address) to use to transfer applicable data to the proper agency/operator.

2.5.1.2 Configuration Temporal Boundary

A transportation system operator needs to be able to set the time interval over which the probe data is collected. The intent is that the probe data records are provided to the PDMS after the configuration boundary expires. The temporal boundary may also be set to be recurring.

2.5.1.3 Configuration Geographical Boundary

A transportation system operator needs to specify a region or section of a roadway over which data is to be collected. Examples include environmental monitoring of a high traffic area by estimating fuel efficiency of vehicles travelling in the area.

2.5.1.4 Configuration Total Distance Traveled

A transportation system operator needs to specify the distance of a path over which data is to be collected. Examples include gathering information about travel delays over certain parts of a roadway.

2.5.1.5 Maximum Age of Data

A transportation system operator needs to be able to limit the age of the collected probe data. After the maximum age expires, the data corresponding to the configuration will likely be purged from the vehicle's records. This allows the transportation system operator to avoid collecting outdated information and limit the duration over which the data is collected.

2.5.1.6 Triggers

A transportation system operator needs to be able to specify triggers that result in collection of data. A trigger may be an event that leads to recording and/or transmittal of instantaneous records or initiate the process of gathering of averaged or summary records.

Triggers may set conditions such as occurrence of certain vehicle events, roadway events, and RF communication events, which start the collection of relevant information. The results, per the configuration, reported by the vehicle, may be instantaneous, summarized, or averaged over time, distance, or a combination of the two.

Applications such as road weather monitoring may only need localized weather-related data if certain weather conditions are in effect, conditions such as a high rate of rainfall that leads to high speeds of the wiper blade could be the triggering event for data gathering at a vehicle. Similarly, a roadway event such as a traffic signal light being out, may be the triggering event. Communication system performance event may include certain changes in channel quality or bandwidth occupancy. These triggering events can be specified as part of the configuration sent to vehicle(s).

Applications such as fuel efficiency may need averaging of data over certain period or distance, or summarization after certain time lapse or distance travelled. Similarly, the average travel time over a defined region may be of interest to a transportation system operator.

2.5.1.7 Vehicle Type and Characteristics

A transportation system operator needs to be able to control the type of vehicle to which the configuration applies (e.g., light duty, truck, bus, etc.). This allows a transportation operator to collect data from specific vehicle types (e.g., commercial vehicles/heavy trucks). Additional characteristics such as vehicle size, weight, and number of occupants may also be collected.

2.5.2 Receive Probe Data Reports

This section contains the system user needs for receiving probe data reports from vehicles, which may contain one or more probe data records.

2.5.2.1 Receive Configuration Identifier

The PDMS needs to receive a configuration identifier that indicates the configuration to which the probe data records correspond.

Note that the vehicle/device operators and owners may desire to exclude any information that can be used for law enforcement; therefore, a subset of requested information/configuration may be provided by the vehicle (not all requested information is guaranteed to be included in a probe data report uploaded in response to a probe data configuration).

2.5.2.2 Received Report Characteristics

The PDMS needs be able to receive characteristics associated with each report, including vehicle class or device type, vehicle size, vehicle weight, or vehicle passenger count (number of occupants).

2.5.2.3 Contents of Record(s)

The PDMS needs to be able receive the probe data metrics and the records indicated by the corresponding configuration (see 2.5.1). This ensures the system can receive what it requested. Note that each record will always include the time stamp, position, position accuracy, and velocity of the vehicle at the instance of a recording.

2.5.2.4 Instantaneous Record(s)

The PDMS may need access to real-time information from a vehicle. Vehicle related information such as hard braking and traction control loss are random and rare; therefore, they may need to be relayed upon occurrence as part of an instantaneous record. The transportation system operator may also want to collect periodic information at the end of a time or distance interval.

2.5.2.4.1 Time of Instantaneous Record(s)

For instantaneous records, the PDMS needs the date and time when a vehicle recorded the probe data.

2.5.2.4.2 Location of Instantaneous Record(s)

For instantaneous records, the PDMS needs the 3D location at which the vehicle recorded the probe data.

2.5.2.4.3 Velocity of Instantaneous Record(s)

For instantaneous records, the PDMS needs the velocity at each location at which the vehicle recorded the probe data.

2.5.2.4.4 Content of Instantaneous Record(s)

The PDMS will need to receive the instantaneous records as defined in a requested configuration.

2.5.2.5 Averaged and Summary Records

The PDMS may need access to certain information that is averaged over time and/or distance. Information such as speed, fuel efficiency, or time stopped may be averaged over certain time period or distant travelled, leading to information that has been averaged over the specified time, distance, or both.

2.5.2.5.1 Start Time

For averaged records, the PDMS needs the time the probe data recording started.

2.5.2.5.2 End Time

For averaged records, the PDMS needs the time the probe data recording stopped.

2.5.2.5.3 Start Location

For averaged records, the PDMS needs the location where the probe data recording started.

2.5.2.5.4 End Location

For averaged records, the PDMS needs the location where the probe data recording stopped.

2.5.2.5.5 Content of Averaged and Summary Record(s)

The PDMS will need to receive the averaged and summary records as defined in a requested configuration.

2.6 Security

The general security needs for these Use Cases are described in this section. These security constraints reflect the sensitive nature of certain data, which is necessary to protect (e.g., personally identifiable information).

2.6.1 Data Source Authenticity and Authorization

The system needs to provide a mechanism to authenticate the source of and verify that it is authorized to send such data.

2.6.2 Data Integrity and Availability

The system needs to provide a mechanism to verify that data has not been changed between sending by the entity that produced the data and reception by the entity that consumes the data.

2.6.3 User Privacy

Participation in the system needs to be optional, with personally identifiable information not being stored, and data not being consumed by unauthorized users.

2.7 Operational Policies and Constraints

This section describes the needs related to the amount of data collected and the type of data collected.

2.7.1 Percentage of Respondents (PoR)

A transportation system operator needs to be able to control the percentage of vehicles that respond to the probe data configuration. This is used to limit the number of vehicles that report probe data to the PDMS according to the desired percentage. This prevents the system from being overloaded in areas with a high concentration of vehicles.

For example, in a rush-hour period where traffic is heavy, a transportation system operator may request that only 10% of vehicles respond. This smaller percentage makes the amount of data collected manageable and prevents overloading the underlying communications interface(s).

2.8 Relationship to the Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) [Informative]

The following are architecture flows from ARC-IT (version 8.3) that are addressed by SAE J2945/C. Vehicles are represented by either vehicle on-board equipment (VOBE), transit vehicle on-board equipment (TOBE), or maintenance and construction vehicle on-board equipment (MCOBE). Roadside units are represented by connected vehicle roadside equipment (CVRE). Centers including transportation information center (TIC), emission management center, and traffic management center (TMC), access archived data system (ADS) to capture required data.

- Center data collection: Collects and stores information that is created in the course of center operations. This data can be used directly by operations personnel or it can be made available to other data users and archives in the region.

- Work zone safety application info: Work zone safety application configuration data and warning parameters and thresholds. This includes work zone configuration including geofenced crew areas and travel lanes that provide a safety boundary between work zone personnel and passing vehicles. This flow also supports remote control of the application so the application can be taken offline, reset, or restarted.

- Vehicle environmental data: Data from vehicle safety and convenience systems that can be used to estimate environmental and infrastructure conditions, including measured air temperature, exterior light status, wiper status, sun sensor status, rain sensor status, traction control status, anti-lock brake status, vertical acceleration, and other collected vehicle system status and sensor information. The collected data is reported along with the location, heading, and time that the data was collected. Both current data and snapshots of recent events (e.g., traction control or anti-lock brake system activations) may be reported.

- Emissions situation data: Emissions-related data as measured and reported by connected vehicles. This flow carries aggregated and filtered data including average and current emissions reported by vehicles as well as associated data (vehicle profiles and speeds) that can be used to estimate aggregate emissions.

- Mobile source emissions data: Measured and/or estimated emissions at point locations from mobile sources including cars and light trucks, heavy trucks and buses. Where applicable, this flow may also include emissions measures or estimates from non-road engines and portable equipment at the location.

- Transit vehicle loading data: Data collected on board the transit vehicle relating to passenger boarding and alighting.

- Vehicle situation data: This flow represents vehicle snapshots that may be provided by the vehicle to support traffic and environmental conditions monitoring. Snapshots are collected by the vehicle for specific events (e.g., when a sensor exceeds a threshold) or periodically and reported based on control parameters when communications is available. Traffic-related data includes snapshots of measured speed and heading and events including starts and stops, speed changes, and other vehicle control events. Environmental data may include measured air temperature, exterior light status, wiper status, sun sensor status, rain sensor status, traction control status, anti-lock brake status, and other collected vehicle system status and sensor information. The collected data is reported along with the location, heading, and time that the data was collected.

- Vehicle control event: Notification that the vehicle has performed an emergency action that could impact the safety of surrounding vehicles. This includes hard braking and activation of traction/stability control systems or other actions that warrant immediate notification of surrounding vehicles. The information flow conveys the vehicle's position, heading, speed, acceleration, transmission, steering wheel angle, braking status, size information, and trajectory.

- Vehicle hazard event: Notification of a potential hazard that is detected by the vehicle, including hazards posed by the vehicle itself. Self-reported hazards include notification that the vehicle is being operated in an unsafe manner or is stopped in the travel lanes or on the shoulder. Detected hazards include unequipped vehicles operating unsafely, traffic queues, and other entities (people, animals, debris, other obstacles) in the travel lanes. It includes vehicle location and status, path, current control actions, and additional information on the detected hazard, if applicable

- Vehicle situation data parameters: A request for vehicle situation data that includes parameters used to control the data that is reported and the flow of data reported by the vehicle. This flow identifies the type of data/snapshots that are requested and reporting parameters such as snapshot frequency, filtering criteria (data thresholds for reporting), and reporting interval.

Table 1 shows how these architecture flows are mapped to the service packages providing ITS services that are supported by the user needs in 2.5. A service package is the subset of the national ITS architecture that provides a specific ITS service.

Table 1 - National architecture mapping (V2I)

User Need Group	Source	Architecture Flow	Destination	Service Packages
Data collection	VOBE TOBE MCOBE	Center data collection	ADS	DM02: Performance monitoring
Data collection	VOBE TOBE MCOBE	Work zone safety monitoring	ADS	MC07: Work zone safety monitoring
Data collection	VOBE TOBE MCOBE	Vehicle environmental monitoring	ADS	MC09: Infrastructure monitoring ST01: Emission monitoring WX01: Weather data collection WX03: Spot weather impact and warning
Data collection	TOBE	Transit vehicle loading data	ADS	PT07: Transit passenger counting
Data collection	VOBE TOBE MCOBE	Traffic situation data	ADS	TM02: Vehicle-based traffic surveillance
Data collection	VOBE TOBE MCOBE	Vehicle hazard event	ADS	VS03: Situational awareness
Data collection	ADS	Vehicle situation data parameters	VOBE TOBE MCOBE	DM02: Performance monitoring MC07: Work zone safety monitoring MC09: Infrastructure monitoring PT07: Transit passenger counting ST01: Emissions monitoring TM02: Vehicle-based traffic surveillance VS03: Situational awareness

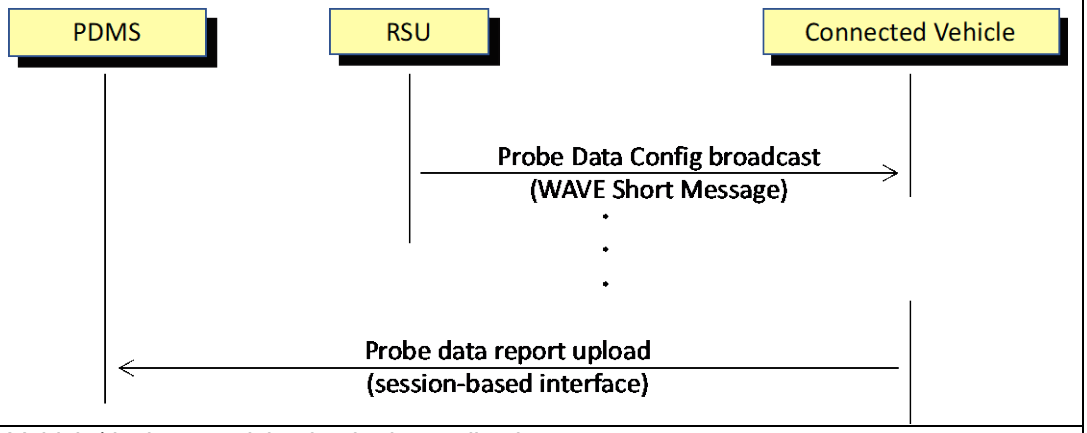
2.9 Operational Scenarios [Informative]

The operational scenarios in this standard consist of example use cases associated with the identified needs of different agencies. The operational scenarios do not imply any specific requirements or design. All operational scenarios presented are initiated by PDMS transmittal of configuration(s) to vehicles and probes consisting of (1) the type of vehicle(s) to be involved in data gathering; (2) the condition(s) under which the capture to start, continue, and stop; (3) the data to be captured; and (4) information on destination for transfer of captured data.

The transmittal of configuration information may occur directly or through the RSU. Alternatives to communicating via RSUs are permitted by this document. In addition, the SCMS may interface to third party sensors or data servers. These interfaces are outside the scope of this document.

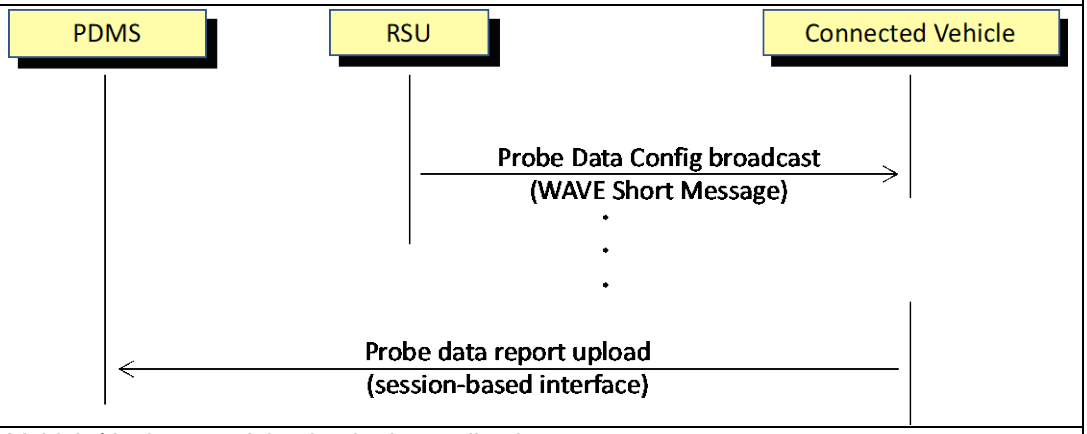
2.9.1 Traffic Signal Performance Reporting

Table 2 - Traffic signal performance reporting

Use Case Name	Traffic signal performance reporting.
Category	Safety, mobility, and environment.
Infrastructure Role	Collection of probe data.
Short Description	Probe data can be used to indicate to infrastructure, for example, time spent at stop lights or arrival on green information leading to compilation of statistical data on impact of traffic signals on traffic flow. Data may be gathered to confirm the operation of connected intersections.
Goal	Improved traffic signal timing plans.
Constraints	Number of vehicles/devices collecting and providing probe data along or near a roadway segment. Accuracy/completeness of the probe data being reported. Security solution in place to enable authentication of data sources and secure data exchange.
Geographic Scope	Localized to roadways where vehicles/devices are equipped to report probe data.
Actors	Vehicles/devices. Roadside units (RSU) or other communications systems (e.g., cellular). PDMS.
Illustration	
Preconditions	Vehicle/devices participating in data collection.
Main Flow	The vehicle/device collects probe-related data. The vehicle/device transmits the traffic signal performance data to the PDMS directly or through the RSU. The PDMS receives traffic signal performance data from the vehicle/device. The PDMS may also collect information from third party traffic information providers. The PDMS processes the probe data received from vehicles/devices and aggregates the data by road segment or intersection. Aggregated probe data is stored by the PDMS for future use in optimizing traffic signal timing plans.
Alternate Flow(s)	The data may also be collected from participating vehicles via alternative communications interfaces such as a cellular system.
Post-Conditions	Improved traffic flow through heavy use corridors.
Information Requirements	Interval-based events specifying data collection in certain areas and/or at certain time of day. For instance, fuel consumption in the identified area may be of importance for the requesting agency. Vehicle events such as time and location of where the vehicle speed falls below expected speeds. Roadway events including timing and speed of arrival on green and arrival on red.
Source Documents/References	https://traffic.dot.ga.gov/ATSPM/Images/ATSPM_Reporting_Details.pdf https://www.fhwa.dot.gov/innovation/everydaycounts/edc_4/atspm.cfm

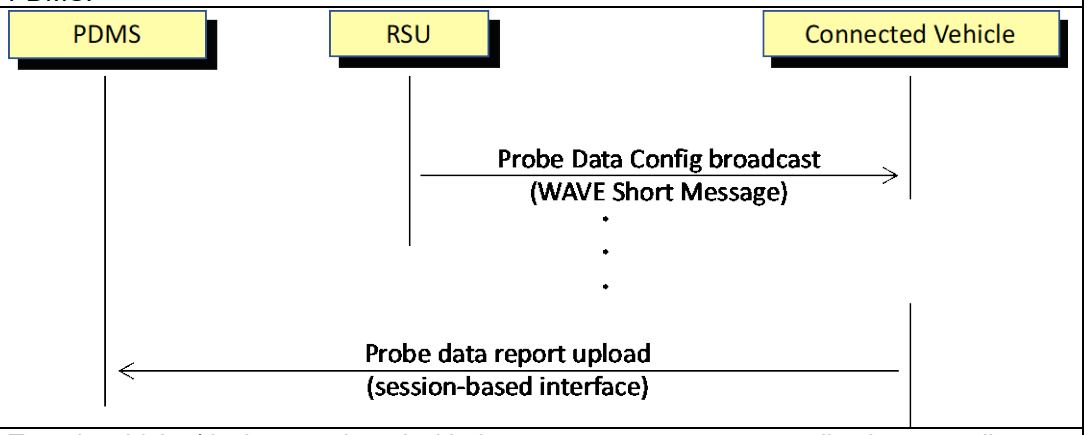
2.9.2 Highway System Performance Reporting

Table 3 - Highway system performance reporting

Use Case Name	Highway system performance reporting.
Category	Safety, mobility, and environment.
Infrastructure Role	Collection of probe data.
Short Description	Probe data can be used to indicate to infrastructure segments with unexpected congestion. For example, low speed and resumed speed data from vehicles on the freeway can be used to pinpoint trouble areas.
Goal	Improved ramp meter timing plans and thereby improved traffic flow
Constraints	Number of vehicles/devices collecting and providing probe data along the stretches of freeway of interest to requesting PDMS. Accuracy/completeness of the probe data being reported. Security solution in place to enable authentication of data sources and secure data exchange.
Geographic Scope	Localized to segments of freeway of interest to requesting PDMS.
Actors	Vehicles/devices. Roadside units (RSU) or other communications systems (e.g., cellular). PDMS.
Illustration	
Preconditions	Vehicle/devices participating in data collection.
Main Flow	The vehicle/device collects probe-related data. The vehicle/device transmits the collected data to the PDMS directly or through the RSU. The PDMS receives data from the vehicle/device. The PDMS may also collect information from third party traffic information providers. The PDMS processes the probe data received from vehicles/devices and aggregates the data by highway segment or intersection. Aggregated probe data is stored by the PDMS for future use in optimizing ramp meter timing plans.
Alternate Flow(s)	The data may also be collected from participating vehicles via alternative communications interfaces such as a cellular system.
Post-Conditions	Improved traffic flow through highways.
Information Requirements	Interval-based events including fuel consumption, time to travel through spatial region, etc. Vehicle events such as low speed and resumed speed. Roadway events such as incident detection that allow categorization of the captured data. Averaged records including average speed over the configuration region, average emission, average fuel consumption, etc. Summary records such as distance travelled over a certain period of time.

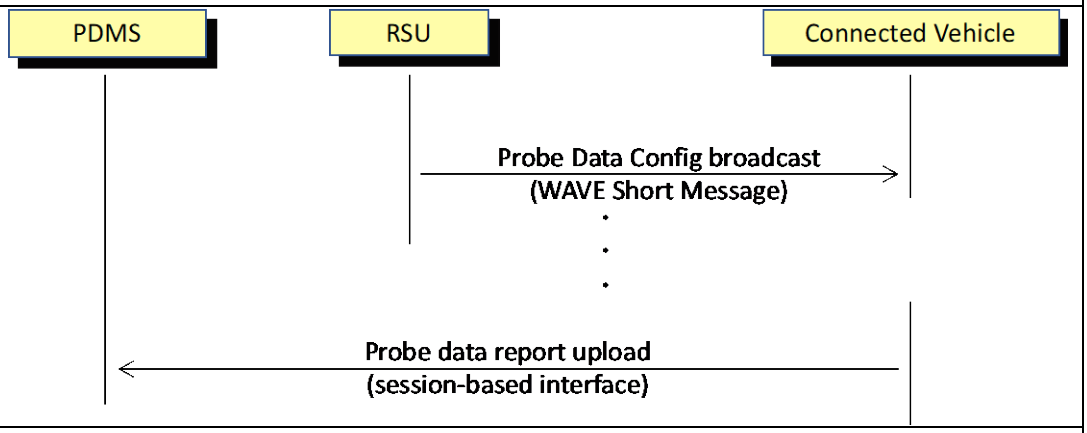
2.9.3 Transit Operation

Table 4 - Transit operation

Use Case Name	Transit operation.
Category	Safety, mobility, and environment.
Infrastructure Role	Collection of probe data.
Short Description	Probe data can be used to indicate to transit authorities, for example, flow of transit vehicles through traffic, ridership volumes by segment, or driver behavior.
Goal	Route optimization and efficiency, improve environment, and satisfied ridership.
Constraints	Number of transit vehicles/devices collecting and providing probe data. Accuracy/completeness of the probe data being reported. Security solution in place to enable authentication of data sources and secure data exchange.
Geographic Scope	Localized to segments of interest to requesting transit authority.
Actors	Transit vehicles/devices. Roadside units (RSU) or other communications systems (e.g., cellular). PDMS.
Illustration	
Preconditions	Transit vehicles/devices equipped with the necessary sensors or applications to collect the vehicle information including ridership data.
Main Flow	The transit vehicle/device collects probe-related data. The transmit vehicle/device transmits the captured data to the PDMS directly or through the RSU. The PDMS receives data from the transit vehicle/device. The PDMS may also collect information from third party traffic information providers. The PDMS processes the probe data received from transit vehicles/devices and aggregates the data by segments specified by transit authority. Aggregated probe data is relayed to the requesting transit authority.
Alternate Flow(s)	The data may also be collected from participating vehicles via alternative communications interfaces such as a cellular system.
Post-Conditions	Improved transit ridership, efficiency, and emissions.
Information Requirements	Interval-based events. Vehicle events. Roadway events such as traffic signal encounters. Averaged records such as average fuel consumption and average emissions. Summary records including total time stopped, and duration of each stop.

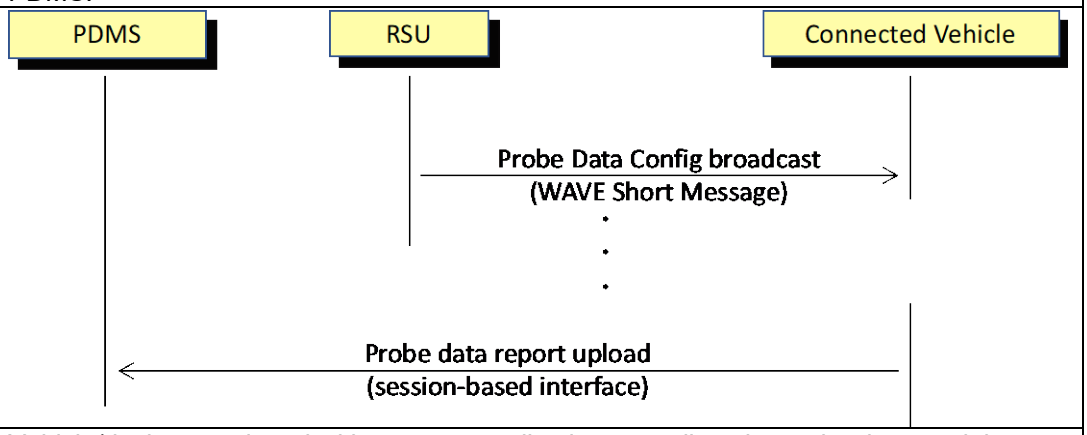
2.9.4 Road Maintenance

Table 5 - Road maintenance

Use Case Name	Road maintenance.
Category	Safety and mobility.
Infrastructure Role	Collection of probe data.
Short Description	Probe data can be used to monitor impact of road maintenance in real time, proactively reroute traffic and minimize/avoid congestions due to road maintenance.
Goal	Improved traffic flow and availability of real-time data to alert impacted travelers.
Constraints	Number of vehicles/devices in impacted areas capable of collecting and providing probe data. Accuracy/completeness of the probe data being reported. Security solution in place to enable authentication of data sources and secure data exchange.
Geographic Scope	Localized to areas with planned road maintenance.
Actors	All vehicles/devices. Roadside units (RSU) or other communications systems (e.g., cellular). PDMS.
Illustration	
Preconditions	Vehicle/devices participating in data collection and having the sensors required for certain type of data such a wheel-based accelerometer for detection of adverse road surface conditions.
Main Flow	The vehicle/device collects probe-related data. The vehicle/device transmits specified data gathered in the identified geographical area to the PDMS directly or through the RSU. The PDMS receives data from the vehicle/device. The PDMS may also collect information from 3rd party traffic information providers. The PDMS processes the probe data received from vehicles/devices and provides information to traffic management entities.
Alternate Flow(s)	The data may also be collected from participating vehicles via alternative communications interfaces such as a cellular system.
Post-Conditions	Improved traffic and safety.
Information Requirements	Interval-based events around the impacted area and collecting movement data from vehicles. Vehicle events such as low speed and resumed speed could be monitored specifically in the defined region. Roadway events such as obstacle detection or adverse road surface conditions can be captured.

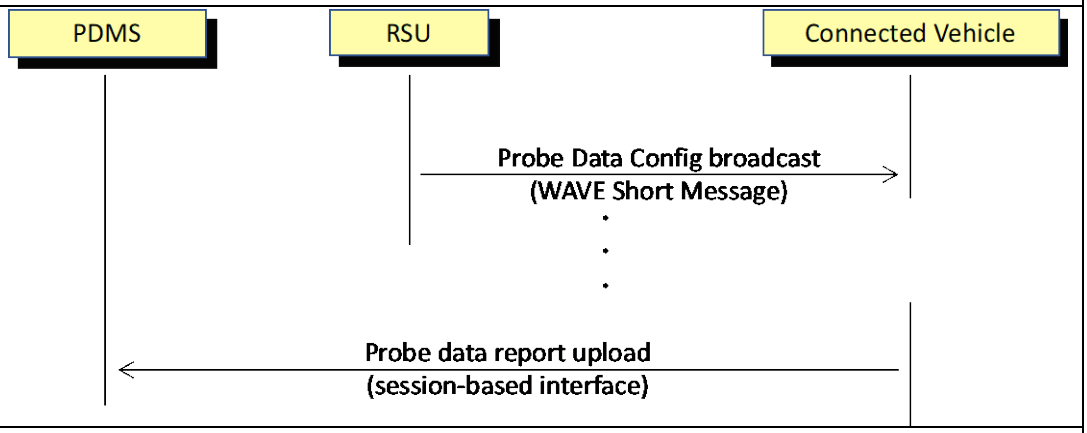
2.9.5 Road Planning

Table 6 - Road planning

Use Case Name	Road planning.
Category	Safety and mobility.
Infrastructure Role	Collection of probe data.
Short Description	Probe data can be used to identify map anomalies and roadway improvements. For example the probe may detect lane geometry inconsistency or unexpected closure.
Goal	Improved roadways and supporting software, i.e., maps.
Constraints	Number of vehicles/devices capable of collecting and providing probe data. Accuracy/completeness of the probe data being reported. Security solution in place to enable authentication of data sources and secure data exchange.
Geographic Scope	Everywhere.
Actors	All vehicles/devices. Roadside units (RSU) or other communications systems (e.g., cellular). PDMS.
Illustration	
Preconditions	Vehicle/devices equipped with maps or applications to collect the probe data, and the interface to report it.
Main Flow	The vehicle/device collects probe-related data. The vehicle/device transmits specified data to the PDMS directly or through the RSU. The PDMS receives data from the vehicle/device, processes the probe data received. Aggregated probe data is stored by the PDMS for future use by roadways design entities in fixing roads and corresponding databases.
Alternate Flow(s)	The data may also be collected from participating vehicles via alternative communications interfaces such as a cellular system.
Post-Conditions	Improved infrastructure, traffic, and safety.
Information Requirements	Roadway events such as low road sign retro reflectivity, low lane marking retro reflectivity, or lane geometry inconsistency with on-board map can help designers in defining improvements to be made. Information on adverse road surface condition, such as location of potholes, will lead to more timely and efficient repairs.

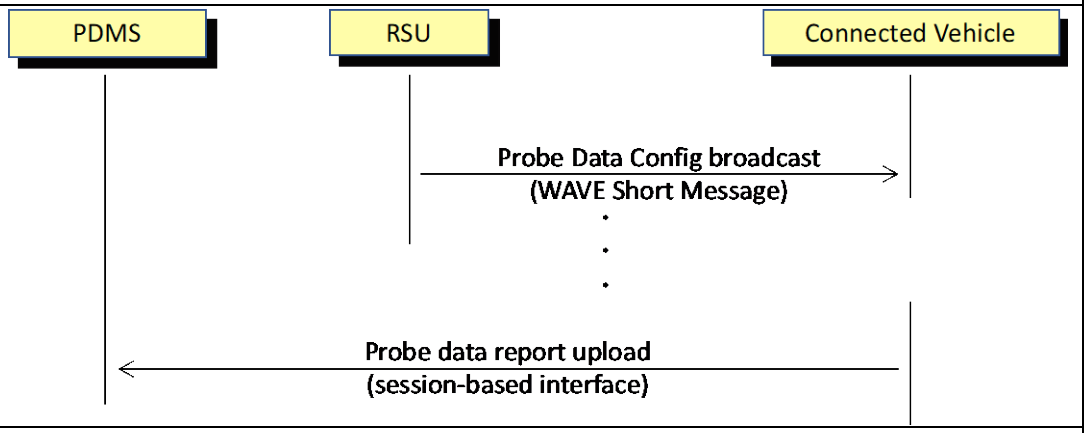
2.9.6 Environmental Monitoring

Table 7 - Environmental monitoring

Use Case Name	Environmental monitoring.
Category	Mobility and environment.
Infrastructure Role	Collection of probe data.
Short Description	Probe data can be used to measure fuel consumption and emissions for different types of vehicles used in optimization of traffic signal timing for best flow and least environmental impact. For example, the probe may gather average emission of certain chemicals while also capturing speed of vehicle through a segment of the city.
Goal	Improved environment and mobility.
Constraints	Number of vehicles/devices equipped with sensors capable of collecting and providing probe data. Accuracy/completeness of the probe data being reported. Security solution in place to enable authentication of data sources and secure data exchange.
Geographic Scope	Defined geographical areas.
Actors	Vehicles/devices equipped with environmental sensors. Roadside units (RSU) or other communications systems (e.g., cellular). PDMS.
Illustration	
Preconditions	Vehicle/devices equipped with environmental sensors providing data to be collected by the probe.
Main Flow	The vehicle/device collects probe-related data. The vehicle/device transmits specified data to the PDMS directly or through the RSU. The PDMS receives data from the vehicle/device, processes the probe data received from vehicles/devices and provides information to traffic management entities.
Alternate Flow(s)	The data may also be collected from participating vehicles via alternative communications interfaces such as a cellular system.
Post-Conditions	Improved traffic and environmental conditions.
Information Requirements	Averaged and summary results related to fuel consumption and emissions.

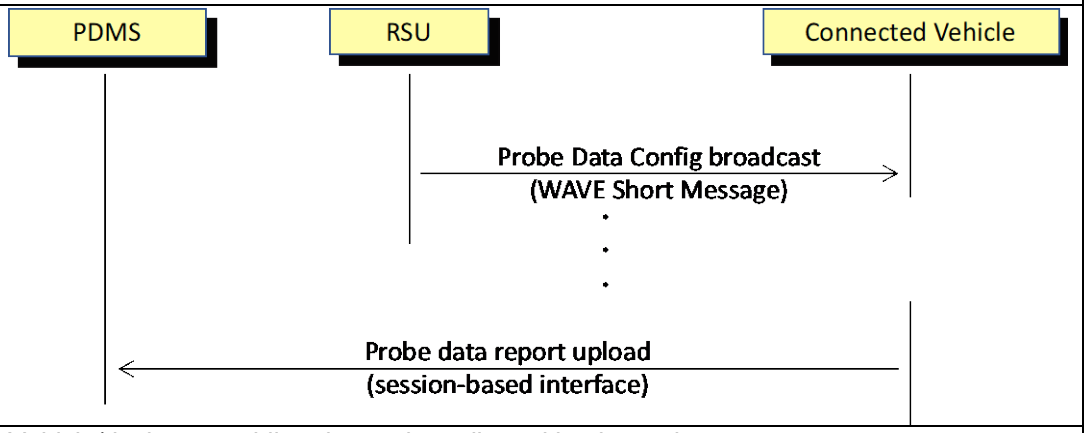
2.9.7 Communications Performance Monitoring

Table 8 - Communications performance monitoring

Use Case Name	Communications performance monitoring.
Category	Infrastructure.
Infrastructure Role	Collection of probe data.
Short Description	Probe data can be used to identify location and level of RF and GNSS anomalies.
Goal	Improved infrastructure.
Constraints	Number of vehicles/devices capable of collecting and providing probe data. Accuracy/completeness of the probe data being reported. Security solution in place to enable authentication of data sources and secure data exchange.
Geographic Scope	Everywhere or in areas identified as having potential communication issues.
Actors	All vehicles/devices. Roadside units (RSU) or other communications systems (e.g., cellular). PDMS.
Illustration	
Preconditions	Vehicle/devices capable of collecting and reporting probe data.
Main Flow	The vehicle/device collects probe-related data. The vehicle/device transmits specified data to the PDMS directly or through the RSU. The PDMS receives data from the vehicle/device, processes the probe data received. Aggregated probe data is stored by the PDMS for engineering analysis.
Alternate Flow(s)	The data may also be collected from participating vehicles via alternative communications interfaces such as a cellular system.
Post-Conditions	Improved infrastructure.
Information Requirements	Communications system performance events.

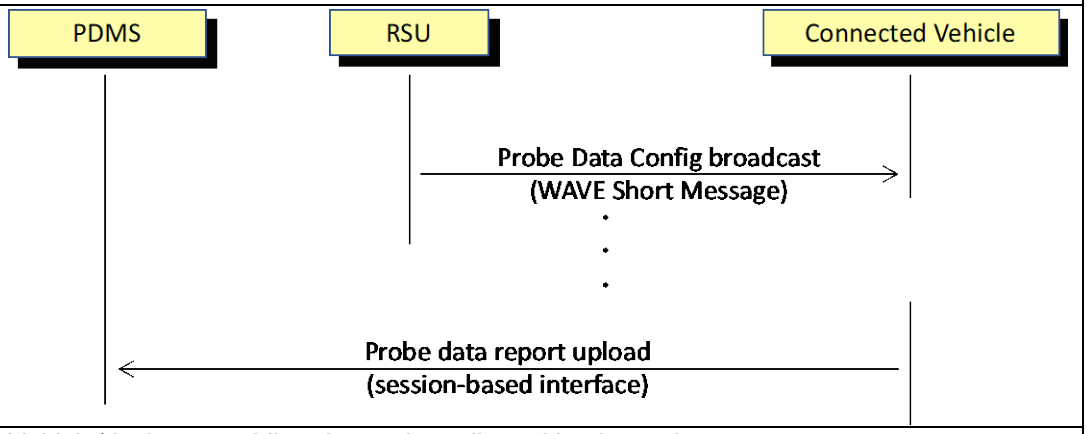
2.9.8 Road Weather Monitoring

Table 9 - Road weather monitoring

Use Case Name	Road weather monitoring.
Category	Mobility and safety.
Infrastructure Role	Collection of weather-related probe data.
Short Description	Probe data can be used to report local weather conditions such as heavy rain, fog, wind, snow, etc.
Goal	Improved mobility and safety through use of real-time and localized information.
Constraints	Number of vehicles/devices capable of collecting and providing probe data. Accuracy/completeness of the probe data being reported. Security solution in place to enable authentication of data sources and secure data exchange.
Geographic Scope	Defined geographical area.
Actors	Vehicles/devices. Roadside units (RSU) or other communications systems (e.g., cellular). PDMS.
Illustration	
Preconditions	Vehicle/devices providing data to be collected by the probe.
Main Flow	The vehicle/device collects weather-related probe data. The vehicle/device transmits specified data to the PDMS directly or through the RSU. The PDMS receives data from the vehicle/device and provides relevant information to traffic management entities for relay of alerts to drivers.
Alternate Flow(s)	The data may also be collected from participating vehicles via alternative communications interfaces such as a cellular system.
Post-Conditions	Improved traffic and safety during periods of bad weather.
Information Requirements	Vehicle events.
Source Documents/References	SAE J2945/3.

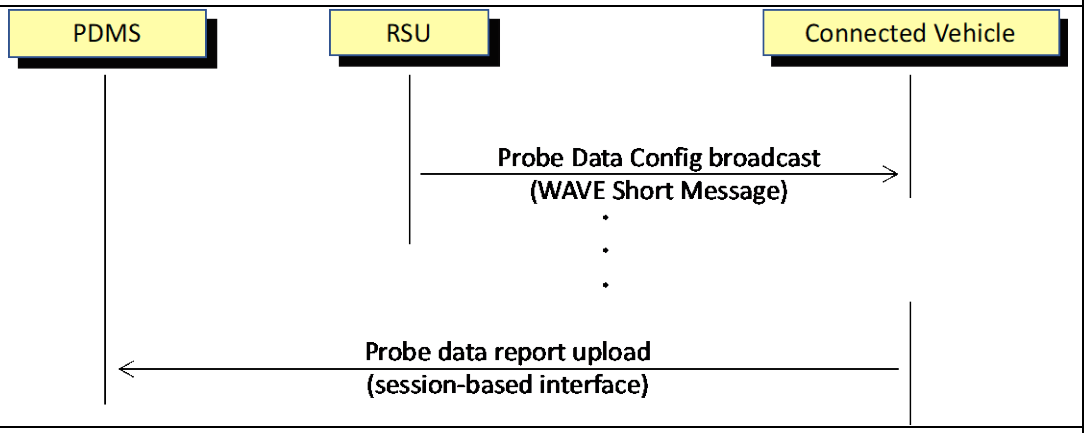
2.9.9 Work Zone Detection and Mapping

Table 10 - Work zone detection and mapping

Use Case Name	Work zone detection and mapping.
Category	Mobility and safety.
Infrastructure Role	Collection of probe data.
Short Description	Probe data can be used to report local road conditions such as slowness of travel due to road closures. High granularity of captured probe data could provide information to update map of the impacted areas automatically and lead to more accurate information for travelers.
Goal	Improved mobility and safety.
Constraints	Number of vehicles/devices participating in collecting and providing probe data. Accuracy/completeness of the probe data being reported. Security solution in place to enable authentication of data sources and secure data exchange.
Geographic Scope	Everywhere.
Actors	Vehicles/devices. Roadside units (RSU) or other communications systems (e.g., cellular). PDMS.
Illustration	
Preconditions	Vehicle/devices providing data to be collected by the probe.
Main Flow	The vehicle/device collects probe-related data. The vehicle/device transmits specified data to the PDMS directly or through the RSU. The PDMS receives data from the vehicle/device and provides relevant information to traffic management entities for relay of alerts to drivers.
Alternate Flow(s)	The data may also be collected from participating vehicles via alternative communications interfaces such as a cellular system.
Post-Conditions	Improved traffic and safety.
Information Requirements	Vehicle events such as travel time through an impacted region. Roadway events such as traffic signal light out.

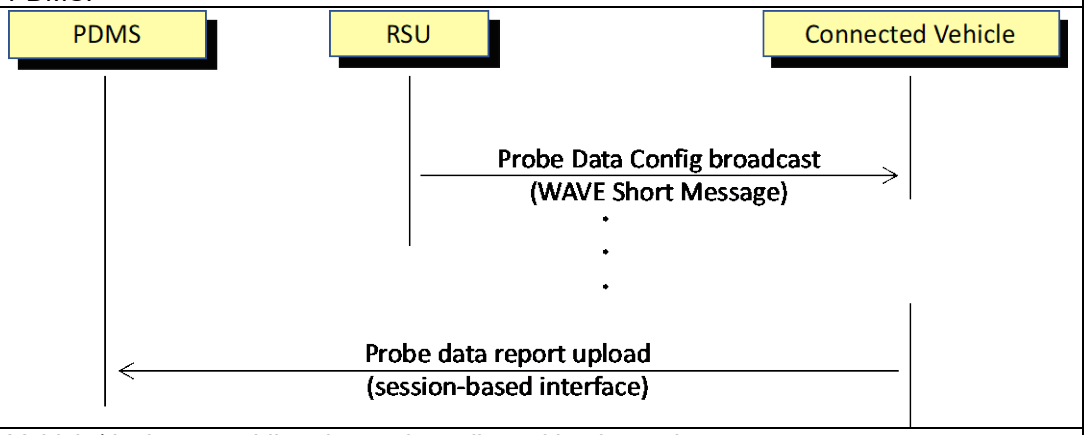
2.9.10 Mobility Assessment

Table 11 - Mobility assessment

Use Case Name	Mobility assessment.
Category	Mobility and safety.
Infrastructure Role	Collection of probe data.
Short Description	Probe data can be used to report local road conditions such as slowness of travel due to road closures. Accurate traffic information could be provided to mapping entities for real-time updates.
Goal	Improved mobility and safety.
Constraints	Number of vehicles/devices participating in collecting and providing probe data. Accuracy/completeness of the probe data being reported. Security solution in place to enable authentication of data sources and secure data exchange.
Geographic Scope	Everywhere.
Actors	Vehicles/devices. Roadside units (RSU) or other communications systems (e.g., cellular). PDMS.
Illustration	
Preconditions	Vehicle/devices providing data to be collected by the probe.
Main Flow	The vehicle/device collects probe-related data. The vehicle/device transmits specified data to the PDMS directly or through the RSU. The PDMS receives data from the vehicle/device and provides relevant information to traffic management entities for relay of alerts to drivers.
Alternate Flow(s)	The data may also be collected from participating vehicles via alternative communications interfaces such as a cellular system.
Post-Conditions	Improved traffic and safety.
Information Requirements	Roadway events.

2.9.11 Infrastructure Asset Management

Table 12 - Infrastructure asset management

Use Case Name	Infrastructure asset management.
Category	Infrastructure.
Infrastructure Role	Collection of probe data.
Short Description	Probe data can be used to report observed infrastructure issues such as low road sign or lane retro reflectivity.
Goal	Improved mobility and safety.
Constraints	Number of vehicles/devices participating in collecting and providing probe data. Accuracy/completeness of the probe data being reported. Security solution in place to enable authentication of data sources and secure data exchange.
Geographic Scope	Everywhere.
Actors	Vehicles/devices. Roadside units (RSU) or other communications systems (e.g., cellular). PDMS.
Illustration	
Preconditions	Vehicle/devices providing data to be collected by the probe.
Main Flow	The vehicle/device collects probe-related data. The vehicle/device transmits specified data to the PDMS directly or through the RSU. The PDMS receives data from the vehicle/device and provides relevant information to infrastructure management entities for relay of alerts to drivers.
Alternate Flow(s)	The data may also be collected from participating vehicles via alternative communications interfaces such as a cellular system.
Post-Conditions	Improved traffic and safety.
Information Requirements	Roadway events.

3. REQUIREMENTS

3.1 Tutorial [Informative]

Detailed information about requirements may be found in NTCIP 8002 Annex B1 Section 3. Refer also to section 3.1.4 of SAE J2945.

Information about NRTM notation may be found in NTCIP 8002 Annex B1 Section 3.3. Text appearing in Sections 3.3.1 through 3.3.3 implements NTCIP 8002 Annex B1 Section 3.3, and is reprinted with permission © 2016 AASHTO/ITE/NEMA from NTCIP 8002 Annex B1.

The NRTM can be used by:

a. A user or specification writer to indicate which requirements are to be implemented in a project-specific implementation.

b. The protocol implementer, as a checklist to reduce the risk of failure to conform to the standard through oversight.

c. The supplier and user, as a detailed indication of the capabilities of the implementation.

d. The user, as a basis for initially checking the potential interoperability with another implementation.

3.2 Scope of the Interface [Informative]

The scope of the configuration interface is limited to the transmission of configuration messages from infrastructure to vehicles/devices. The session oriented interface enables exchange of data between vehicle/device and the PDMS via any communications system that supports the session protocols as specified in this document.

3.3 Needs to Requirements Traceability Matrix (NRTM)

The NRTM provides a mapping between the user needs and the functional requirements which have been developed to meet those needs.

3.3.1 Notation [Informative]

Information about NRTM notation may be found in NTCIP 8002 Annex B1 section 3.3.

3.3.1.1 Conformance Symbols

The following symbols are used to indicate status in the conformance column of the NRTM table:

Table 13 - Conformance symbols

Symbol	Value
M	Mandatory: The system is required to implement this functionality.
M.#	Every item of the group labeled by the same numeral # is mandatory, but only one is active at a time.
O	Optional: The system does not need to implement the feature to be standards compliant.
O.# (range)	Part of an option group: At least the number of options indicated by the “(range)” is required from the options labeled with the same numeral #.(1)
C	Conditional: The system must implement functionality corresponding to this requirement if another requirement is implemented.
NA	Not applicable (i.e., logically impossible in the scope of the standard).
X	Excluded or prohibited.

(1) The O.# (range) notation is used to show a set of selectable options (e.g., O.2 (1..*)) would indicate that one or more of the option group two options must be implemented. Two character combinations are used for dynamic requirements. In this case, the first character refers to the static (implementation) status, and the second refers to the dynamic (use); thus, .MO. means mandatory to be implemented, optional to be used.

3.3.1.2 Conditional Status Notation

The following predicate notation may be used:

Table 14 - Predicate notations

<predicate>:	This notation introduces a single item that is conditional on the <predicate>.
<predicate>::	This notation introduces a table or a group of tables, all of which are conditional on the <predicate>.
(predicate)	This notation introduces the first occurrence of the predicate either in the NRTM table or that specific user need. The feature associated with this notation is the base feature for all options that have this predicate in their conformance column.

The <predicate>: notation means that the status following it applies only when the NRTM states that the feature or features identified by the predicate are supported. In the simplest case, <predicate> is the identifying tag of a single NRTM item. When the group predicate is true then the associated section shall be completed. The symbol <predicate> also may be a Boolean expression composed of several indices. .AND., .OR., and .NOT. shall be used to indicate the Boolean logical operations.

The predicates used in this document are as follows:

- Requested: Indicates the corresponding information (probe data records) was requested in the configuration.

3.3.1.3 Support Column Symbols

The support column can be used by a procurement specification to identify the required features for the given procurement or by an implementer to identify which features have been implemented. In either case, the user circles the appropriate answer (yes, no, or NA) in the support column:

Table 15 - Support column symbols

Yes	To be supported (or supported) by the implementation.
No	Does not have to be supported (or not supported) by the implementation.
NA	Not applicable.

3.3.2 Instructions for Completing the NRTM [Informative]

To claim conformance with this standard, an implementation must satisfy the mandatory and selected optional requirements as identified in the NRTM.

The columns in the NRTM table are the user need ID and user need title columns, FR ID (functional requirement ID) and FR title (functional requirement title) columns, the conformance column, the support column, and the additional specifications column.

3.3.2.1 User Need ID and User Need Title Columns

The NRTM is based upon the user needs defined in each section. The section number and user need name are indicated within these columns.

3.3.2.2 FR ID and FR Title Columns

The requirements are defined within 3.5 to 3.6. The NRTM references the traces from user needs to these requirements. The section number and requirements name are indicated within these columns.

3.3.2.3 Conformance Column

The notations and symbols used to indicate status and conditional status in the NRTM, for this column are defined in 3.3.1.1 and 3.3.1.2. Not all of these notations and symbols may be used in SAE J2945/C.

3.3.2.4 Support Column

In the “support” column, each response shall be selected either from the indicated set of responses (for example: yes, no, NA), or it shall reference additional items that are to be attached.

If a conditional requirement is inapplicable, use the not applicable (NA) choice.

3.3.2.5 Additional Specifications Column

The additional specifications column may (and should) be used by a procurement specification to provide additional notes and requirements for the product to be procured or may be used by an implementer to provide any additional details about the implementation. In some cases, default text already exists in this field, which the user should complete in order to fully specify the implementation. However, additional text can be added to this field as needed to fully specify a feature. Performance requirements should also be specified in this column.

3.3.2.6 Needs to Requirements Traceability Matrix (NRTM) Table

To claim conformance with this standard, an implementation shall satisfy the mandatory and selected optional requirements as identified in the NRTM.

Table 16 - NRTM table

User Need ID	User Need	FR ID	Functional Requirement	Conformance	Support	Additional Specifications
2.4	Architectural Needs			M	Yes	
2.4.1	Communications Interfaces			M	Yes	
2.4.1.1	Configuration Interface			M	Yes	
		3.4.1.1	Configuration interface	M	Yes	
2.4.1.2	Data Collection Interface			M	Yes	
		3.4.1.2	Data collection interface	M	Yes	
2.5	Features					
2.5.1	Configure Probe Data Recording			M	Yes	
2.5.1.1	Configuration Descriptor			M	Yes	
		3.5.1.1	Configuration descriptor	M	Yes	
		3.5.1.1.1	Configuration identifier	M	Yes	
		3.5.1.1.3	Vehicle selection	M	Yes	
		3.5.1.1.3	Vehicle participation	M	Yes	
2.5.1.2	Configuration Temporal Boundary			O	Yes/No	
		3.5.1.2	Configuration temporal boundary	M	Yes	
2.5.1.3	Configuration Geographical Boundary			O	Yes/No	
		3.5.1.3	Configuration geographical boundary	M	Yes	
2.5.1.4	Configuration Total Distance Traveled			O	Yes/NA	
		3.5.1.4	Configuration total distance traveled	M	Yes	
2.5.1.5	Maximum Age of Data			M	Yes	
		3.5.1.5	Maximum age of data	M	Yes	
2.5.1.6	Triggers			M	Yes	
		3.5.1.6.1	Triggers resulting in instantaneous records (event based)	O.2(1…*)	Yes/No	
		3.5.1.6.1.1	Interval-based events	O.2(1…*)	Yes/No	
		3.5.1.6.1.2	Vehicle events	O.2(1…*)	Yes/No	
		3.5.1.6.1.3	Roadway events	O.2(1…*)	Yes/No	
		3.5.1.6.1.4	Communications system performance events	O.2(1…*)	Yes/No	
		3.5.1.6.2	Triggers resulting in averaged and summary records	O.2(1…*)	Yes/No	
		3.5.1.6.2.1	Averaged records	O.2(1…*)	Yes/No	
		3.5.1.6.2.2	Summary records	O.2(1…*)	Yes/No	
2.5.1.7	Vehicle Type and Characteristics			O	Yes/No	
		3.5.1.7	Vehicle	O	Yes/No	
2.5.2	Receive Probe Data Reports					
2.5.2.1	Receive Configuration Identifier			M	Yes	
		3.5.2.1	Receive configuration identifier	M	Yes	
2.5.2.2	Received Report Characteristics			M	Yes	
		3.5.2.2	Received report characteristics	M	Yes	
2.5.2.3	Contents of Record(s)			Requested: M	Yes/No	
		3.5.2.3	Contents of record(s)	M	Yes	
2.5.2.4	Instantaneous Record(s)			Requested: M	Yes/No	
2.5.2.4.1	Time of Instantaneous Record(s)			M	Yes	
		3.5.2.4.1	Time of instantaneous record(s)	M	Yes	

User Need ID	User Need	FR ID	Functional Requirement	Conformance	Support	Additional Specifications
2.5.2.4.2	Location of Instantaneous Record(s)			M	Yes	
		3.5.2.4.2	Location of instantaneous record(s)	M	Yes	
2.5.2.4.3	Velocity of Instantaneous Record(s)			M	Yes	
		3.5.2.4.3	Velocity of instantaneous record(s)	M	Yes	
2.5.2.4.4	Content of Instantaneous Record(s)					
		3.5.2.4.4	Interval-based data	M	Yes	
		3.5.2.4.5	Velocity of instantaneous record(s)	M	Yes	
		3.5.2.4.6	Roadway data	M	Yes	
		3.5.2.4.7	Communications system performance data	M	Yes	
2.5.2.5	Averaged and Summary Records			Requested: O	Yes/No	
2.5.2.5.1	Start Time			M	Yes/NA	
		3.5.2.5.1	Start time	M	Yes/NA	
2.5.2.5.2	End Time			M	Yes/NA	
		3.5.2.5.2	End time	M	Yes/NA	
2.5.2.5.3	Start Location			M	Yes/NA	
		3.5.2.5.3	Start location	M	Yes/NA	
2.5.2.5.4	End Location			M	Yes/NA	
		3.5.2.5.4	End location	M	Yes/NA	
2.5.2.5.5	Content of Averaged and Summary Record(s)					
		3.5.2.5.5	Averaged data	M	M	
		3.5.2.5.6	Summary data velocity of instantaneous record(s)	M	M	
2.6	Security			M		
2.6.1	Data Source Authenticity and Authorization			M	Yes	
		3.6.1.1	Roadside units	M	Yes	
		3.6.1.2	Probe data management subsystem	M	Yes	
		3.6.1.3	Probe data report upload destination	M	Yes	
2.6.2	Data Integrity and Availability			M	Yes	
		3.6.2	Data integrity and availability	M	Yes	
2.6.3	User Privacy			M	Yes	
		3.6.4	Identification	M	Yes	
		3.6.4.1	Discarding identifying information	M	Yes	
		3.6.4.2	Secure and privacy-aware storage of security credentials	M	Yes	

3.4 Architectural Requirements

3.4.1 Communications Interfaces

3.4.1.1 Configuration Interface

The system shall implement an interface to the vehicle to provide the configuration information (3.5.1).

3.4.1.2 Data Collection Interface

The system shall implement an interface to the vehicle to receive the probe data reports (3.5.2).

3.5 Message/Features Requirements

An entity in the infrastructure may specify the information it seeks to gather from vehicles and probes. In 3.5.1 the details of the configuration message and its components are provided. Section 3.5.2 provides the details of the response message and its content to be assembled by the participating vehicles and probes.

3.5.1 Configure Probe Data Recording

The system specifies the conditions for recording of the data by sending configuration messages to the vehicle(s). A descriptor identifies requestors and the different configurations requested. This section outlines the requirements of the configuration information sent by the system.

Vehicles record and upload probe data in response to a configuration. Vehicles upload probe data when they cross the geographical (see 3.5.1.3) or temporal boundary (see 3.5.1.2) associated with a configuration. If a connection is not available, a vehicle may delay upload of the probe data until one becomes available.

3.5.1.1 Configuration Descriptor

The system shall send a configuration identifier including destination for submittal of recorded data to the vehicle. This is used by the vehicle in relaying the data back and by the system to identify the requested probe data configuration when the vehicle reports the probe data to the system. The vehicle relays the gathered information at the end of the first completed condition, configuration temporal boundary, configuration geographical boundary, configuration total distance traveled, maximum age of data, or upon encountering triggers.

3.5.1.1.1 Configuration Identifier

The system shall associate each individual configuration by a unique configuration identifier.

3.5.1.1.2 Vehicle selection

The system shall indicate the class of vehicles (see 3.5.1.7) to participate in gathering of the identified data. The subject vehicles may not have the capability to record and report all the requested data, in which case the vehicles can report the subset of the requested data that they can record.

3.5.1.1.3 Vehicle participation

The system shall have the means to specify the percentage of the selected vehicle classes that it seeks data from. A vehicle uses this information to determine whether it participates in the probe data configuration by calculating a random number between 0 and 1 using a uniform distribution. If the value of the random number exceeds the percentage, the vehicle does not participate. Note that not all vehicles will have the capability to record and report all the requested data, in which case the vehicles can report the subset of the requested data that they can record.

3.5.1.2 Configuration Temporal Boundary

The system shall send the configuration temporal boundary specifying the time period and recording interval of the desired data gathering. The temporal boundary may be recurring on a daily or weekly basis between a specified start and end time. The vehicle uploads its data at the end of the temporal boundary.

3.5.1.3 Configuration Geographical Boundary

The system shall send the geographical boundary and desired direction of travel under which the probe data is to be gathered. This is used by the vehicle in detecting geographical areas where the requested data is to be gathered. The vehicle uploads its data when exiting the geographical boundary.

3.5.1.4 Configuration Total Distance Traveled

The system shall send the total distance of travel over which the probe data is to be gathered by the vehicle. This is used by the vehicle in measurement of the length of the path where the requested data is to be gathered. The vehicle uploads its data at the end of path.

3.5.1.5 Maximum Age of Data

The system shall send the maximum age of the data to be gathered to the vehicle. This is used by the vehicle in purging old and unacceptable data thus limiting the amount of probe data to be sent to the system. The vehicle will upload its data before the data reaches its maximum age.

3.5.1.6 Triggers

The system may require certain data to be captured by the vehicle(s) under certain specified conditions. These conditions, or triggers, are set to indicate immediate collection of data or start to data collection for averaged or summary information.

3.5.1.6.1 Triggers Resulting in Instantaneous Records (Event Based)

The system shall specify triggers that request immediate initiation of data collection, upon meeting the specified condition, and timely transmittal of captured record(s). An instantaneous trigger may represent a request for data corresponding to one of the following events:

- Interval-based events (reporting at the end of a time or distance interval).
- Vehicle/device events.
- Roadway events.
- Communications system performance events.

3.5.1.6.1.1 Interval-Based Events

The system shall send triggers that specify data collection by the vehicle over intervals of time and distance within the specified temporal boundary (see 3.5.1.2) and/or within the specified spatial boundary (see 3.5.1.3).

- Time: Indicates metrics are recorded at the end of each time interval.
- Distance: Indicates metrics are recorded at the end of each distance interval.

If a combination of time, distance, and region is used, the trigger is whichever interval expires first, after which a new recording interval begins.

Metrics recorded at the end of each interval:

- Wiper status.
- V2V-equipped vehicle count within a specified range (total over the interval based on BSMs). Multiple range bins may be specified. Note that this number may not be accurate over long time periods due to vehicle address randomization as required for privacy.
- Weather data (SAE J2945/3).
- Number of vehicle occupants.
- For transit vehicles:
    - Current and average number of passengers over the last interval.
    - Schedule adherence.

Additionally, each record will always include the time stamp, position, position accuracy, and velocity of the vehicle at the moment of recording (see 2.5.2.4).

3.5.1.6.1.2 Vehicle Events

The system shall send triggers that specify the initiation of recording based on the occurrence of a vehicle event. Note that vehicles upload this data based on expiration of a temporal boundary (3.5.1.2) or exiting a geographical boundary (3.5.1.3). Such vehicle events include:

- Head lights, fog lights, or hazard lights turned on/off (can indicate each individually).
- Vehicle location and speed before and after occurrence of:
    - ABS activated.
    - Traction control loss.
    - Stability control activated.
    - Hard braking.
    - Swerve (lateral acceleration) exceeds a certain threshold.
- Wipers status change.
- Low speed (falls below a certain threshold for a defined period of time).
- Resumed speed (speed goes above a certain threshold).
- Vehicle enters or exits a region defined by a geofence.
- Emergency vehicle detected by a non-emergency vehicle.
- Emergency vehicle light bar turned on/off (reported by the emergency vehicle only).
- TSP/EVP requested (transit and emergency vehicles only).
- Transit vehicle passenger count change and resulting number of occupants.
- Transit vehicle door opened and number of passengers entering/exiting.
- V2X message reception: reception of any V2X message over the communications interface(s), identified by indicating the desired data dictionary (SAE J2735, ETSI and ISO data dictionary documents) and message IDs in the configuration. (Note: Capability is intended primarily for testing and not for commercial operation.)
- Driver alerts and warnings:
    - SAE J2945/1 applications:
        - Emergency electronic brake lights.
        - Forward crash warning.
        - Blind spot warning/lane change warning.
        - Intersection movement assist.
        - Left turn assist.
        - Control loss warning.

- Red light violation warning (RLVW): Driver is warned of a potential red-light violation.
- Emergency vehicle alert (EVA): Driver is alerted to the presence of an emergency vehicle.
- Other warnings and alerts (catch-all category).

Additionally, each record will always include the time stamp, position, position accuracy, and velocity of the vehicle at the moment of recording (see 2.5.2.4).

3.5.1.6.1.3 Roadway Events

The system shall send requests that specify the initiation of recording based on the occurrence of a roadway event. Such roadways events include:

- Obstacle detection.
- Adverse road surface condition (non-weather related: potholes, road roughness). This can be implemented using wheel-based accelerometers. Refer to SAE J2945/3.
- Traffic signal encounters:[2]
  - Approach delay in seconds higher than a threshold (measure of time at an intersection).
  - Approach speed in kilometers per hour lower than a threshold.
  - Arrival on green (status of traffic signal at arrival to intersection).
  - Arrival on red (status of traffic signal at arrival to intersection).
  - Pedestrian delay in seconds (pedestrian waiting at a cross street more than a threshold).
  - Mismatch detected between the received signal phase and timing (SPAT) message and the phase of the encountered traffic signal.
- Traffic signal light out or in need of repair.
- Mismatch of the road geometry as conveyed by the received MAP message and physically encountered.
- Road sign detection, including type of sign.
- Low road sign retro reflectivity (falls below a specified threshold).
- Low lane marking retro reflectivity (falls below a specified threshold).
- Road sign inconsistency or unexpected closure (posted sign inconsistent with on-board map).
- Lane geometry inconsistency (difficult to interpret because of being covered up or ambiguous, or different from on-board map).
- Incident detection (car accident, wrong way driver, slowdown in opposite direction).
- Detection of work zone characteristics: workers present, lane shifts and lane closures.

[2] FHWA, Automated Traffic Signal Performance Measures Case Studies, https://ops.fhwa.dot.gov/arterial_mgmt/performance_measures.htm.

- Detection of inclement weather or weather-related road surface condition (SAE J2945/3—heavy rain, fog, wind, ice, snow).
- Railroad crossing activated.
- Drawbridge activated.

Additionally, each record always includes the time stamp, position, position accuracy, and velocity of the vehicle for the instance of recording (see 2.5.2.4).

3.5.1.6.1.4 Communications System Performance Events

The system shall send requests that specify the initiation of recording based on the occurrence of a communications system performance events event. Such events include:

- RF triggers:
    - SAE J2945/1 channel busy percentage exceeds a specified threshold.
    - RSU encountered.
    - Number of RSUs observed in last X seconds exceeds a certain threshold.
    - V2X radio interference exceeds certain threshold in dBm.
    - SAE J2945/1 vehicle density in range exceeds a specified threshold (number of vehicles).
    - SAE J2945/1 CQI falls below a specified threshold (poor link quality).
    - SAE J2945/1 tracking error estimate exceed a specified threshold in meters. Note: Tracking error is a result of the delay with which a vehicle receives another vehicle's kinematic state data due to transmission latencies and packet losses, and it is distinct from accuracy-related errors of the positioning subsystem. Refer to SAE J2945/1.
- GNSS performance triggers:
    - HDOP exceeds a specified threshold (to be reported only a single time if vehicle stationary).
    - Satellites in view goes below a specified threshold.
    - Jamming detected/cleared.

Additionally, each record will always include the time stamp, position, position accuracy, and velocity of the vehicle at the moment of recording (see 2.5.2.4).

3.5.1.6.2 Triggers Resulting in Averaged and Summary Records

The system shall send triggers that initiate collection of an averaged or summary probe data record over a pre-defined region. A collection region is defined using a borderline, polygon, geofence, lane, and/or heading. Collection duration (time elapsed or distance driven) is used to limit total the time duration or total distance driven within the region over which the averaged or summary probe data record is collected.

3.5.1.6.2.1 Averaged Records

The system shall request specific parameters to be captured and presented as an average over time elapsed or distance driven. Refer to probe data report requirements (3.5.2.5) for units associated with these configuration parameters. Such parameters include:

- Average speed: Average speed over the configuration region, including standard deviation.
- Average duration of each stop, including standard deviation.
- Average fuel consumption.
- Average emissions (hydrocarbons, CO, CO_2, NO, NO_2, SO_2, O_3, PM10: particulates of 10 μm or less in diameter, PM25: particulates of 2.5 μm or less in diameter).
- Average number of occupants.

3.5.1.6.2.2 Summary Records

The system shall request specific parameters to be captured and summarized for the time elapsed or distance driven within the region. Refer to probe data report requirements (3.5.2.5) for units associated with these configuration parameters. These parameters include:

- Total travel time to traverse the region.
- Total vehicle distance traveled within the region.
- Total vehicle time traveled within the region.
- Total fuel consumption.
- Total vehicle emissions (hydrocarbons, CO, CO_2, NO, NO_2, SO_2, O_3, PM10: particulates of 10 μm or less in diameter, PM25: particulates of 2.5 μm or less in diameter).
- Number of low speed events: number of times speed dropped below a low speed threshold for a specified low speed period (low speed threshold must be greater than 5 km/h).
- Total time stopped: Seconds spent at speed less than the specified stopped threshold.
- Total number of stops: Number of times the speed fell below the specified stopped threshold.
- Location and duration of each stop: Each location and duration in seconds where the speed drops below the specified stopped threshold.
- Number of vehicles passed: Number of vehicles passed over the configuration region.
- Number of surpassed vehicles: Number of vehicles that passed the recording vehicle over the configuration region.
- Messages received: Total messages received by the message type (note dictionary identifier above) indicated in the configuration.

3.5.1.7 Vehicle Class

The system shall send an identifier to identify vehicle types it wants information from. The following vehicle classes (FHWA 1 through 13) are included:

1. Motorcycles.
2. Passenger cars.
3. Other two-axle, four-tire single unit vehicles.
4. Buses.
5. Two-axle, six-tire, single-unit trucks.
6. Three-axle single-unit trucks.
7. Four or more axle single-unit trucks.
8. Four or fewer axle single-trailer trucks.
9. Five-axle single-trailer trucks.
10. Six or more axle single-trailer trucks.
11. Five or fewer axle multi-trailer trucks.
12. Six-axle multi-trailer trucks.
13. Seven or more axle multi-trailer trucks.

3.5.2 Receive Probe Data Reports

This section outlines the requirements for the system to receive data it identifies as part of the configuration information it sends to vehicles and probes. Requirements listed in this section cover all the requested data; however, vehicles and probes participating in data gathering may not be capable of gathering every requested parameter.

Vehicles record and upload probe data in response to a configuration. Vehicles upload probe data when they cross the geographical (see 3.5.1.3) or temporal boundary (see 3.5.1.2) associated with a configuration.

3.5.2.1 Receive Configuration Identifier

The system shall be capable of receiving configuration identifier from vehicle. This is used by the system to match the received probe data with a previous configuration request.

3.5.2.2 Received Report Characteristics

The system shall be able to receive characteristics of the vehicle in each report. The characteristics include vehicle class, device type, vehicle size, vehicle weight, and vehicle passenger count.

3.5.2.3 Contents of Record(s)

The system shall be able to receive the contents requested in the configuration as indicated by the corresponding configuration identifier that was sent to the vehicle/device. The system must be capable of receiving what it requested. The vehicle or probe may not be capable of providing parts of the requested data.

3.5.2.4 Instantaneous Record(s)

The system shall be capable of receiving instantaneous records collected by a vehicle or probe containing information that are based on:

- Interval-based events (reporting at the end of a time or distance interval).
- Vehicle/device events.
- Roadway events.
- Communications system performance events.

3.5.2.4.1 Time of Instantaneous Record(s)

The system shall be capable of receiving the timestamp associated with record(s) received. If previous probe data reports associated with the requested configuration were already sent to the system by the vehicle/device, the vehicle/device may record and report only the data recorded since the last report.

3.5.2.4.2 Location of Instantaneous Record(s)

The system shall be capable of receiving the location stamp associated with record(s) received.

3.5.2.4.3 Velocity of Instantaneous Record(s)

The system shall be capable of receiving the velocity at each location associated with each record received.

3.5.2.4.4 Interval-Based Data

The system shall be capable of receiving instantaneous records designated as interval-based records that contain any of the following:

- Wiper status, including rate (on/off, low, medium, high).
- V2V-equipped vehicle count.
- Weather data (SAE J2945/3).
- Current and average number of passengers.
- Transit vehicle schedule adherence.
- Number of occupants (at the end of the interval).

3.5.2.4.5 Vehicle and Device Data

The system shall be capable of receiving instantaneous records designated as vehicle events that contain any of the following:

- Head lights, fog lights, or hazard lights turned on/off.
- ABS activated.
- Traction control loss.
- Stability control activated.
- Hard braking.

- Swerve (lateral acceleration) exceeding threshold.
- Wipers status change.
- Low speed indicator.
- Resumed speed indicator.
- Vehicle enters or exits a defined region.
- Emergency vehicle detected by a non-emergency vehicle.
- Emergency vehicle light bar turned on/off (reported by the emergency vehicle only).
- TSP/EVP requested (transit and emergency vehicles only).
- Transit Vehicle passenger count change and resulting number of occupants.
- Transit vehicle door opened and number of passengers entering/exiting.
- identified V2X messages received.

3.5.2.4.6 Roadway Data

The system shall be capable of receiving instantaneous records designated as roadway events that contain any of the following:

- Obstacle detection.
- Adverse road surface condition (non-weather related: potholes, road roughness).
- Traffic signal encounters:
    - Approach delay in seconds higher than threshold (measure of time at an intersection).
    - Approach speed in kilometers per hour higher than threshold.
    - Arrival on green (status of traffic signal at arrival to intersection).
    - Arrival on red (status of traffic signal at arrival to intersection).
    - Pedestrian delay (pedestrian waiting at a cross street more than threshold).
- Traffic signal light out or in need of repair.
- Road sign detection, including type of sign.
- Low road sign retro reflectivity (falls below threshold).
- Low lane marking retro reflectivity (falls below threshold).
- Road sign inconsistency or unexpected closure (posted sign inconsistent with on-board map).
- Lane geometry inconsistency (difficult to interpret because of being covered up or ambiguous, or different from on-board map).
- Incident detection (car accident, wrong way driver, slowdown in opposite direction).

- Detection of work zone characteristics: Workers present, lane shifts, and lane closures.
- Detection of inclement weather or weather-related road surface condition (SAE J2945/3—heavy rain, fog, wind, ice, snow).
- Railroad crossing or draw bridge activated.

3.5.2.4.7 Communications System Performance Data

The system shall be capable of receiving instantaneous records designated as roadway events that contain any of the following:

- SAE J2945/1 channel busy percentage as measured over last 100 ms exceeds threshold.
- Encountered RSU information (Source MAC/Layer 2 Source ID of the RSU).
- Count of observed RSUs exceeding threshold.
- V2X radio interference exceeds threshold.
- SAE J2945/1 vehicle density in range exceeds threshold.
- SAE J2945/1 CQI falls below threshold (poor link quality).
- SAE J2945/1 tracking error estimate exceed threshold.
- GNSS performance triggers:
    - HDOP exceeds threshold.
    - Satellites in view goes below threshold.
    - Jamming detected/cleared.

3.5.2.5 Averaged and Summary Records

The system shall be cable of receiving records designated as averaged or summarized that contain averaged or summary of data collected over pre-defined temporal or geographical region.

3.5.2.5.1 Start Time

The system shall be capable of receiving the timestamp associated with the start of recorded data associated with averaged and summary record(s).

3.5.2.5.2 End Time

The system shall be capable of receiving the timestamp associated with the end of data recording associated with averaged and summary record(s).

3.5.2.5.3 Start Location

The system shall be capable of receiving location of the point where the vehicle started gathering data recording associated with averaged and summary record(s).

3.5.2.5.4 End Location

The system shall be capable of receiving location of the point where the vehicle ended recording data associated with averaged and summary record(s).

3.5.2.5.5 Averaged Data

The system shall be capable of receiving records designated as averaged that contain any of the following:

- Average speed (kilometers per hour).
- Average duration of each stop, including standard deviation (milliseconds).
- Average fuel consumption.
- Average emissions:
  - Hydrocarbons: Parts per million.
  - CO: Parts per million.
  - CO_2: Parts per billion.
  - NO: Parts per million.
  - NO_2: Parts per billion.
  - SO_2: Parts per billion.
  - O_3: Parts per one hundred billion.
  - PM10: Particulates of 10 μm or less in diameter (micrograms per cubic meter).
  - PM25: Particulates of 2.5 μm or less in diameter (micrograms per cubic meter).
- Average number of occupants.

3.5.2.5.6 Summary Data

The system shall be capable of receiving records designated as summary that contain any of the following:

- Total travel time to traverse the region (seconds).
- Total vehicle distance traveled within the region over a certain time period (kilometers).
- Total vehicle time traveled within the region (seconds).
- Total fuel consumption (liters).
- Total vehicle emissions:
  - Hydrocarbons: Parts per million.
  - CO: Parts per million.
  - CO_2: Parts per billion.
  - NO: Parts per million.
  - NO_2: Parts per billion.
  - SO_2: Parts per billion.

- O_3: Parts per one hundred billion.
- PM10: Particulates of 10 μm or less in diameter (micrograms per cubic meter).
- PM25: Particulates of 2.5 μm or less in diameter (micrograms per cubic meter).

- Number of low speed events: number of times speed dropped below a low speed threshold for the specified low speed period.
- Total time stopped.
- Total number of stops.
- Location and duration of each stop.
- Number of vehicles passed.
- Number of surpassed vehicles.
- Messages received: Total messages received by the message type.

3.6 Security

3.6.1 Data Source Authenticity and Authorization

3.6.1.1 Roadside Units

Configuration messages shall be signed using IEEE 1609.2 certificates containing the appropriate permissions, per the IEEE 1609.2 security profile of Annex C.1, indicating that the sender was authorized to send such message. If the configuration message is transmitted by an RSU, it may be signed by the RSU prior to transmission or it may be signed elsewhere and forwarded to the RSU for transmission unmodified.

3.6.1.2 Probe Data Management Subsystem

The interface between the PDMS and vehicles shall be secured using transport layer security (TLS). The system allows clients to establish authenticated and secure sessions with multiple centers.

3.6.1.3 Probe Data Report Upload Destination

The certificate used to sign the probe data configuration message shall include the URL in the certificateID type hostname (refer to IEEE 1609.2 for the exact certificate structure).

3.6.2 Data Integrity and Availability

The RSU shall ensure that the configuration messages it disseminates to the OBUs are validly signed using an IEEE 1609.2 certificate according to the IEEE 1609.2 security profile in Annex C.1.

3.6.3 User Privacy

3.6.4 Identification

All participating vehicles and device types, shall use IEEE 1609.2 identity certificates instead of pseudonym certificates.

Note that there may be participants that have a lower privacy expectation (e.g., IOO-owned fleet vehicles).

3.6.4.1 Discarding Identifying Information

The system (PDMS) shall discard all participating-vehicle identifying information, except security certificates used to establish a secure session, immediately after the secure session has been terminated.

3.6.4.2 Secure and Privacy-Aware Storage of Security Credentials

The system (PDMS) shall encrypt and securely store the identity certificate used by a vehicle to establish a secure session, such that they can only be accessed later as part of a duly authorized misbehavior investigation.

Note that the implementation means by which this privacy-aware secure storage is achieved is out of scope.

4. DIALOGS [NORMATIVE]

4.1 Tutorial [Informative]

Detailed information about dialogs may be found in NTCIP 8002 Annex B1 Section 4. Refer also to SAE J2945 Section 3.1.

4.2 Specified Dialogs [Normative]

The dialogs presented in this section are intended to be available for use over multiple media, e.g., DSRC, 3GPP PC5, or private or public cellular networks. Note that the dialogs refer to a connected vehicle object, which represents the vehicle/device in the figures in the following subsections.

4.2.1 Probe Data Configuration Interfaces

4.2.1.1 Broadcast Interface Option

RSUs broadcast probe data configuration (PDC) messages carried by WSMs as shown in Figure 4. PDC messages are UPER-encoded and repeated at a configurable rate. See B.1 for the specific configuration of the WAVE short message protocol (WSMP) and security used for the RSU broadcast interface. Note that the probe data configuration messages indicate the percent of respondents, so not all vehicles will accept the configuration (5.2.2). A vehicle decides whether to participate as stated in 3.5.1.1.3.

The URL used by a vehicle to upload the data upon end of or exit from a temporal or geographical boundary is included in the certificateID type hostname in the certificate used to sign the PDC (refer to Appendix C and to IEEE 1609.2 for the exact certificate structure).

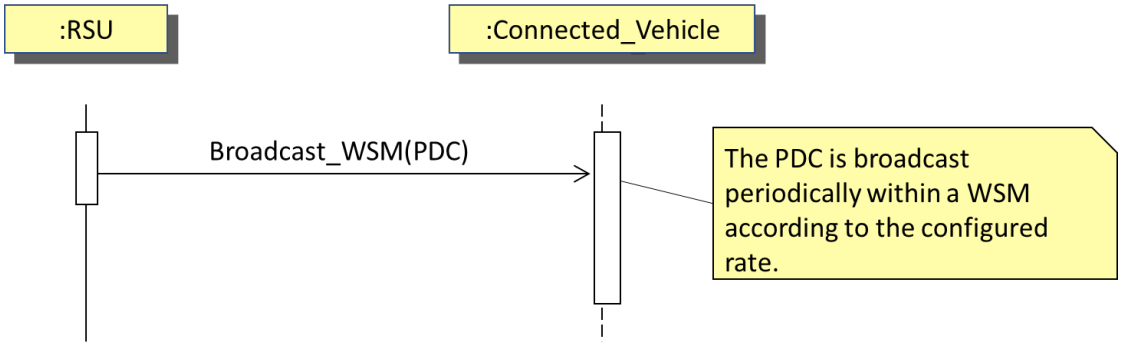


Figure 4 - Dialog for broadcasting probe data configuration messages from the roadside

4.2.1.2 Query Option

Vehicles/devices may query the PDMS for a configuration (see Figure 5). The mechanism for initially connecting to the PDMS and determining how often a vehicle/device queries the PDMS is outside the scope of SAE J2945/C, but typically this would be done by preconfiguring a vehicle/device with a URL and periodically querying the PDMS reachable at that URL. For a query-based approach, the PDC sent in response to the query is encoded using JSON encoding rules (JER).

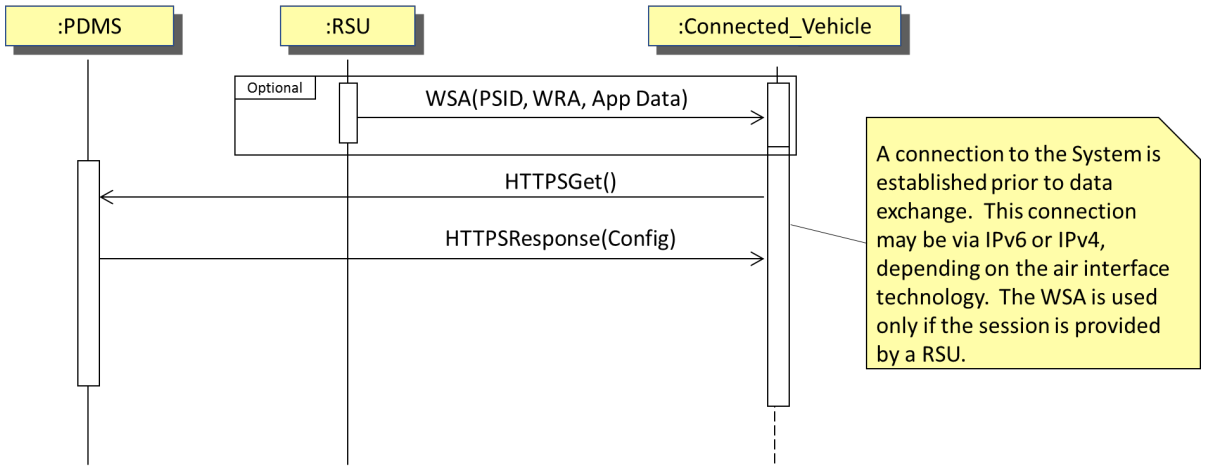


Figure 5 - Dialog for querying for the probe data configuration

4.2.2 Probe Data Upload to the PDMS

The session-oriented data upload interface between a vehicle/device and the PDMS is illustrated in Figure 6. An IP-based interface (IPv6 or IPv4) is used for this data exchange. PDMS related messages are exchanged over a secure session-based interface (see C.1 for the security configuration used for IP-based data exchange).

If the IP-based data upload is being performed via an RSU, a signed WAVE service advertisement is used to provide the IPv6 configuration to the vehicle/device (see B.2 for the configuration of the WSA used). RSUs may be placed at strategic locations to enable uploading of data by vehicles that do not support a cellular interface. When using the WSA, the destination URL is included in the certificateID type hostname in the certificate used to sign the WSA, and the matching URL included in the certificate used to sign the PDC indicates which configuration(s) are applicable (see Appendix C and to IEEE 1609.2 for the exact certificate structure).

If the data upload is occurring via a non-RSU based interface that supports IP (e.g., a cellular or wireless local area network), the IPv4 or IPv6 interface is configured according to the corresponding specification for that interface. For an IP-based data upload over a WAN or LAN interface, the lower layers are transparent and outside the scope of this document.

A probe data report (PDR) message is used to exchange data between vehicles/devices and the PDMS. The PDR is encoded using JSON encoding rules (JER) and is encapsulated with the hypertext transport protocol (HTTP) (see Appendix H for more information).

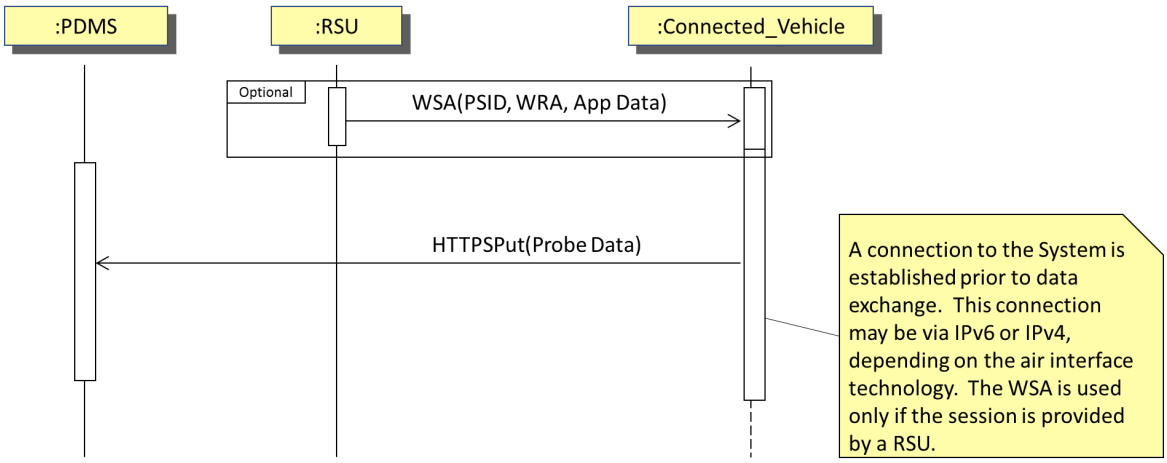


Figure 6 - Probe data upload

In Figure 6, an RSU providing configuration data may broadcast a WSA advertising the details of the information to be captured. The WSA may include IPv6 routing information in its WRA.

5. PROBE DATA CONFIGURATION MESSAGE [NORMATIVE]

In the following object definitions, the ASN.1 entities used by PDMS to define the characteristics and conditions for the data to be gathered by probes is outilied. Appendix H provides the complete ASN.1 module for PDC.

5.1 Message: MSG_ProbeDataConfigMessage (PDC)

Use: This message is used by PDMS to send a unique set of configuration triggers for data to be collected by participating vehicles/devices. Each PDC can include as many as 255 unique configurations.

ASN.1 Representation:

```
ProbeDataConfigMessage ::= SEQUENCE (SIZE(1..255, ...)) OF ProbeDataConfig
```

Remarks: This message needs to be added to the SAE J2735 list of messages. The message ID assigned is 35. SSPs used in the certificates attached to this message are defined in Appendix C.

5.2 PDC Data Frames

5.2.1 Data Frame: DF_ProbeDataConfig

Use: This data frame is sent by PDMS to participating vehicles and probes to uniquely identify the configuration and its requested data collection, including triggering events and conditions, maximum age of the gathered data to be provided, and any applicable geographical and/or temporal boundaries for concluding collection and uploading the data.

ASN.1 Representation:

```
ProbeDataConfig ::= SEQUENCE {
   descriptor        ConfigDescriptor,
   triggers          ConfigTriggers,
   maxAgeOfData      INTEGER (1..90), -- in days
   boundary          ConfigBoundary    OPTIONAL,
   ...
}
```

Used by: MSG_ProbeDataConfigMessage

5.2.2 Data Frame: DF_ConfigDescriptor

Use: This data frame is sent by PDMS to identify the configuration, the requester's address, and optionally the types of vehicles and probes to be involved and the desired population of participating vehicles and probes.

ASN.1 Representation:

```
ConfigDescriptor ::= SEQUENCE {
   identifier        ConfigId,
   vehClass          CfgVehicleClass      OPTIONAL,
   roadAuthorityID   RoadAuthorityID      OPTIONAL,
   percentOfResp     INTEGER (1..10)      OPTIONAL,
   -- '1' indicates report 10% of the time, '10' is 100%
   ...
}
```

Used by: DF_ProbeDataConfig

5.2.3 Data Frame: DF_ConfigBoundary

Use: This data frame allows selection of a boundary as temporal or geographical. The ValidRegion data frame, defined in SAE J2735, provides the means for designating one or more geographic areas within which data is to be gathered. ValidRegion includes the direction of travel and optionally the spatial distance and/or the geographical boundary (road segment, circle, or defined enclosed region) where the configuration applies. Temporal boundary is used to set the schedule for the data capture.

ASN.1 Representation:

```
ConfigBoundary ::= CHOICE {
   temporalBoundary     ConfigTemporalBoundary,
   geoAndDistBoundary   ValidRegion, -- From J2735
   ...
}
```

Used by: DF_ ProbeDataConfig

5.2.4 Data Frame: DF_ConfigTemporalBoundary

Use: Defines applicable periods for an event. The start and end time of a temporal boundary along with the desired recurrence (daily, hourly, etc.) are defined in this data frame. Definition for EventRecurrence is copied from SAE J2945/4 RSM.

ASN.1 Representation:

```
ConfigTemporalBoundary ::= SEQUENCE {
   beginTime         DDateTime, --From J2735
   endTime           DDateTime, --From J2735
   recurring         CfgEventRecurrence, --borrowed from J2945/4 RSM
   ...
}
```

Used by: DF_ConfigBoundary

5.2.5 Data Frame: DF_CfgEventRecurrence

Use: Copied from SAE J2945/4 RSM, this data frame defines the recurrence conditions of a temporal boundary. The definition may cover certain hours of the day, certain days of the week, and periods of time that the condition applies.

ASN.1 Representation:

```
-- Definition for EventRecurrence borrowed from J2945/4 RSM
-- Defines applicable periods for an event.
CfgEventRecurrence ::= SEQUENCE {
    startTime   DTime   OPTIONAL,  -- Time of day this period starts
    endTime     DTime   OPTIONAL,  -- Time of day this period ends
    startDate   DDate   OPTIONAL,  -- Date this period starts
    endDate     DDate   OPTIONAL,  -- Date this period ends
    -- Define days of the week for applicable periods (used by EventRecurrence)
    monday      BOOLEAN,
    tuesday     BOOLEAN,
    wednesday   BOOLEAN,
    thursday    BOOLEAN,
    friday      BOOLEAN,
    saturday    BOOLEAN,
    sunday      BOOLEAN,
    -- exclusion: TRUE: The period defined here is excluded,
    -- i.e., the period is NOT applicable to the event
    exclusion   BOOLEAN OPTIONAL,
    ...
}
```

Used by: DF_ConfigTemporalBoundary

5.2.6 Data Frame: DF_ConfigTriggers

Use: This data frame defines a trigger to start instantaneous data capture or an averaged or summarized data capture .

ASN.1 Representation:

```
ConfigTriggers ::= CHOICE {
   instantaneousTriggers   CfgInstantaneousEventTriggers,
   avgAndSumTriggers       CfgAveragedAndSummaryTriggers,
   ...
}
```

Used by: DF_ ProbeDataConfig

5.2.7 Data Frame: DF_CfgInstantaneousEventTriggers

Use: This data frame defines each instantaneous trigger. Instantaneous capture of data can be set to be over time or distance intervals, defined vehicle or roadway events, or based on performance of communication links in use by the probe.

ASN.1 Representation:

```
CfgInstantaneousEventTriggers ::= CHOICE {
   intervalEvents    CfgIntervalEvents,
   vehicleEvents     CfgVehicleEvents,
   roadwayEvents     CfgRoadwayEvents,
   commSysPerfEvents CfgCommSysPerfEvents,
   ...
}
```

Used by: DF_ DF_ConfigTriggers

5.2.8 Data Frame: DF_CfgIntervalEvents

Use: This data frame identifies the information to be gathered over the predefined intervals starting immediately at the entry to tempral or geographical boundary as defined in 5.2.3.

ASN.1 Representation:

```
CfgIntervalEvents ::= SEQUENCE {
   interval             CfgInterval,
   wiperStatus          BOOLEAN                 OPTIONAL,
   vehCount             BOOLEAN                 OPTIONAL,
   -- Count of V2V equipped vehicles encountered during the interval
   weatherData          BOOLEAN                 OPTIONAL,
   transitVehData       CfgTransitVehicleData   OPTIONAL,
   -- Multiple parameters from Transit vehicles
   numOfOccupants       BOOLEAN                 OPTIONAL,
   ...
}
```

Used by: DF_ CfgInstantaneousEventTriggers

5.2.9 Data Frame: DF_CfgTransitVehicleData

Use: This data frame identifies a transit vehicle information to be gathered by the transit vehicle within the defined interval.

ASN.1 Representation:

```
CfgTransitVehicleData ::= SEQUENCE {
   currNumPasngers   BOOLEAN     OPTIONAL,
   avgNumPasngers    BOOLEAN     OPTIONAL,
   trnstVehSchAdh    BOOLEAN     OPTIONAL,
   ...
}
```

Used by: DF_ CfgIntervalEventsInstance

5.2.10 Data Frame: DF_CfgInterval

Use: This data frame specifies the interval to be used, either a time interval or a disctance interval can be specified.

ASN.1 Representation:

```
CfgInterval ::= CHOICE {
   timeInterval         INTEGER(1..36000),   -- in tenths of seconds up to an hour
   distanceInterval     INTEGER(1..100),     -- in 0.1 kilometers
```

Used by: DF_CfgIntervalEvents

5.2.11 Data Frame: DF_CfgVehicleEvents

Use: An instantaneous trigger may be used to identify a vehicle condition to be captured by the probe, the VehicleEvents data frame identifies such events to be captured by the probe or vehicle. Events may include changes in the state of a vehicle component, such as headlights, or be based on a threshold such as swerve exceeding a defined value.

ASN.1 Representation:

```
CfgVehicleEvents ::= SEQUENCE {
   headLights              BOOLEAN                   OPTIONAL,
   fogLights               BOOLEAN                   OPTIONAL,
   hazardLights            BOOLEAN                   OPTIONAL,
   kinematicEvents         CfgKinematicEvents        OPTIONAL,
   wiperStatusChange       BOOLEAN                   OPTIONAL,
   lowSpeed                CfgLowSpeedCriteria       OPTIONAL,
   -- Speed falls below a threshold (MIN 5 km/hr) for a defined duration (in seconds)
   resumedSpeed            INTEGER (1..100)          OPTIONAL,
   -- Speed goes above a certain threshold, in KPH
   vehEntrsExitsRegion     BOOLEAN                   OPTIONAL,
   -- Vehicle enters or exits the region defined in ConfigBoundary
   emerVehDetect           BOOLEAN                   OPTIONAL,
   -- Emergency vehicle detected by a non-emergency vehicle (MAY NEED TO REVISIT)
   emerAndTransInfo        CfgEmerAndTransitInfo     OPTIONAL,
   -- Info pertaining to emergency or transit vehicles
   v2xMsgRecption          CfgMsgRecepIndicators     OPTIONAL,
   -- V2X message reception: reception of any V2X message over the communications
   -- interface(s), identified by indicating the desired data
   -- dictionary (e.g. SAE J2735, ETSI and ISO data dictionary documents) and
   --  message IDs in the configuration.
   ...
}
```

Used by: DF_CfgInstantaneousEventTriggers

5.2.12 Data Frame: DF_ CfgKinematicEvents

Use: Capture of events related to the movement of the vehicle may be specified. Optionally, before and after samples of time, position, and speed of the vehicle at specified time intervals may be requested.

ASN.1 Representation:

```
CfgKinematicEvents ::= SEQUENCE {
   events            CfgEvents,
   hysteresis        CfgHysteresis        OPTIONAL,
...
}
```

Used by: DF_CfgVehicleEvents

5.2.13 Data Frame: DF_ CfgEvents

Use: Specifies the occurance or condition for kinematic events to be captured.

ASN.1 Representation:

```
CfgEvents ::= SEQUENCE {
   absActivated            BOOLEAN              OPTIONAL,
   tractionCtlLoss         BOOLEAN              OPTIONAL,
   stabilityCtlActivated   BOOLEAN              OPTIONAL,
   hardBraking             BOOLEAN              OPTIONAL,
   swerveThreshold         INTEGER (1..50)      OPTIONAL,
   -- lateral acceleration exceeds a certain threshold
   -- e.g. 18 represents 1.8 m/s2, 36 represents 3.6 m/s2 (units = 0.1 m/s2)
   -- Measured in meters per second squared and the threshold value of comfort
   -- is 1.8 m/s2, with medium comfort and discomfort levels of 3.6 m/s2
   -- and 5 m/s2, respectively.
   ...
}
```

Used by: DF_ CfgKinematicEvents

5.2.14 Data Frame: DF_ CfgHysteresis

Use: Specifies the number and rate of desired samples before and after a kinematic event. A request for ten samples signifies ten samples before the event and ten samples after. When hysteresis is requested, the entire data set associated with the trigger is reported in the PDR.

ASN.1 Representation:

```
CfgHysteresis ::= SEQUENCE {
   hysSamples     INTEGER(1..10),
   -- Value indicates the number of samples before and after the event
   hysRate        INTEGER(1..10),
   -- In 100 mSecs, value indicates sampling interval for hysteresis
   ...
}
```

Used by: DF_ CfgKinematicEvents

5.2.15 Data Frame: DF_ CfgEmerAndTransitInfo

Use: This data frame is used to se the triggering conditions for emergency and transit vehicle data.

ASN.1 Representation:

```
CfgEmerAndTransitInfo ::= CHOICE {
   emerVehLightBar      BOOLEAN,
   -- Emergency vehicle light bar turned on/off (reported by emergency vehicle only)
   reqTspEvp            BOOLEAN,
   -- TSP/EVP requested (transit and emergency vehicles only)
   transitVehPassCnt    BOOLEAN,
   -- Transit Vehicle passenger count change and resulting number of occupants
   transitVehDoor       BOOLEAN,
   -- Transit vehicle door opened and number of passengers entering / exiting
   ...
}
```

Used by: DF_CfgVehicleEvents

5.2.16 Data Frame: DF_CfgMsgRecepIndicators

Use: This data frame is used to indicate V2X messages received by the vehicle. Messages to be detected are identified by message ID and are based on the data dictionary specified. V2X message event reported by a vehicle or probes indicates reception of the message specified in a configuration therefore multiple configurations may be used to identify the message detected.

ASN.1 Representation:

```
CfgMsgRecepIndicators ::= SEQUENCE {
   msgDictionary  CfgMsgDictionary                    OPTIONAL,
   messages SEQUENCE (SIZE(1..8, ...)) OF DSRCmsgID   OPTIONAL,
   --DSRCmsgID imported from DSRC
   ...
}
```

Used by: DF_CfgVehicleEvents

5.2.17 Data Frame: DF_CfgRoadwayEvents

Use: This data frame identifies the roadway events to be captured by the probe or vehicle. Events may include certain detected conditions of a roadway such as detection of an obstacle, or detection of conditions not meeting set thresholds.

ASN.1 Representation:

```
-- The following are criteria by which the associated event will be reported
CfgRoadwayEvents ::= SEQUENCE {
   obstacleDetected        BOOLEAN,
   adverseRoadSurface      BOOLEAN,
   -- Adverse road surface condition (non-weather related: potholes, road roughness).
   trafficSigEncounters    CfgTrafficSigEncounters OPTIONAL,
   -- Traffic signal related parameters
   trfsigLightOut          BOOLEAN,
   trfsigRoadGeoMismatch   BOOLEAN,
   roadSignInfo            CfgRoadSignInfo         OPTIONAL,
   lowLaneMarkReflect      INTEGER (1..100)        OPTIONAL,
   -- Identify types of roadsigns and report back reflectivity
   -- Low lane marking retro reflectivity (falls below a specified threshold
   -- in % light returned)
   roadsignIncnstncy       BOOLEAN,
   -- Roadsign inconsistency or unexpected closure (posted sign inconsistent
   -- with on-board map)
   laneGeoIncnstncy        BOOLEAN,
```

```
      -- Lane geometry inconsistency (difficult to interpret because of being covered
      -- up or ambiguous, or different from on-board map)
      incidentDetect          BOOLEAN,
      -- Incident detection (car accident, wrong way driver, slowdown in
      -- opposite direction)
      workZoneCharDetect      BOOLEAN,
      -- Detection of work zone characteristics: workers present, lane shifts and
      -- lane closures
      inclWeatherDetect       BOOLEAN,
      -- Detection of inclement weather or weather-related road surface
      -- condition (SAE J2945-3 - heavy rain, fog, wind, ice, snow)
      railrdCrossActivated    BOOLEAN,
      -- Railroad crossing activated
      drawBridgeActivated     BOOLEAN,
      -- Draw bridge activated
      ...
   }
```

Used by: DF_CfgInstantaneousEventTrigger

5.2.18 Data Frame: DF_CfgTrafficSigEncounters

Use: This data frame identifies the traffic signal encounters to be captured by the probe or vehicle. The triggering event is based on a corresponding threshold for events related to flow of traffic or status of traffic signals upon arrival at the intersection. Arrival is when the vehicle passes the stop bar at a signalized intersection, or passes the stop or yield sign. The encounter information is only reported for the signal info applicable to the vehicle (i.e., the part of the signal phase and timing inforemation that applies to the vehicle as it passes through the intersection). Connected intersections where SPAT and MAP messages are available can also be identified in this trigger to narrow the triggers to only those intersections.

ASN.1 Representation:

```
   CfgTrafficSigEncounters ::= SEQUENCE {
      intersections           SEQUENCE (SIZE(1..100)) OF IntersectionID OPTIONAL,
      -- Intersection IDs typically used in SPAT and MAP messages
      trfcsigApproachDelay    INTEGER (1..3600) OPTIONAL,
      -- In seconds, triggered if higher
      trfsigApproachSpeed     INTEGER (1..200)  OPTIONAL,
      -- In KPH, triggered if lower
      trfsigArrivalGreen      BOOLEAN           OPTIONAL,
      trfsigArrivalRed        BOOLEAN           OPTIONAL,
      trfsigPedDelay          INTEGER (1..300)  OPTIONAL,
      -- In seconds, triggered if higher
      trfsigSpatMismatch      BOOLEAN           OPTIONAL,
      trfsigSpatTimingError   BOOLEAN           OPTIONAL,
      ...
   }
```

Used by: DF_CfgRoadwayEvents

5.2.19 Data Frame: DF_CfgRoadSignInfo

Use: This data frame identifies the information about road signs to be captured by the probe or vehicle. The expected reflectivity of roadsigns has been identified as means of triggering transmittal of this information.

ASN.1 Representation:

```
CfgRoadSignInfo ::= SEQUENCE {
   roadsignDetection    CfgRoadSignTypes,
   -- Road sign types
   lowRoadsignReflect1  INTEGER (1..250)  OPTIONAL,
   -- min threshold for 1st color
   lowRoadsignReflect2  INTEGER (1..250)  OPTIONAL,
   -- Min threshold for 2nd color

   -- Low roadsign retroreflectivity (in cd/lx/m2 falls below a specified threshold)
   -- Reflectivity threshold is dependent on the type of roadsign
   -- Reference: U.S.DOT, FHWA, Manual on Uniform Traffic Control Devices for
   -- Streets and Highways, 2009 Edition
   ...
}
```

Used by: DF_CfgRoadwayEvents

5.2.20 Data Frame: DF_CfgRoadSignTypes

Use: This data frame identifies the types of road signs. The list is gathered from U.S. DOT, FHWA, Manual on Uniform Traffic Control Devices for Streets and Highways, 2009 Edition.

ASN.1 Representation:

```
CfgRoadSignTypes ::= SEQUENCE {
   whiteOnGreen   BOOLEAN  OPTIONAL,
   blackOnYellow  BOOLEAN  OPTIONAL,
   blackOnOrange  BOOLEAN  OPTIONAL,
   whiteOnRed     BOOLEAN  OPTIONAL,
   blackOnWhite   BOOLEAN  OPTIONAL,
   octagon        BOOLEAN  OPTIONAL,
   eqlatTriangle  BOOLEAN  OPTIONAL,
   circle         BOOLEAN  OPTIONAL,
   pennant        BOOLEAN  OPTIONAL,
   pentagon       BOOLEAN  OPTIONAL,
   crossbuck      BOOLEAN  OPTIONAL,
   diamond        BOOLEAN  OPTIONAL,
   trapezoid      BOOLEAN  OPTIONAL,
   other          Boolean  OPTIONAL,
   -- Reference: U.S.DOT, FHWA, Manual on Uniform Traffic Control Devices for
   -- Streets and Highways, 2009 Edition
   ...
}
```

Used by: DF_CfgRoadSignInfo

5.2.21 Data Frame: DF_CfgCommSysPerfEvents

Use: This data frame identifies the triggering factors to capture communication system performance parameters. The desired information to be captured could be initiated by change of status of certain parameters or triggered by deviation from a set threshold.

ASN.1 Representation:

```
CfgCommSysPerfEvents ::= SEQUENCE {
   j2945-1ChanBusyThresh   INTEGER (1..100)  OPTIONAL,
   -- Based on J2945/1 Channel busy percentage measured over last 100ms
   rfDataRsuInfo           BOOLEAN           OPTIONAL,
   numRsusObservedThresh   INTEGER (1..254)  OPTIONAL,
   -- Threshold for numOfRsusObserved

   -- RF Triggers:
   rfV2xJamDetectThresh    INTEGER (1..140)  OPTIONAL,
   -- 5.9 GHZ V2X Radio Jamming detection (if equipped)in -dBm
   j2945-1VehDensThresh    INTEGER (1..255)  OPTIONAL,
   -- J2945/1 Vehicle Density in range exceeds specified threshold
   -- (number of vehicles)
   j2945-1CqiBelowThresh   INTEGER (1..100)  OPTIONAL,
   -- J2945/1 CQI falls below a specified threshold (poor link quality)
   j2945-1TrackErrorThresh    INTEGER (1..100)  OPTIONAL,
   -- J2945/1 Tracking Error estimate exceed a specified threshold in meters.

   -- GNSS Performance Triggers:
   gnssHdopExceedsThresh   INTEGER (1..20)   OPTIONAL,
   -- HDOP exceeds a specified threshold
   -- If stationary do not report more than once
   gnssSatsBelowThresh     INTEGER (1..20)   OPTIONAL,
   -- Number of Satellites in view goes below a specified threshold
   gnssJammingDetect       BOOLEAN           OPTIONAL,
   -- Jamming detected
   ...
}
```

Used by: DF_CfgInstantaneousEventTrigger

5.2.22 Data Frame: DF_CfgAveragedAndSummaryTriggers

Use: This data frame is used in setting the parameters for an average or summary trigger.

ASN.1 Representation:

```
CfgAveragedAndSummaryTriggers ::= CHOICE {
   averagedTriggers        CfgAveragedTriggers     OPTIONAL,
   summaryTriggers         CfgSummaryTriggers      OPTIONAL,
   ...
}
```

Used by: DF_ ConfigTriggers

5.2.23 Data Frame: DF_CfgAveragedTriggers

Use: This data frame specifies the information to be averaged. The definition of the parameters could include one or a number of measured parameters. The identified parameter(s) are to be averaged within the specified, time, distance, or geography and reported thereafter.

ASN.1 Representation:

```
CfgAveragedTriggers ::= SEQUENCE {
   avgSpeed             BOOLEAN  OPTIONAL,--in KPH
   avgStopDuration      BOOLEAN  OPTIONAL,--in Seconds
   avgFuelConsumption   BOOLEAN  OPTIONAL,--in Liters
   avgEmissions         BOOLEAN  OPTIONAL,
   avgNumOfOccupants    BOOLEAN  OPTIONAL,
   ...
}
```

Used by: DF_CfgAveragedAndSummaryTrigger

5.2.24 Data Frame: DF_CfgSummaryTriggers

Use: This data frame specifies the information to be summarized. The identified parameter(s) are to be measured within the specified, time, distance, or geography and reported thereafter.

ASN.1 Representation:

```
CfgSummaryTriggers ::= SEQUENCE {
   regTravelTime           BOOLEAN              OPTIONAL,
   -- Total travel time to traverse the region in seconds
   regVehDistTraveled      BOOLEAN              OPTIONAL,
   -- Total vehicle distance traveled within the region (kilometers).
   regVehTimeTraveled      BOOLEAN              OPTIONAL,
   -- Total vehicle time traveled within the region (seconds)
   fuelConsumption         BOOLEAN              OPTIONAL,
   -- Total fuel consumption in liters
   totalVehEmissions       BOOLEAN              OPTIONAL,
   -- Total vehicle emissions
   numOfLowSpeedEvents     CfgLowSpeedCriteria  OPTIONAL, -- Low speed threshold
   -- Number of times speed dropped below a low speed threshold (low speed threshold
   -- must be greater than 5 km/h)
   timeStopped             CfgStoppedCriteria   OPTIONAL, -- Stopped speed threshold
   -- Seconds spent at speed less than the specified stopped threshold
   numOfStopped            CfgStoppedCriteria   OPTIONAL,
   -- Number of times the speed fell below the specified stopped threshold
   locOfStops              BOOLEAN              OPTIONAL,
   -- Each location and duration in seconds where the speed drops below the
   -- specified stopped threshold
   regNumOfVehPassed       BOOLEAN              OPTIONAL,
   -- Number of vehicles passed over the configuration region
   regNumOfSurpassedVeh    BOOLEAN              OPTIONAL,
   -- Number of vehicles that passed the recording vehicle over the configuration
   -- region
   totalMsgsReceived       CfgMsgRecepIndicators   OPTIONAL,
   -- Total messages received by the message type indicated in the configuration
   ...
}
```

Used by: DF_CfgAveragedAndSummaryTrigger

5.2.25 Data Frame: DF_CfgLowSpeedCriteria

Use: This data frame specifies the low speed condition used in triggering the data capture. The criteria specifies the low speed threshold and optionally the duration for the speed to stay below the defined threshold before for the LowSpeedCriteria is achieved.

ASN.1 Representation:

```
CfgLowSpeedCriteria  ::= SEQUENCE {
   lowSpeedThreshold       INTEGER (5..100),             -- KPH
   lowSpeedTimeThresh      INTEGER (1..30)   OPTIONAL,   -- in seconds
   ...
}
```

Used by: DF_CfgVehicleEvents and DF_CfgSummaryTriggers

5.2.26 Data Frame: DF_CfgStoppedCriteria

Use: This data frame defines a stop as speed falling below a threshold for certain duration.

ASN.1 Representation:

```
CfgStoppedCriteria ::= SEQUENCE {
   stoppedSpeedThreshold   INTEGER (1..30),  -- in KPH
   amountOfTimeBelow       INTEGER (1..300), -- in seconds
   ...
}
```

Used by: DF_CfgSummaryTriggers

5.2.27 Data Frame: DF_CfgVehicleClass

Use: This data frame allows the requesting entity to identify the types of vehicles or probes to participate in data capture.

ASN.1 Representation:

```
-- The following are FHWA defined vehicle classes (types)
-- See ProbeDataReport module for enumerated values
CfgVehicleClass   ::= SEQUENCE {
   motorcycles                         BOOLEAN,
   passengerCars                       BOOLEAN,
   other2axle4tireSingleUnitVehs       BOOLEAN,
   buses                               BOOLEAN,
   twoAxle6TireSingleUnitTrucks        BOOLEAN,
   threeAxleSingleUnitTrucks           BOOLEAN,
   fourOrMoreAxleSingleUnitTrucks      BOOLEAN,
   fourOrFewerAxleSingleTrailerTrucks  BOOLEAN,
   fiveAxleSingleTrailerTrucks         BOOLEAN,
   sixOrMoreAxleSingleTrailerTrucks    BOOLEAN,
   fiveOrFewerAxleMultiTrailerTrucks   BOOLEAN,
   sixAxleMultiTrailerTrucks           BOOLEAN,
   sevenOrMoreAxleMultiTrailerTrucks   BOOLEAN,
   ...
}
```

Used by: DF_ConfigDescriptor

5.3 PDC Data Elements

5.3.1 Data Element: DE_ConfigId

Use: This data element provides the identifier for the configuration used in capturing the data.

ASN.1 Representation:

```
ConfigId ::= INTEGER (1..255)
```

Used by: DF_ConfigDescriptor

5.3.2 Data Element: DE_CfgMsgDictionary

Use: This data element is used to specify the data dictionary for the detection of messages (e.g., SAE J2735, ETSI, and ISO data).

ASN.1 Representation:

```
CfgMsgDictionary ::= ENUMERATED {
   sae      (1),
   etsi     (2),
   iso      (3),
   ...
}
```

Used by: DF_ CfgMsgRecepIndicators

5.4 Probe Data Configuration Imports

DDate, DTime, DDateTime, DSRCmsgID, IntersectionID, RoadAuthorityID FROM Common {joint-iso-itu-t (2) country (16) us (840) organization (1) sae (114566) v2x-communications (1) technical-committees (1) v2x-core (5) technical-reports (1) j2735 (2735) part-0 (0) asn1-module (1) common (38) version-1 (1)}

```
ValidRegion FROM TravelerInformation {joint-iso-itu-t (2) country (16) us (840) organization (1) sae (114566) v2x-communications (1) technical-committees (1) v2x-core (5) technical-reports (1) j2735 (2735) part-0 (0) asn1-module (1) travelerInformation (20) version-1 (1)}
```

6. PROBE DATA REPORT MESSAGE [NORMATIVE]

In the following object definitions, the ASN.1 entities used by PDMS to define the characteristics for the data to be reported by probes is outilied. Appendix H provides the complete ASN.1 module for PDR.

6.1 Message: MSG_ProbeDataReport (PDR)

Use: This message is used by vehicles and probes to report (upload) gathered data to the requesting PDMS. The message contains a unique identifier that corresponds to the unique set of triggers set forth by the corresponding previously received PDC. The reporting device communicates directly with the requesting PDMS over an IP-based interface.

ASN.1 Representation:

```
ProbeDataReportMessage ::= SEQUENCE {
   configId          ConfigId,
   reportChar        ReportCharacteristics,
   roadAuthorityID   RoadAuthorityID               OPTIONAL,
   instantaneousRecs RptInstantaneousRecords       OPTIONAL,
   avgAndSumRec      RptAveragedAndSummaryRecord   OPTIONAL,
   ...
}(WITH COMPONENTS {..., instantaneousRecs PRESENT} |
  WITH COMPONENTS {..., avgAndSumRec PRESENT})
```

Remarks: This message needs to be added to the SAE J2735 list of messages. The message ID assigned is 36. SSPs used in the certificates attached to this message are defined in Appendix C.

6.2 PDR Data Frames

6.2.1 Data Frame: DF_ReportCharacteristics

Use: This data frame is used by a probe or vehicle as an identifier in relaying captured data to the requesting PDMS. The mandatory parameters provided in this data frame are for the moment this data frame is assembled for transmittal. The captured probe or vehicle data will be accompanied with their corresponding parameters, as specified.

ASN.1 Representation:

```
ReportCharacteristics ::= SEQUENCE {
   -- The next four data elements are mandatory in every report
   timeStamp         DdateTime,
   position          Position3D,
   posaccuracy       PositionalAccuracy,
   velocity          RptVelocity,
   vehicleClass      RptVehicleClass   OPTIONAL, -- FHWA classes
   devType           RptDevType        OPTIONAL, -- OBU Type
   vehicleSize       VehicleSize       OPTIONAL,
   vehicleMass       VehicleMass       OPTIONAL,
   vehPassengerCount INTEGER (1..255)  OPTIONAL,
   ...
}
```

Used by: MSG_ProbeDataReportMessage

6.2.2 Data Frame: DF_RptDevType

Use: This data frame, used by a vehicle or probe, provides the type of OBU in use.

ASN.1 Representation:

```
-- Device Types (OBU type)
RptDevType ::= SEQUENCE {
   oemOrAftermarket  BOOLEAN,
   canOrIvnConnected BOOLEAN,
   mcoCapable        BOOLEAN OPTIONAL,
   ...
}
```

Used by: DF_ReportCharacteristics

6.2.3 Data Frame: DF_RptInstantaneousRecords

Use: This data frame identifies the instantaneous records to follow. As many as 255 instantaneous records may be included in a message.

ASN.1 Representation:

```
RptInstantaneousRecords ::= SEQUENCE (SIZE(1..255, ...)) OF RptInstantaneousRecord
```

Used by: MSG_ProbeDataReportMessage

6.2.4 Data Frame: DF_RptInstantaneousRecord

Use: This data frame is sent when a vehicle or probe has captured data in response to a request for instantaneous data capture. The information relayed back always includes the time, location, and speed of the vehicle at the moment the data was captured.

ASN.1 Representation:

```
RptInstantaneousRecord ::= SEQUENCE {
   timeOfInstantRec  DdateTime,
   locOfInstantRec   Position3D,
   accOfPosition     PositionalAccuracy
   velOfInstantRec   RptVelocity,
   record            RptInstantaneousRecordData OPTIONAL,
   ...
}
```

Used by: DF_RptInstantaneousRecords

6.2.5 Data Frame: DF_RptVelocity

Use: This data frame contains velocity as a combination of heading and speed as defined in J2735.

ASN.1 Representation:

```
-- Heading and Speed imported from J2735
RptVelocity ::= SEQUENCE {
   speed       Speed,               -- in km/h
   speedStdDev StdDev   OPTIONAL,   -- in km/h
   heading     Heading  OPTIONAL,
   ...
}
```

Used by: DF_RptInstantaneousRecord, DF_RptHysteresis, DF_ReportCharacteristics

6.2.6 Data Frame: DF_RptInstantaneousRecordData

Use: This data frame is used by the vehicle or probe to specify the type of response to follow, interval events, vehicle events, roadway events, or communication system performance events.

ASN.1 Representation:

```
RptInstantaneousRecordData ::= CHOICE {
   intervalEvents    RptIntervalEvents,
   vehEvents         RptVehicleEvents,
   roadwayEvents     RptRoadwayEvents,
   commSysPerfEvents RptCommSysPerfEvents,
   ...
}
```

Used by: DF_RptInstantaneousRecord

6.2.7 Data Frame: DF_RptAveragedAndSummaryRecord

Use: This data frame provides the temporal and geographical start and end for the relayed averaged or summary results.

ASN.1 Representation:

```
RptAveragedAndSummaryRecord ::= SEQUENCE {
   startTime      DdateTime,  --Time at the start of data capture
   startLoc       Position3D, --Position at startTime
   startaccOfPos  PositionalAccuracy, --Accuracy of starting position
   endTime        DdateTime,  --Time at the end of data capture
   endLoc         Position3D, -- Position at endTime
   endaccOfPos    PositionalAccuracy,  --Accuracy of ending position
   record         RptAvgAndSummaryRecordData,
   ...
}
```

Used by: MSG_ProbeDataReportMessage

6.2.8 Data Frame: DF_RptAvgAndSummaryRecordData

Use: This data frame provides the captured averaged or summary results.

ASN.1 Representation:

```
RptAvgAndSummaryRecordData ::= CHOICE {
   averagedRecord    RptAveragedRecord,
   summaryRecord     RptSummaryRecord,
   ...
}
```

Used by: DF_RptAveragedAndSummaryRecord

6.2.9 Data Frame: DF_RptIntervalEvents

Use: This data frame provides the results of the captured information at the intervals specified in the configuration.

ASN.1 Representation:

```
RptIntervalEvents ::= SEQUENCE {
   wiperStatus    RptWiperStatus       OPTIONAL,
   vehCount       INTEGER (0..10000)   OPTIONAL,
   -- Number of V2V-equipped vehicles encountered
   weatherData    RptVehicleReport     OPTIONAL,
   transitVehData RptTransitVehData    OPTIONAL,
   numOfOccupants INTEGER (0..255)     OPTIONAL,
   -- 254 indicates > 253, 255 is reserved
   ...
}
```

Used by: DF_RptInstantaneousRecordData

6.2.10 Data Frame: DF_RptVehicleReport

Use: This data frame contains weather data information as defined in the RWM message specified by SAE J2945/3.

ASN.1 Representation:

```
RptVehicleReport ::= SEQUENCE (SIZE(1..32)) OF NtcipEssData
-- NtcipEssData is defined in RWM (J2945/3)
```

Used by: DF_RptIntervalEvents.

6.2.11 Data Frame: DF_RptTransitVehData

Use: This data frame provides the data gathered by transit vehicle at specified intervals.

ASN.1 Representation:

```
RptTransitVehData ::= SEQUENCE {
   currNumPasngers   INTEGER (0..255)     OPTIONAL,
   avgNumPasngers    INTEGER (0..255)     OPTIONAL,
   trnstVehSchAdh    INTEGER (-200..55)   OPTIONAL,
-- Neg nums indicates running behind,
-- positive indicates running ahead of schedule, in minutes
   ...
}
```

Used by: DF_ RptIntervalEvents

6.2.12 Data Frame: DF_RptVehicleEvents

Use: This data frame provides the results of the captured vehicle events specified in the configuration. TRUE is transmitted if the corresponding event occurred (triggered). V2X message event indicates reception of the message specified in a configuration therefore multiple configurations may be used to identify the message detected.

ASN.1 Representation:

```
RptVehicleEvents ::= CHOICE {
   headLights           NULL,
   fogLights            NULL,
   hazardLights         NULL,
   kinematicEvents      RptKinematicEvents,
   wiperStatusChange    NULL,
   lowSpeed             NULL,
   resumedSpeed         NULL,
   vehEntrsExitsRegion  NULL,
   emerVehDetect        NULL,
   emerVehLightBar      NULL,
   reqTspEvp            NULL,
   transitVehPassCnt    NULL,
   transitVehDoor       NULL,
   v2xMsgRecption       NULL,
   -- Indicates reception of the V2X message identified in the configuration.
   driverAlertsAndWarnings    RptDriverAlertsAndWarnings,
   ...
}
```

Used by: DF_RptInstantaneousRecordData

6.2.13 Data Frame: DF_ RptDriverAlertsAndWarnings

Use: This data frame provides the details of driver alerts and warnings. Most are defined in SAE J2945/1, and this document defines additional categories.

ASN.1 Representation:

```
RptDriverAlertsAndWarnings ::= CHOICE {
   j2945Slash1Eebl         NULL,
   -- Emergency Electronic Brake Lights
   j2945Slash1Fcw          NULL,
   -- Forward Crash Warning
   j2945Slash1BswLcw       NULL,
   -- Blind Spot Warning/Lane Change Warning
   j2945Slash1Ima          NULL,
   -- Intersection Movement Assist
   j2945Slash1Lta          NULL,
   -- Left Turn Assist
   j2945Slash1Clw          NULL,
   -- Control Loss Warning
   redLightViolationWarn   NULL,
   emerVehAlert            NULL,
   otherAlert              NULL,
   otherWarning            NULL,
   ...
}
```

Used by: DF_ RptVehicleEvents

6.2.14 Data Frame: DF_RptKinematicEvents

Use: This data frame provides data on events that occur while vehicle is in motion. The information will include sample before and after the identified event.

ASN.1 Representation:

```
RptKinematicEvents ::= SEQUENCE {
   events            RptEvents,
   hysteresis        RptHysteresisRecord  OPTIONAL,
   ...
}
```

Used by: DF_ RptVehicleEvents

6.2.15 Data Frame: DF_RptEvents

Use: This data frame identifies the kinematic event that has occurred.

ASN.1 Representation:

```
RptEvents ::= CHOICE {
   absActive            BOOLEAN,
   tractionCtlLoss      BOOLEAN,
   stabilityCtlActive   BOOLEAN,
   hardBraking          BOOLEAN, -- Defined in J2945/1
   swerve               BOOLEAN,
   ...
}
```

Used by: DF_ RptKinematicEvents

6.2.16 Data Frame: DF_RptHysteresisRecord

Use: This data frame provides up to 20 data samples showing the vehicle or device location and velocity before and after the triggered event, a maximum of ten before and ten after the detected event.

ASN.1 Representation:

```
RptHysteresisRecord ::= SEQUENCE (SIZE(1..20)) OF RptHysteresis
```

Used by: DF_ RptKinematicEvents

6.2.17 Data Frame: DF_RptHysteresis

Use: This data frame provides the parameters captured before and after a kinematic event.

ASN.1 Representation:

```
RptHysteresis ::= SEQUENCE {
   time                Dtime,
   position            Position3D,
   positionalAccuracy  PositionalAccuracy   OPTIONAL,
   velocity            RptVelocity,
   ...
}
```

Used by: DF_ RptHysteresisRecord

6.2.18 Data Frame: DF_RptRoadwayEvents

Use: This data frame provides the results of the captured roadway events.

ASN.1 Representation:

```
RptRoadwayEvents ::= CHOICE {
   obstacleDetected        NULL,
   adverseRoadSurface      RptRoadRoughness,
   trfsigEncounters        RptTrafficSigEncounters,
   trfsigLightOut          NULL,
   roadsignDetection       NULL,
   lowRoadsignReflect      NULL,
   lowLaneMarkReflect      NULL,
   roadsignIncnstncy       NULL,
   laneGeoIncnstncy        NULL,
   incidentDetect          NULL,
   workZoneCharDetect      NULL,
   inclWeatherDetect       NULL,
   railrdCrossActiv        NULL,
   drawBridgeActiv         NULL,
   ...
}
```

Used by: DF_RptInstantaneousRecordData

6.2.19 Data Frame: DF_RptTrafficSigEncounters

Use: This data frame provides the traffic conditions at intersections encountered by the vehicle.

ASN.1 Representation:

```
RptTrafficSigEncounters ::= SEQUENCE {
    intersectionID          IntersectionID  OPTIONAL, -- Imported from J2735
    -- Received by OBU in SPAT and MAP messages
    trafficMetrics          RptTrafficMetrics,
    ...
   }
```

Used by: DF_ RptRoadwayEvents

6.2.20 Data Frame: DF_RptTrafficMetrics

Use: This data frame provides the traffic flow information at intersections encountered by the vehicle.

ASN.1 Representation:

```
RptTrafficMetrics ::= CHOICE {
    trfsigApproachDelay     NULL,
    trfsigApproachSpeed     NULL,
    trfsigArrivalGreen      NULL,
    trfsigArrivalRed        NULL,
    trfsigPedDelay          NULL,
    trfsigSpatMismatch      NULL,
    trfsigSpatTimingError   NULL,
    ...
}
```

Used by: DF_ RptTrafficSigEncounters

6.2.21 Data Frame: DF_RptCommSysPerfEvents

Use: This data frame provides the captured communication system performance events.

ASN.1 Representation:

```
RptCommSysPerfEvents ::= SEQUENCE {
   j2945-1ChanBusy         NULL,
   rfDataRsuInfo           OCTET STRING (SIZE(6)),
   -- Report Source MAC / Layer 2 Source ID of any RSUs that we see/hear
   numOfRsusObserved       INTEGER (1..255),
   -- Count of encountered RSUs if count is higher than threshold
   rfV2xJamDetect          NULL,
   j2945-1VehDens          NULL,
   j2945-1CqiBelow         NULL,
   j2945-1TrackingError    NULL,
   gnssHdopExceeds         NULL,
   gnssErrElipse           NULL,
   gnssSatsBelow           NULL,
   jammingDetect           NULL,
   ...
}
```

Used by: DF_RptInstantaneousRecordData

6.2.22 Data Frame: DF_RptAveragedRecord

Use: This data frame provides the results of any averaged data that is requested.

ASN.1 Representation:

```
RptAveragedRecord ::= SEQUENCE {
   avgSpeed             Speed               OPTIONAL,
   -- in km/h
   speedStdDev          StdDev              OPTIONAL,
   -- in km/h
   avgStopDuration      INTEGER (1..36000)  OPTIONAL,
   -- in tenths of seconds up to an hour
   avgStopStdDev        StdDev              OPTIONAL,
   -- in tenths of seconds
   avgFuelConsumption   INTEGER (1..255)    OPTIONAL,
   avgEmissions         RptEmissions        OPTIONAL,
   avgNumOfOccupants    INTEGER (1..255)    OPTIONAL,
   ...
}
```

Used by: DF_RptAvgAndSummaryRecordData

6.2.23 Data Frame: DF_RptSummaryRecord

Use: This data frame provides the results of any summary records requested.

ASN.1 Representation:

```
RptSummaryRecord ::= SEQUENCE {
   regTravelTime        INTEGER (1..3600)    OPTIONAL,
   -- Total travel time to traverse the region in seconds
   regVehDistTraveled   INTEGER (1..500)     OPTIONAL,
   -- Total vehicle distance traveled in kilometers
   regVehTimeTraveled   INTEGER (1..3600)    OPTIONAL,
   -- Total vehicle time traveled within the region (seconds)
   fuelConsumption      INTEGER (1..255)     OPTIONAL,
   -- Total fuel consumption in liters
   totalVehEmissions    RptEmissions         OPTIONAL,
   -- Total vehicle emissions
   numOfLowSpeedEvents  INTEGER (1..255)     OPTIONAL,
   -- Number of times speed dropped below a low speed threshold
   timeStopped          INTEGER (1..36000)   OPTIONAL,
   -- Total stopped time in tenths of seconds up to an hour
   numOfStopped         INTEGER (1..255)     OPTIONAL,
   -- Number of times the speed fell below the specified threshold
   locOfStops           RptLocOfStops        OPTIONAL,
   -- Each location and duration in seconds where the speed drops below
   -- the specified stopped threshold for the specified duration
   regNumOfVehPassed    INTEGER  (1..255)    OPTIONAL,
   -- Number of vehicles passed over the configuration region
   regNumOfSurpassedVeh INTEGER  (1..255)    OPTIONAL,
   -- Number of vehicles that passed the recording vehicle over the configuration
   -- region
   totalMsgsReceived    INTEGER  (1..255)    OPTIONAL,
   -- Total messages received by the message type indicated in the configuration
   ...
}
```

Used by: DF_RptAvgAndSummaryRecordData

6.2.24 Data Frame: DF_RptEmissions

Use: This data frame provides the results of emission data gathered.

ASN.1 Representation:

```
RptEmissions ::= SEQUENCE {
   hydrocarbons   INTEGER (1..1000) OPTIONAL, -- in parts per million
   co             INTEGER (1..1000) OPTIONAL, -- in parts per million
   co2            INTEGER (1..1000) OPTIONAL, -- in parts per billion
   no             INTEGER (1..1000) OPTIONAL, -- in parts per million
   no2            INTEGER (1..1000) OPTIONAL, -- in parts per billion
   so2            INTEGER (1..1000) OPTIONAL, -- in parts per billion
   o3             INTEGER (1..1000) OPTIONAL, -- in parts per 100 billion
   -- Particulates of 10 micrometers or less in diameter
   pm10           INTEGER (1..1000) OPTIONAL, -- in micrograms per cubic meter
   -- Particulates of 2.5 micrometers or less in diameter
   pm25           INTEGER (1..1000) OPTIONAL, -- in micrograms per cubic meter
   ...
}
```

Used by: DF_RptAveragedRecord and DF_RptSummaryRecord

6.2.25 Data Frame: DF_RptLocOfStops

Use: This data frame provides the position and duration for each stop made by the vehicle.

ASN.1 Representation:

```
RptLocOfStops ::= SEQUENCE {
   locationOfStop    Position3D,
   locAccOfStop      PositionalAccuracy,  -- Imported from J2735
   durationOfStop    INTEGER  (1..36000), -- in tenths of seconds up to an hour
   ...
}
```

Used by: DF_RptSummaryRecord

6.2.26 Data Frame: DF_ RptRoadRoughness

Use: This data frame provides a measure for road roughness and can be used to report bumpy roads and potholes.

ASN.1 Representation:

```
RptRoadRoughness ::= SEQUENCE {
   meanVerticalVariation      MeanVariation,
   verticalVariationStdDev    StdDev            OPTIONAL,
   -- Standard deviation in microns
   meanHorizontalVariation    MeanVariation     OPTIONAL,
   horizontalVariationStdDev  StdDev            OPTIONAL,
   -- Standard deviation in microns
   ...
}
```

Used by: DF_ RptRoadwayEvents

6.3 PDR Data Elements

6.3.1 Data Element: DE_RptVehicleClass

Use: This data element allows the requesting entity to identify the types of vehicles or probes to participate in data capture.

ASN.1 Representation:

```
-- The following are FHWA defined vehicle classes (types)
RptVehicleClass   ::= ENUMERATED {
   motorcycles                          (1),
   passengerCars                        (2),
   other2axle4tireSingleUnitVehs        (3),
   buses                                (4),
   twoAxle6TireSingleUnitTrucks         (5),
   threeAxleSingleUnitTrucks            (6),
   fourOrMoreAxleSingleUnitTrucks       (7),
   fourOrFewerAxleSingleTrailerTrucks   (8),
   fiveAxleSingleTrailerTrucks          (9),
   sixOrMoreAxleSingleTrailerTrucks     (10,
   fiveOrFewerAxleMultiTrailerTrucks    (11),
   sixAxleMultiTrailerTrucks            (12),
   sevenOrMoreAxleMultiTrailerTrucks    (13),
   ...
}
```

Used by: DF_ReportCharacteristics

6.3.2 Data Element: DE_RptWiperStatus

Use: This data element is used in relaying the status of wipers in a vehicle.

ASN.1 Representation:

```
RptWiperStatus ::= ENUMERATED {off, low, medium, high, ...}
```

Used by: DF_RptIntervalEvents and DF_RptInstantaneousRecord

6.3.3 Data Element: DE_ MeanVariation

Use: This data element provides the mean value of the size measurements of a detected adverse road condition.

ASN.1 Representation:

```
MeanVariation ::= INTEGER (0..25000)
    -- Measured in microns (.001 mm)
    -- Range is 0 to 25 mm (0 to 25000 microns)
    -- Measured in microns (.001 mm)
```

Used by: DF_ RptRoadRoughness

6.3.4 Data Element: DE_ StdDev

Use: This data element provides the standard deviation of of the size measurements of a detected adverse road condition.

ASN.1 Representation:

```
StdDev ::= INTEGER (0..10000)
```

Used by: DF_ RptRoadRoughness and DF_RptAveragedRecord

6.4 Probe Data Report Imports

```
   Dtime, DdateTime, IntersectionID, Speed, Heading, PositionalAccuracy, Position3D,
RoadAuthorityID, VehicleSize, VehicleMass FROM Common {joint-iso-itu-t (2) country (16) us
(840) organization (1) sae (114566) v2x-communications (1) technical-committees (1) v2x-
core (5) technical-reports (1) j2735 (2735) part-0 (0) asn1-module (1) common (38) version-
1 (1)}

   NtcipEssData FROM RoadWeatherMessage {joint-iso-itu-t (2) country (16) us (840)
organization (1) sae (114566) v2x-communications (1) technical-committees (6)
infrastructure-applications (6) technical-reports (1) j2945 (2945) slash-3 (3) asn1-module
(1) roadWeatherMessage (1) version-2 (2)}

   ConfigId FROM ProbeDataConfig {joint-iso-itu-t (2) country (16) us (840) organization
(1) sae (114566) v2x-communications (1) technical-committees (1) infrastructure-
applications (6) technical-reports (1) j2945 (2945) slash-c (12) asn1-module (1)
probeDataConfig (1) version-1 (1)}
```

7. NOTES

7.1 Revision Indicator

A change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY INFRASTRUCTURE APPLICATIONS TECHNICAL COMMITTEE

APPENDIX A - REQUIREMENTS TRACEABILITY MATRIX (RTM) [NORMATIVE]

A.1 NOTATION [INFORMATIVE]

Refer to SAE J2945.

A.2 INSTRUCTIONS FOR COMPLETING THE RTM [INFORMATIVE]

Refer to SAE J2945.

A.3 REQUIREMENTS TRACEABILITY MATRIX (RTM) TABLE

Table 17 - NRTM table

Requirements Traceability Matrix (RTM)					
FR ID	**Functional Requirement**	**Dialog ID**	**Object ID**	**Object Name**	**Additional Specifications**
3.4	Architectural requirements				
3.4.1	Communications interfaces				
3.4.1.1	Configuration interface	4.2.1	5.1	Message: MSG_ProbeDataConfigMessage (PDC)	
3.4.1.2	Data collection interface	4.2.2	6.1 5.3.1	Message: MSG_ProbeDataReport (PDR) Data Element: DE_ConfigId	
3.5	Message/features requirements				
3.5.1	Configure probe data recording	4.2.1	5.2.1 5.2.2 5.2.6	Data Frame: DF_ProbeDataConfig Data Frame: DF_ConfigDescriptor Data Frame: DF_ConfigTrigger	
3.5.1.1	Configuration descriptor	4.2.1	5.2.2	Data Frame: DF_ConfigDescriptor	
3.5.1.1.1	Configuration identifier	4.2.1	5.3.1	Data Element: DE_ConfigId	
3.5.1.1.2	Vehicle selection	4.2.1	5.2.27	Data Frame: DF_CfgVehicleClass	
3.5.1.1.3	Vehicle participation	4.2.1	5.2.2	Data Frame: DF_ConfigDescriptor	
3.5.1.2	Configuration temporal boundary	4.2.1	5.2.3 5.2.4 5.2.5	Data Frame: DF_ConfigBoundary Data Frame: DF_ConfigTemporalBoundary Data Frame: DF_CfgEventRecurrence	
3.5.1.3	Configuration geographical boundary	4.2.1	5.2.3 SAE J2735	Data Frame: DF_ConfigBoundary ValidRegion	
3.5.1.4	Configuration total distance traveled	4.2.1	5.2.3 SAE J2735	Data Frame: DF_ConfigBoundary ValidRegion	
3.5.1.5	Maximum age of data	4.2.1	5.2.1	Data Frame: DF_ProbeDataConfig	
3.5.1.6	Triggers				
3.5.1.6.1	Triggers resulting in instantaneous records (event based)	4.2.1	5.2.6 5.2.7 5.2.8 5.2.11 5.2.17 5.2.21	Data Frame: DF_ConfigTrigger Data Frame: DF_CfgInstantaneousEventTrigger Data Frame: DF_CfgVehicleEvents Data Frame: DF_CfgRoadwayEvents Data Frame: DF_CfgCommSysPerfEvents	
3.5.1.6.1.1	Interval-based events	4.2.1	5.2.8 5.2.10 5.2.9	Data Frame: DF_CfgIntervalEvents Data Frame: DF_CfgInterval Data Frame: DF_CfgTransitVehicleData	
3.5.1.6.1.2	Vehicle events	4.2.1	5.2.11 5.2.12 5.2.13 5.2.14 5.2.25 5.2.15 5.2.16 5.3.2	Data Frame: DF_CfgVehicleEvents Data Frame: DF_ CfgKinematicEvents Data Frame: DF_ CfgEvents Data Frame: DF_ CfgHysteresis Data Frame: DF_CfgLowSpeedCriteria Data Frame: DF_ CfgEmerAndTransitInfo Data Frame: DF_CfgMsgRecepIndicators Data Element: DE_CfgMsgDictionary	
3.5.1.6.1.3	Roadway events	4.2.1	5.2.17 5.2.18 5.2.19 5.2.20	Data Frame: DF_CfgRoadwayEvents Data Frame: DF_CfgTrafficSigEncounters Data Frame: DF_CfgRoadSignInfo Data Frame: DF_CfgRoadSignTypes	

Requirements Traceability Matrix (RTM)					
FR ID	Functional Requirement	Dialog ID	Object ID	Object Name	Additional Specifications
3.5.1.6.1.4	Communications system performance events	4.2.1	5.2.21	Data Frame: DF_CfgCommSysPerfEvents	
3.5.1.6.2	Triggers resulting in averaged and summary records	4.2.1	5.2.22 5.2.25 5.2.26	Data Frame: DF_CfgAveragedAndSummaryTriggers Data Frame: DF_CfgLowSpeedCriteria Data Frame: DF_CfgStoppedCriteria	
3.5.1.6.2.1	Averaged records	4.2.1	5.2.23	Data Frame: DF_CfgAveragedTriggers	
3.5.1.6.2.2	Summary records	4.2.1	5.2.24	Data Frame: DF_CfgSummaryTriggers	
3.5.1.7	Vehicle class	4.2.1	5.2.27	Data Frame: DF_CfgVehicleClass	
3.5.2	Receive probe data reports				
3.5.2.1	Receive configuration identifier	4.2.2	6.1 5.3.1	MSG_Message: MSG_ProbeDataReport (PDR) Data Element: DE_ConfigId	
3.5.2.2	Received report characteristics	4.2.2	6.2.1 6.2.5 6.3.1 6.2.2	Data Frame: DF_ReportCharacteristics Data Frame: DF_RptVelocity Data Element: DE_RptVehicleClass Data Frame: DF_RptDevType	
3.5.2.3	Contents of record(s)	4.2.2	6.1 6.2.3 6.2.7	Message: MSG_ProbeDataReport (PDR) Data Frame: DF_RptInstantaneousRecords Data Frame: DF_RptAveragedAndSummaryRecord	
3.5.2.4	Instantaneous record(s)	4.2.2	6.2.6	Data Frame: DF_RptInstantaneousRecordData	
3.5.2.4.1	Time of instantaneous record(s)	4.2.2	6.2.4	Data Frame: DF_RptInstantaneousRecord	
3.5.2.4.2	Location of instantaneous record(s)	4.2.2	6.2.4	Data Frame: DF_RptInstantaneousRecord	
3.5.2.4.3	Velocity of instantaneous record(s)	4.2.2	6.2.4 6.2.5	Data Frame: DF_RptInstantaneousRecord Data Frame: DF_RptVelocity	
3.5.2.4.4	Interval-based data	4.2.2	6.2.9 6.2.10 6.2.11 6.3.2	Data Frame: DF_RptIntervalEvents Data Frame: DF_RptVehicleReport NtcipEssData Data Frame: DF_RptTransitVehData Data Element: DE_RptWiperStatus	RWM 2945/3
3.5.2.4.5	Vehicle and device data	4.2.2	6.2.12 6.2.13 6.2.14 6.2.15 6.2.16 6.2.17 6.2.5	Data Frame: DF_RptVehicleEvents Data Frame: DF_ RptDriverAlertsAndWarnings Data Frame: DF_RptKinematicEvents Data Frame: DF_RptEvents Data Frame: DF_RptHysteresisRecord Data Frame: DF_RptHysteresis Data Frame: DF_RptVelocity	
3.5.2.4.6	Roadway data	4.2.2	6.2.18 6.2.19 6.2.26 6.3.3 6.3.4	Data Frame: DF_RptRoadwayEvents Data Frame: DF_RptTrafficSigEncounters Data Frame: DF_ RptRoadRoughness Data Element: DE_ MeanVariation Data Element: DE_ StdDev	
3.5.2.4.7	Communications system performance data	4.2.2	6.2.21	Data Frame: DF_RptCommSysPerfEvents	
3.5.2.5	Averaged and summary records	4.2.2	6.2.7	Data Frame: DF_RptAveragedAndSummaryRecord	
3.5.2.5.1	Start time	4.2.2	6.2.7	Data Frame: DF_RptAveragedAndSummaryRecord	startTime
3.5.2.5.2	End time	4.2.2	6.2.7	Data Frame: DF_RptAveragedAndSummaryRecord	endTime
3.5.2.5.3	Start location	4.2.2	6.2.7	Data Frame: DF_RptAveragedAndSummaryRecord	startLocation
3.5.2.5.4	End location	4.2.2	6.2.7	Data Frame: DF_RptAveragedAndSummaryRecord	endLocation

Requirements Traceability Matrix (RTM)					
FR ID	**Functional Requirement**	**Dialog ID**	**Object ID**	**Object Name**	**Additional Specifications**
3.5.2.5.5	Averaged data	4.2.2	6.2.8 6.2.22 6.2.24 6.3.4	Data Frame: DF_RptAvgAndSummaryRecordData Data Frame: DF_RptAveragedRecord Data Frame: DF_RptEmissions Data Element: DE_ StdDev	
3.5.2.5.6	Summary data	4.2.2	6.2.8 6.2.23 6.2.24 6.2.25	Data Frame: DF_RptAvgAndSummaryRecordData Data Frame: DF_RptSummaryRecord Data Frame: DF_RptEmissions Data Frame: DF_RptLocOfStops	
3.6	Security				
3.6.1.1	Roadside units	4.2.1, 4.2.2	NA	NA	Appendix C
3.6.1.2	Probe data management subsystem	4.2.1, 4.2.2	NA	NA	Appendix C
3.6.1.3	Probe data report upload destination	4.2.1, 4.2.2	NA	NA	Appendix C
3.6.2	Data integrity and availability	4.2.1, 4.2.2	NA	NA	Appendix C
3.6.4	Identification	4.2.1, 4.2.2	NA	NA	Appendix C
3.6.4.1	Discarding identifying information	4.2.1, 4.2.2	NA	NA	Appendix C
3.6.4.2	Secure and privacy-aware storage of security credentials	4.2.1, 4.2.2	NA	NA	Appendix C

APPENDIX B - IEEE 1609.3 CONFIGURATION [NORMATIVE]

B.1 WSMP

The recommended repetition rate for broadcast WSMs containing PDC from roadside to vehicle is one to two times per second, but system deployers are free to choose the most appropriate rate for their environment. Refer to SAE J2945 or SAE J3161 for recommendations on user priority and corresponding parameters.

Table 18 - WSMP configuration parameters

Parameter	Recommended Setting	Notes
Peer MAC address/layer 2 destination ID	All 1s (binary)	Broadcast address
PSID	0x84	Mobile probe exchanges
Channel identifier	Chosen by implementer	
Transmit power level	Refer to recommended maximums in SAE J2945 and SAE J3161; lower power may be desirable in some cases	May be changed by the implementer to meet challenges of the RF environment at the RSU location

B.2 WSA

The recommended WSA configuration used is shown in Table 19.

Table 19 - Recommended WSA configuration parameters

Parameter	Recommended Setting	Notes
Basic Parameters (Local WSMP and Local and Network IP-Based Services)		
WSA transmit power	Set by system implementer	May vary from installation to installation
WSA data rate		
WSA channel identifier		
Repeat rate	Five (transmitted five times in a 5 second interval) to ten (transmitted ten times in a 5 second interval)	
PSID	0x84	
PSC	Set by system implementer	Typically not used
Service channel identifier	Set by system implementer	If the implementer desires to have data uploaded via a cellular network, the implementer sets the alternate interface field accordingly (refer to IEEE 1609.3)
Channel access	Immediate	May not apply in single-channel systems
Transmit power	Refer to recommended maximums in SAE J2945 or SAE J3161; lower power may be desirable in some cases	Power in dBm
Priority (EDCA parameter set or PPPP)	Refer to J2945 or SAE J3161	Refer to SAE J2945 or SAE J3161
IP Service Parameters (Not Used if WSMP-Based)		
IPv6 address	Set by system implementer	
Service port	Set by system implementer	
Provider MAC address/layer 2 destination ID	Set by system implementer	Used only if separate provider and advertiser
WRA (Used to Support the Session-Oriented Interface)		
Router lifetime	Set by system implementer (may vary from installation to installation)	
IP prefix		
Prefix length		
Default gateway		
Primary DNS		Required if a URL is used
Secondary DNS		Optional
Gateway MAC address		Optional

APPENDIX C - SECURITY [NORMATIVE]

C.1 PDC BROADCAST SECURITY PROFILE [NORMATIVE]

C.1.1 IEEE 1609.2 Security Profile Identification

Table 20 provides the security profile identification features for PDCs broadcast by RSUs. This broadcast uses a WAVE Short Message to carry the PDC, and the URL used to indicate to the vehicle/device shall be included in certificateID type hostname within the certificate attached to the signed PDC (refer to IEEE 1609.2 for the exact certificate structure).

When using a WSA, the security profile defined for WSAs in IEEE 1609.3 is used with the additional requirement that the certificate used to sign the WSA shall include the URL in the certificateID type hostname (refer to IEEE 1609.2 for the exact certificate structure). This URL is used to indicate to the vehicle/device the destination of the PDR.

Table 20 - PDC broadcast application security profile identification

Name	Type	Recommended Values	Description
Name	Text string	“PDC_Broadcast_Security_Profile”	
PSID	List of PSID	0x84	The PSID to be used by SDEEs that use this profile.
Other considerations	Text string	This security profile is used for broadcasting probe-related information from RSUs	A description of the conditions under which this security profile is to be used.

C.1.2 Sending

Table 21 provides the security profile for message sending within the probe data PSID.

Table 21 - PDC application security profile for sending messages

Name	Type	Recommended Values	Notes
Sign data	Enumerated	True	Sign all broadcast PDC messages for data origin authentication and non-repudiation.
Signed data in payload	Boolean	True	
External data	Boolean	False	
External data source	Text	NA	
External data hash algorithm	Enumerated	NA	
Set generation time in security headers	Boolean	True	Needed to determine if message lies within the validity period of the signing credential. In this case, the generation time is the time that the RSU or WDMS encapsulated and signed the PDC source message for relay. Due to SAE J2735 timestamp and 1609.2 Time64 encoding mismatches, time is re-expressed in a valid 1609.2 format by the sender in the security header.
Set generation location in security headers	Boolean	False	Signed messages (by the RSU or by the PDMS) do not need to indicate generation location. The signing certificate will indicate “authority to sign” for a given region.
Set expiry time in security headers	Boolean	True	
Signed SPDU lifetime	Time interval	Variable	The signing application needs to set the time interval for this SPDU lifetime. The recommended default value is 240 minutes, but the actual value may vary considerably depending on the PDC content. The shorter the SPDU lifetime, the shorter the period of validity for the vehicle/probe data. In a rapidly changing environment, the desirable lifetime may be shorter.
Signer identifier policy type	Enumerated	Simple	

Name	Type	Recommended Values	Notes
Simple signer identifier policy: Minimum inter cert time	Time interval (for example, “1 second”)	Always	All PDC messages will contain the signing public key certificate.
Simple signer identifier policy: Exceptions	Boolean	False	
Simple signer identifier policy: Signer identifier cert-chain length	Integer or enumerated	1	Will use the RSU’s or WDMS’s authorization certificate only within the message. We will assume full pre-distribution of CA certs to the fleets.
Text signer identifier policy	Text	NA	
Sign with fast verification	Enumerated	Yes: Compressed	
EC point format	Enumerated	Compressed	Matches convention established for other SAE J2735 messages.
p2pcd_useInteractive-Form	Boolean	False	PDC doesn’t fit the P2PCD paradigm where the device requesting the certs sends the same messages as the device using the certs, so P2PCD doesn’t work here.
p2pcd_max-ResponseBackoff	Time or NA	NA	
p2pcd_response-ActiveTimeout	Time or NA	NA	
p2pcd_request-ActiveTimeout	Time or NA	NA	
p2pcd_observed-RequestTimeou	Time or NA	NA	
p2pcd_currentlyUsed-TriggerCertificate-Time	Time or NA	NA	
p2pcd_response-CountThreshold	Integer or NA	NA	
Repeat Signed SPDUs	Boolean	True	Following the initial, transmitted PDU containing PDC, each following one may be a re-transmit of the first so long as they are within the validity period of the message (as set by the signing application).
Time between signing	Time or NA	Set to message lifetime	Note that if the message changes, it is in effect a new message, and a new signature is generated.
Encrypt data	Enumerated	No	PDC messages are in plaintext.
PDU functional types	List of enumerated values	Application PDU TLS Handshake	The PDU functional types that may be signed with certificates containing the PSID reflect the fact that this certificate can be used in TLS handshake.

C.1.3 Receiving

Table 22 provides the message reception security features for the PDC broadcast application security profile.

Table 22 - PDC broadcast application security profile for receiving messages

Name	Type	Recommended Values	Notes
Use preprocessing	Enumerated	True	The full certificate chain will not be received with PDC messages (devices are assumed configured with certificate authority certificates necessary to establish trust). Refer to IEEE 1609.2 for further information on constructing certificate chains.
Verify data	Enumerated	True	Verify all unique PDC messages.
Relevance: replay	Boolean	False	RSU will purposefully be replaying messages.
Relevance: Generation time in past	Boolean	False	
Validity period	Time interval	NA	Use expiry time, not generation time, to decide whether to reject messages.
Relevance: Generation time in future	Boolean	True	

Name	Type	Recommended Values	Notes
Acceptable future data period	Time	48 hours	
Generation time source	Enumerated	Security header	
Relevance: Expiry time	Boolean	True	
Expiry time source	Enumerated	Security header	
Consistency: Generation location	Boolean	False	
Relevance: Generation location distance	Boolean or text	False	
Validity distance	Distance in meters or variable	NA	The geographic area to which the message applies is part of the RWM contents.
Generation location source	Enumerated	NA	
Additional geographic consistency conditions	Boolean	False	
Identified region representation accuracy	Text or NA	NA	
Overdue CRL tolerance	Time period or text	NA	RSU or WDMS cert will not be revoked; it will expire.
Relevance: Certificate expiry	Boolean	True	
Accept encrypted data	Enumerated or text	No	This entire message should be in plaintext.

C.1.4 Security Management

Table 23 provides the security management features for the PDC broadcast application security profile.

Table 23 - PDC broadcast application security management security profile

Name	Type	Value	Notes
Signing key algorithm	Enumerated	ecdsaNistP256withSha256	
Encryption algorithm	Enumerated	NA	
Implicit or explicit certificates	Enumerated	Implicit	What is supported by SCMS.
EC point format	Enumerated	Compressed	Point compression more vital on rapidly transmitted messages.
SupportedGeographic regions	Array of enumerated	Rectangular, Polygonal, Identified: Country and Subregions	The type of geographic region supported for conformant certificates. For example, a region could be the USA, and a subregion could be state or county. For smaller or more complex subregions, polygons or rectangles can be used.
Maximum certificate chain length	Integer	8	
Use individual linkage ID	Boolean	NA	
Use group linkage ID	Boolean	NA	
Signature algorithms in chain or CRL	Sequence of enumerated	ecdsaNistP256withSha256	

C.1.5 Other

Table 23 provides the security management features for the PDC broadcast application security profile.

Table 24 - Fields subject to policy updates

Field	Type	Value	Notes
Fields that may be subject to policy update		Overdue CRL tolerance, p2pcd_flavor, signing key algorithm, signature algorithms in chain or CRL.	These fields may be updated by a SCMS in the future.

C.2 IP INTERFACE [NORMATIVE]

For session-oriented data exchange with the PDMS, ISO 21177 is used. This is an extension of transport layer security (TLS) v1.3 as specified in RFC 8446 that allows the use of multiple different authentication and encryption mechanisms, and the statement of multiple different permissions or properties of the communicating parties within a single secure communications session.

Both the server (the PDMS) and the client (vehicle/device) present an IEEE 1609.2 certificate in the TLS handshake with provider service identifier equal to 0x84. The server certificate has a service specific permissions field that identifies it as a PDMS and the client (vehicle/device) certificate has a service specific permissions field that identifies it as a client (vehicle/device). Individual client and server implementations can have additional authentication requirements (for example, around the client and server identity). If they do, they use the ISO 21177 extended authentication mechanisms to indicate those additional requirements.

C.2.1 Security Management for using TLS

The security management profiles in Tables 25 and 26 provide the certificate structure information for uploads to the PDMS from the vehicle/device. This structure also applies to the PDMS side of the TLS-based session, and the PDMS shall include the URL in the certificateID type hostname in its certificate (refer to IEEE 1609.2 for the exact certificate structure). For the vehicle side of the TLS-based session, the identity certificate shall set the certificateID type hostname to a string that identifies the fleet owner and that vehicle.

Note that the SSPs as described in the next section are used in the certificates for TLS, to indicate authorization of the sender.

Table 25 - PDR upload security profile identification

Name	Type	Recommended Values	Description
Name	Text string	“PDR_Upload_Security_Profile”	
PSID	List of PSID	0x84	The PSID to be used by SDEEs that use this profile.
Other considerations	Text string	This security profile is used for uploading probe data reports from vehicle to PDMS	A description of the conditions under which this security profile is to be used.

Table 26 - PDR upload (TLS) security management security profile

Name	Type	Value	Notes
Signing key algorithm	Enumerated	Use standard TLS	
Encryption algorithm	Enumerated	Use standard TLS	
Implicit or explicit certificates	Enumerated	Implicit	What is supported by the SCMS.
EC point format	Enumerated	NA	Point compression more vital on rapidly transmitted messages
SupportedGeographic regions	Array of enumerated	NA	The type of geographic region supported for conformant certificates. For example, a region could be the USA, and a subregion could be state or county. For smaller or more complex subregions, polygons or rectangles can be used.
Maximum certificate chain length	Integer	8	
Use individual linkage ID	Boolean	NA	
Use group linkage ID	Boolean	NA	
Signature algorithms in chain or CRL	Sequence of enumerated	NA	

C.2.2 User Privacy

The participation feature is implemented by the vehicle/probe data service provider or supplier of the vehicle/device. Participation is done in advance, i.e., it is an out of band operation that is based on agreements between service or device provider and user. These agreements are outside the scope of this document.

NOTE: Encryption via TLS also provides privacy from third parties (other than the PDMS).

NOTE: Future versions of this document may also include support for encrypting probe data records upon generation and storing on the vehicle/device.

C.3 SERVICE SPECIFIC PERMISSIONS [NORMATIVE]

This annex provides the service specific permissions (SSP) format for the vehicle/probe reporting using the probe data report as specified in this document, i.e., when associated with PSID 0x84. The SSP design used in this document applies the recommended approach from SAE J2945/5. Refer to SAE J2945/5 for the corresponding security analysis.

C.3.1 Activity groups and SSP design

The SSP design used in this document consists of 8-bit length string used to indicate authorization to send a probe data configuration. The activity bits are specified in Table 27. The SSP can be omitted entirely, in which case the default behavior is allowed.

The SSP sender is the entity providing the information.

Table 27 - Entity activity groups: probe data configuration

Entity Activity Group	Entity Activities	SSP Activity Bit
Vehicle/probe data configuration: Configuration provided to the vehicle broadcast from an RSU or from the PDMS via a query	PDC broadcast or query response as described in 4.2.1 for the indicated state or territory.	Bits 1-51
Probe data reporting: Vehicle/device reporting (upload to the PDMS: sender is any vehicle with a certificate including PSID 0x84)	PDR upload by a participating vehicle as specified in 4.2.2. These 13 bits indicate the FHWA vehicle class in numerical order (classes 1 through 13).	Bits 52-64

The SSP design used for road vehicle/probe applications conformant with this document is:

- Bits 1 through 51: Probe data configuration indicating the state or other region for which probe data collection is permitted. The bit for each state uses the list of states in the U.S. alphabetical order (i.e., bit 1 = Alabama, bit 2 = Alaska, etc.). Bit 51 is used to indicate U.S. territories (Puerto Rico, U.S. Virgin Islands, Guam, Northern Mariana Islands, American Samoa). The SSP is extensible so additional regions can be added in the future.

- Bits 52 through 64: Probe data report by the corresponding class of vehicle (FHWA classes 1-13). Refer to https://www.fhwa.dot.gov/policyinformation/tmguide/tmg_2013/vehicle-types.cfm. The SSP is extensible so additional vehicle types/classes can be added in the future.

A sender shall not engage in an activity in one of the identified entity activity groups unless the indicated bit in the SSP in its certificate is set. A receiver that receives an incorrectly authorized message or is otherwise requested to carry out an incorrectly authorized activity (i.e., an activity in an entity activity group identified here for which the sender does not have the indicated bit set in its SSP) shall not react to the message as if it was validly authorized and shall not carry out a corresponding activity.

For the session-oriented interface, certificates with the PSID 0x84 are used in an ISO 21177 TLS handshake only and are not used directly to sign 1609.2 SPDUs. Broadcast PDCs are signed as 1609.2 SPDUs.

C.4 SECURITY RISK ANALYSIS [INFORMATIVE]

SAE J2945/C contains several use cases where the probe data management subsystem (PDMS) sends a message via RSU towards vehicles/devices or in response to a query, and vehicles/devices send back collected data (via RSU or directly via other links such as cellular connection).

1. Traffic signal performance reporting.
2. Highway system performance reporting.
3. Transit operation.
4. Road maintenance.
5. Road planning.
6. Environmental monitoring.
7. Communications performance monitoring.
8. Road weather monitoring.
9. Work zone detection and mapping.
10. Mobility assessment.
11. Infrastructure asset management.

These scenarios are analyzed in Table 28 through 38 according to the framework documented in SAE J2945/5.

C.4.1 Analysis

The risk analysis for the use case traffic signal performance reporting follows. The impact with respect to confidentiality (C), integrity (I), and availability (A).

Table 28 - Risk analysis: Traffic signal performance reporting

Use Case: Traffic signal performance reporting			
Purpose: Improved traffic signal timing plans; probe data indicates time spent at stop lights			
Actors: • PDMS • RSUs • Participating connected vehicles/devices			
Information Flow	**Entity Activities**	**Description**	**Impact (Low/Med/High)**
Traffic signal data reporting (shown as “session-oriented”)	PDR upload by a participating vehicle	A vehicle sends the collected traffic signal data report to the PDMS, via RSU or some other link	C: Low I: Low A: Low
Probe data configuration	PDC broadcast or query response	Configuration provided to the vehicle broadcast from an RSU or from the PDMS via a query	C: Low I: Low A: Low
Notes, Assumptions, and Extensibility Management: NOTE 1: The confidentiality level is rated Low as there is no need to conceal the observed timing of traffic signal; however, the sending of the info in the clear may lead to passive tracking of the reporting vehicle. NOTE 1.1: For participating vehicles, there should be no privacy concern on the link from them to the PDMS, but in order to support privacy from eavesdropper, application layer encryption should be applied end to end (e.g., TLS1.3). NOTE 2: The integrity level is low because a decision about a changed traffic signal plan will be taken only after aggregating significant input from different reporting vehicles NOTE 3: The availability level is low because a lost message may only cause traffic signal inefficiencies, not accidents.			

The risk analysis for the use case highway system performance reporting follows.

Table 29 - Risk analysis: Highway system performance reporting

Use Case: Highway system performance reporting			
Purpose: improved ramp meter timing; probe data indicates stop-and-go areas			
Actors: • PDMS • RSUs • Connected vehicles/devices			
Information Flow	**Entity Activities**	**Description**	**Impact (Low/Med/High)**
Highway performance data reporting (shown as “session-oriented”)	PDR upload by a participating vehicle	A vehicle sends the collected highway system performance data report to the PDMS, via RSU or some other link	C: Low I: Low A: Low
Probe data configuration	PDC broadcast or query response	Configuration provided to the vehicle broadcast from an RSU or from the PDMS via a query	C: Low I: Low A: Low
Notes, Assumptions, and Extensibility Management: NOTE 1: The confidentiality level is rated low as there is no need to conceal the observed highway ramp meter data. However, the sending of the info in the clear may lead to passive tracking of the reporting vehicle. NOTE 2: The integrity level is low because a decision about a changed ramp metering schedule will be taken only after aggregating significant input from different reporting vehicles. NOTE 3: The availability level is low because a lost message may only cause ramp signal inefficiencies, not accidents.			

The risk analysis for the use case transit operation follows.

Table 30 - Risk analysis: Transit operation reporting

Use Case: Transit operation reporting			
Purpose: Route optimization/ridership satisfaction; transit authorities can have visibility into the flow of transit vehicles, ridership, driver behavior			
Actors: • PDMS • RSUs • Transit vehicles			
Information Flow	**Entity Activities**	**Description**	**Impact (Low/Med/High)**
Transit data reporting (shown as “session-oriented”)	PDR upload by a participating vehicle	A transit vehicle sends the collected data report to the PDMS, via RSU or directly via some other link	C: Low I: Low A: Low
Probe data configuration	PDC broadcast or query response	Configuration provided to the vehicle broadcast from an RSU or from the PDMS via a query	C: Low I: Low A: Low
Notes, Assumptions, and Extensibility Management: NOTE 1: The confidentiality level is rated low as there is no need to conceal the observed transit vehicle flow data. However, the sending of the info in the clear may lead to passive tracking of the reporting vehicle. NOTE 2: The integrity level is low because a decision about a changed transit schedules or routes will be taken only after aggregating significant input from different reporting transit vehicles. NOTE 3: The availability level is low because a lost message may only cause transit routes inefficiencies, not accidents.			

The risk analysis for the use case road maintenance follows.

Table 31 - Risk analysis: Road maintenance reporting

Use Case: Road maintenance reporting			
Purpose: Improved traffic flow and availability of real-time data to alert impacted travelers			
Actors: • PDMS • RSUs • All connected vehicles/devices			
Information Flow	**Entity Activities**	**Description**	**Impact (Low/Med/High)**
Road maintenance reporting (shown as “session-oriented”)	PDR upload by a participating vehicle	A vehicle/device sends the collected data report to the PDMS, via RSU or directly via some other link	C: Low I: Low A: Low
Probe data configuration	PDC broadcast or query response	Configuration provided to the vehicle broadcast from an RSU or from the PDMS via a query	C: Low I: Low A: Low
Notes, Assumptions, and Extensibility Management: NOTE 1: The confidentiality level is rated low as there is no need to conceal the observed road maintenance data for a given area. However, the sending of the info in the clear may lead to passive tracking of the reporting vehicle. NOTE 2: The integrity level is low because a decision about advising vehicles far away to reroute will be taken only after aggregating significant input from different reporting vehicles. NOTE 3: The availability level is low because a lost message may only cause route inefficiencies, not accidents.			

The risk analysis for the use case road planning follows.

Table 32 - Risk analysis: Road planning reporting

Use Case: Road planning reporting			
Purpose: Improved roadways and maps; report road geometry inconsistency or unexpected closures			
Actors: • PDMS • RSUs • All connected vehicles/devices			
Information Flow	**Entity Activities**	**Description**	**Impact (Low/Med/High)**
Road planning reporting (shown as “session-oriented”)	PDR upload by a participating vehicle	A vehicle/device sends the collected data report to the PDMS, via RSU or directly via some other link	C: Low I: Low A: Low
Probe data configuration	PDC broadcast or query response	Configuration provided to the vehicle broadcast from an RSU or from the PDMS via a query	C: Low I: Low A: Low
Notes, Assumptions, and Extensibility Management: NOTE 1: The confidentiality level is rated low as there is no need to conceal the observed road planning data for a given area. However, the sending of the info in the clear may lead to passive tracking of the reporting vehicle. NOTE 2: The integrity level is low because a roadway design change (for more efficient repairs, for example) or update to digital maps will be taken only after aggregating significant input from different reporting vehicles. NOTE 3: The availability level is low because a lost message may only cause route inefficiencies, not accidents. If the digital map for a given area (e.g., with lane closure) is not updated it would be because there are none or few such messages being uploaded.			

The risk analysis for the use case environmental monitoring follows.

Table 33 - Risk analysis: Environmental monitoring reporting

Use Case: Environmental monitoring reporting (fuel consumption, emissions)			
Purpose: Improved environment and mobility			
Actors: • PDMS • RSUs • All connected vehicles/devices			
Information Flow	**Entity Activities**	**Description**	**Impact (Low/Med/High)**
Environmental data reporting (shown as “session-oriented”)	PDR upload by a participating vehicle	A vehicle/device sends the collected data report to the PDMS, via RSU or directly via some other link	C: Low I: Low A: Low
Probe data configuration	PDC broadcast or query response	Configuration provided to the vehicle broadcast from an RSU or from the PDMS via a query	C: Low I: Low A: Low
Notes, Assumptions, and Extensibility Management: NOTE 1: The confidentiality level is rated low as the observed environmental data for a given area from the perspective of one vehicle is not sensitive info, but it is not “none.” The emissions are observed from other cars around, not the emissions of the ego vehicle. However, the sending of the info in the clear may lead to passive tracking of the reporting vehicle. NOTE 2: The integrity level is low because an assessment of the emissions in a given area (for informational purposes) will be taken only after aggregating significant input from different reporting vehicles. NOTE 3: The availability level is low because these are just informational purposes and the PDMS aggregating them would only be able to assess the state of the environment in an area at given time periods; roadway changes are unlikely to be planned as a result (but advisory messages could be sent).			

The risk analysis for the use case communications performance monitoring follows.

Table 34 - Risk analysis: Communications performance monitoring reporting

Use Case: Communications performance monitoring reporting (RF, GNSS anomalies)			
Purpose: Improved infrastructure			
Actors: • PDMS • RSUs • All connected vehicles/devices			
Information Flow	**Entity Activities**	**Description**	**Impact (Low/Med/High)**
Communications Performance data reporting (shown as “session-oriented”)	PDR upload by a participating vehicle	A vehicle/device sends the collected data report to the PDMS, via RSU or directly via some other link	C: Low I: Low A: Medium
Probe data configuration	PDC broadcast or query response	Configuration provided to the vehicle broadcast from an RSU or from the PDMS via a query	C: Low I: Low A: Low
Notes, Assumptions, and Extensibility Management: NOTE 1: The confidentiality level is rated low there is no need to conceal the observed communications performance data for a given area. However, the sending of the info in the clear may lead to passive tracking of the reporting vehicle. NOTE 2: The integrity level is low because changes to road infrastructure in a given area will be taken only after aggregating significant input from different reporting vehicles. NOTE 3: The availability level is medium because if these messages don’t reach the PDMS, vehicles in the area may experience some performance or accuracy issues for other V2X applications that use those communication interfaces.			

The risk analysis for the use case road weather monitoring follows. It uses data structures defined in SAE J2945/3.

Table 35 - Risk analysis: Road weather monitoring reporting

Use Case: Road weather monitoring reporting (heavy rain, fog, wind, snow)			
Purpose: Improved mobility and safety through use of real-time and localized information			
Actors: • PDMS • RSUs • All connected vehicles/devices			
Information Flow	**Entity Activities**	**Description**	**Impact (Low/Med/High)**
Road weather monitoring reporting (shown as “session-oriented”)	PDR upload by a participating vehicle	A vehicle/device sends the collected data report to the PDMS, via RSU or directly via some other link	C: Low I: Low A: Low
Probe data configuration	PDC broadcast or query response	Configuration provided to the vehicle broadcast from an RSU or from the PDMS via a query	C: Low I: Low A: Low
Notes, Assumptions, and Extensibility Management: NOTE 1: The confidentiality level is rated low there is no need to conceal the observed road weather data for a given area. However, the sending of the info in the clear may lead to passive tracking of the reporting vehicle. NOTE 2: The integrity level is low because a decision will be taken only after aggregating significant input from different reporting vehicles. NOTE 3: The availability level is low because if these messages don’t reach the PDMS, vehicles should still be able to drive as safely as the road conditions allow, since the combination of one or more of human driver or vehicle sensors should allow the detection of these road weather conditions in a timely fashion.			

The risk analysis for the use case work zone detection and mapping follows.

Table 36 - Risk analysis: Work zone detection and mapping reporting

Use Case: Work zone detection and mapping reporting			
Purpose: Improved mobility and safety (for more accurate info for travelers)			
Actors: • PDMS • RSUs • All connected vehicles/devices			
Information Flow	**Entity Activities**	**Description**	**Impact (Low/Med/High)**
Work zone detection and mapping reporting (shown as “session-oriented”)	PDR upload by a participating vehicle	A vehicle/device sends the collected data report to the PDMS, via RSU or directly via some other link	C: Low I: Low A: Low
Probe data configuration	PDC broadcast or query response	Configuration provided to the vehicle broadcast from an RSU or from the PDMS via a query	C: Low I: Low A: Low
Notes, Assumptions, and Extensibility Management: NOTE 1: The confidentiality level is rated low as there is no need to conceal the observed work zone data for a given area. However, the sending of the info in the clear may lead to passive tracking of the reporting vehicle. NOTE 2: The integrity level is low because a decision about advising vehicles far away to reroute will be taken only after aggregating significant input from different reporting vehicles. NOTE 3: The availability level is low because a lost message may only cause route inefficiencies, not accidents.			

The risk analysis for the use case mobility assessment follows.

Table 37 - Risk analysis: Mobility assessment reporting

Use Case: Mobility assessment reporting			
Purpose: Improved mobility and safety (for more accurate info for travelers)			
Actors: • PDMS • RSUs • All connected vehicles/devices			
Information Flow	**Entity Activities**	**Description**	**Impact (Low/Med/High)**
Mobility assessment reporting (shown as “session-oriented”)	PDR upload by a participating vehicle	A vehicle/device sends the collected data report to the PDMS, via RSU or directly via some other link	C: Low I: Low A: Low
Probe data configuration	PDC broadcast or query response	Configuration provided to the vehicle broadcast from an RSU or from the PDMS via a query	C: Low I: Low A: Low
Notes, Assumptions, and Extensibility Management: NOTE 1: The confidentiality level is rated low as there is no need to conceal the observed mobility data (e.g., slowness due to road closure) for a given area. However, the sending of the info in the clear may lead to passive tracking of the reporting vehicle. NOTE 2: The integrity level is low because a decision to contact a traffic management entity to send alerts to drivers will be taken only after aggregating significant input from different reporting vehicles. NOTE 3: The availability level is low because a lost message may only cause route inefficiencies, not accidents.			

The risk analysis for the use case infrastructure asset management follows.

Table 38 - Risk analysis: Infrastructure asset management reporting

Use Case: Infrastructure asset management reporting (low road sign, lane retro reflectivity)			
Purpose: Improved mobility and safety			
Actors: • PDMS • RSUs • All connected vehicles/devices			
Information Flow	**Entity Activities**	**Description**	**Impact (Low/Med/High)**
Infrastructure asset management data reporting (shown as “session-oriented”)	PDR upload by a participating vehicle	A vehicle/device sends the collected data report to the PDMS, via RSU or directly via some other link	C: Low I: Low A: Low
Probe data configuration	PDC broadcast or query response	Configuration provided to the vehicle broadcast from an RSU or from the PDMS via a query	C: Low I: Low A: Low
Notes, Assumptions, and Extensibility Management: NOTE 1: The confidentiality level is rated low as there is no need to conceal the observed mobility data (e.g., slowness due to road closure) for a given area. However, the sending of the info in the clear may lead to passive tracking of the reporting vehicle. NOTE 2: The integrity level is low because a decision to relay this data to an infra-management entity will be taken only after aggregating significant input from different reporting vehicles. NOTE 3: The availability level is low because a lost message may only cause a delay in infrastructure asset repair, not accidents.			

APPENDIX D - DOCUMENTATION OF REVISIONS [INFORMATIVE]

This document is the first publication of SAE J2945/C.

APPENDIX E - USER REQUESTS

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APPENDIX F - MISBEHAVIOR CONSIDERATIONS [INFORMATIVE]

This appendix outlines principles for misbehavior detection and reporting for the PDC application. For this initial version, only a definition of what constitutes “misbehaving transmission” is provided, along with high level possible mitigations. The scope covers both transmissions via WSA or WSMP between RSUs and OBUs, as well as via HTTPS/IP connections between the OBUs and the PDMS in the network. Specific mechanisms for detection and reporting misbehavior will be defined in subsequent versions.

According to SAE J2945/5, misbehavior detection “allows devices to (1) locally detect incorrect messages, whether malicious or harmful or not, and avoid acting based on them, and (2) if appropriate, determine that incorrect messages should be reported to a central misbehavior authority for additional enforcement if necessary to preserve the integrity of the application ecosystem.”

F.1 MISBEHAVIOR DETERMINATION:

RSUs: In the probe data collection system, misbehavior on the part of the RSU consists of sending incorrect information in the PDC configuration messages (either as WSAs or HTTPS responses), or sending them with a too high frequency (WSAs only), or with a setting so as to cause undue computational burden on affected OBUs (both WSAs and HTTPS responses).

OBUs: In the probe data reporting system, misbehavior on the part of OBUs consists of sending false reports, i.e., reports containing data that in part or in whole does not correspond to the actual facts or conditions experienced at the time and location indicated in the report.

F.2 MITIGATIONS FOR MISBEHAVIOR:

RSUs: RSUs are expected to employ protection against DOS attack-induced resource depletion.

OBUs: A probe data consuming system can manage misbehavior of reporting devices by a number of mechanisms to identify reports containing aberrant or outlier data, including:

- Crowdsourcing: Consensus among multiple reporters when conditions are reported by more than one reporter.
- Cross-comparison: Comparison with data from other sensors when those are available (e.g., roadway sensors), or reports from other independent sources (for example cellular operators can provide average speed of vehicles in the cell, from cell tower data; or a user navigation service provider can provide average speed based on user data).
- Using the number of invalid reports as a parameter when deciding whether to take action to change or remediate that situation (e.g., recall malfunctioning/misbehaving vehicle for repair).

F.3 MISBEHAVIOR REPORTING:

This document does not provide a means for probe data collection systems to report misbehaving OBU reporters to a misbehavior authority (MA) for investigation and possible revocation. It is expected that probe data collection systems exercise management control over probe data reporters and can use that control to make local decisions about which OBU’s reports to ignore.

APPENDIX G - APPLICABLE STANDARDS [INFORMATIVE]

The following SAE Standards are useful for implementing probe data applications as described in this document:

SAE J2735

SAE J2945

SAE J2945/3

SAE J2945/5

SAE J3161

APPENDIX H - ASN.1 MODULES [NORMATIVE]

The ASN.1 schemas presented here can be compiled as part of a single project along with the imported ASN.1 modules from SAE J2735.

H.1 PROBE DATA CONFIGURATION ASN.1 MODULE

```
ProbeDataConfig

{joint-iso-itu-t (2) country (16) us (840) organization (1) sae (114566)

v2x-communications (1) technical-committees (1) infrastructure-applications (6)

technical-reports (1) j2945 (2945) slash-c (12) asn1-module (1) probeDataConfig (0)

version-1 (1)}


--

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```

```
DEFINITIONS AUTOMATIC TAGS ::=
BEGIN

IMPORTS
```

```
    DDate, DTime, DDateTime, DSRCmsgID, IntersectionID, RoadAuthorityID
    FROM Common {joint-iso-itu-t (2) country (16) us (840) organization (1)
    sae (114566) v2x-communications (1) technical-committees (1)
    v2x-core (5) technical-reports (1) j2735 (2735) part-0 (0)
    asn1-module (1) common (38) version-1 (1)}

    ValidRegion
    FROM TravelerInformation {joint-iso-itu-t (2) country (16) us (840) organization (1)
    sae (114566) v2x-communications (1) technical-committees (1)
    v2x-core (5) technical-reports (1) j2735 (2735) part-0 (0)
    asn1-module (1) travelerInformation (20) version-1 (1)}
;

ProbeDataConfigMessage ::= SEQUENCE (SIZE(1..255, ...)) OF ProbeDataConfig

ProbeDataConfig ::= SEQUENCE {
    descriptor          ConfigDescriptor,
    triggers            ConfigTriggers,
    maxAgeOfData        INTEGER (1..90), -- in days
    boundary            ConfigBoundary  OPTIONAL,
    ...
}

ConfigDescriptor ::= SEQUENCE {
    identifier      ConfigId,
    vehClass        CfgVehicleClass     OPTIONAL,
    roadAuthorityID RoadAuthorityID     OPTIONAL,
    percentOfResp   INTEGER (1..10)     OPTIONAL,
    -- '1' indicates report 10% of the time, '10' is 100%
    ...
```

```
}

ConfigId ::= INTEGER (1..255)

-- The following are FHWA defined vehicle classes (types)
-- See ProbeDataReport module for enumerated values
CfgVehicleClass ::= SEQUENCE    {
    motorcycles                         BOOLEAN,
    passengerCars                       BOOLEAN,
    other2axle4tireSingleUnitVehs       BOOLEAN,
    buses                               BOOLEAN,
    twoAxle6TireSingleUnitTrucks        BOOLEAN,
    threeAxleSingleUnitTrucks           BOOLEAN,
    fourOrMoreAxleSingleUnitTrucks      BOOLEAN,
    fourOrFewerAxleSingleTrailerTrucks  BOOLEAN,
    fiveAxleSingleTrailerTrucks         BOOLEAN,
    sixOrMoreAxleSingleTrailerTrucks    BOOLEAN,
    fiveOrFewerAxleMultiTrailerTrucks   BOOLEAN,
    sixAxleMultiTrailerTrucks           BOOLEAN,
    sevenOrMoreAxleMultiTrailerTrucks   BOOLEAN,
    ...
}

ConfigBoundary ::= CHOICE {
    temporalBoundary    ConfigTemporalBoundary,
    geoAndDistBoundary  ValidRegion, -- From J2735
    ...
}

-- Defines applicable periods for an event.
```

```
ConfigTemporalBoundary ::= SEQUENCE {
    beginTime           DDateTime, --From J2735
    endTime             DDateTime, --From J2735
    recurring           CfgEventRecurrence, --borrowed from J2945/4 RSM
    ...
}

-- Definition for EventRecruarance borrowed from J2945/4 RSM.
CfgEventRecurrence ::= SEQUENCE {
    startTime   DTime   OPTIONAL,  -- Time of day this period starts
    endTime     DTime   OPTIONAL,  -- Time of day this period ends
    startDate   DDate   OPTIONAL,  -- Date this period starts
    endDate     DDate   OPTIONAL,  -- Date this period ends
    -- Define days of the week for applicable periods (used by EventRecurrence)
    monday      BOOLEAN,
    tuesday     BOOLEAN,
    wednesday   BOOLEAN,
    thursday    BOOLEAN,
    friday      BOOLEAN,
    saturday    BOOLEAN,
    sunday      BOOLEAN,
    -- exclusion: TRUE: The period defined here is excluded,
    -- i.e., the period is NOT applicable to the event
    exclusion   BOOLEAN OPTIONAL,
    ...
}

ConfigTriggers ::= CHOICE {
    instantaneousTriggers   CfgInstantaneousEventTriggers,
    avgAndSumTriggers       CfgAveragedAndSummaryTriggers,
```

```
    ...
}

CfgInstantaneousEventTriggers ::= CHOICE {
    intervalEvents      CfgIntervalEvents,
    vehicleEvents       CfgVehicleEvents,
    roadwayEvents       CfgRoadwayEvents,
    commSysPerfEvents   CfgCommSysPerfEvents,
    ...
}

CfgIntervalEvents ::= SEQUENCE {
    interval        CfgInterval,
    wiperStatus     BOOLEAN                 OPTIONAL,
    vehCount        BOOLEAN                 OPTIONAL,
    -- Count of V2V equipped vehicles encountered during the interval
    weatherData     BOOLEAN                 OPTIONAL,
    transitVehData  CfgTransitVehicleData   OPTIONAL,
    -- Multiple parameters from Transit vehicles
    numOfOccupants  BOOLEAN                 OPTIONAL,
    ...
}

CfgTransitVehicleData ::= SEQUENCE {
    currNumPasngers BOOLEAN     OPTIONAL,
    avgNumPasngers  BOOLEAN     OPTIONAL,
    trnstVehSchAdh  BOOLEAN     OPTIONAL,
    ...
}
```

```
CfgInterval ::= CHOICE {
    timeInterval            INTEGER(1..36000),  -- in tenths of seconds up to an hour
    distanceInterval        INTEGER(1..100),    -- in 0.1 kilometers
    ...
}


CfgVehicleEvents ::= SEQUENCE {
    headLights              BOOLEAN                 OPTIONAL,
    fogLights               BOOLEAN                 OPTIONAL,
    hazardLights            BOOLEAN                 OPTIONAL,
    kinematicEvents         CfgKinematicEvents      OPTIONAL,
    wiperStatusChange       BOOLEAN                 OPTIONAL,
    lowSpeed                CfgLowSpeedCriteria     OPTIONAL,
    -- Speed falls below a threshold (MIN 5 KPH) for a defined duration (in seconds)
    resumedSpeed            INTEGER (1..100)        OPTIONAL,
    -- Speed goes above a certain threshold, in KPH
    vehEntrsExitsRegion     BOOLEAN                 OPTIONAL,
    -- Vehicle enters or exits the region defined in ConfigBoundary
    emerVehDetect           BOOLEAN                 OPTIONAL,
    -- Emergency vehicle detected by a non-emergency vehicle
    emerAndTransInfo        CfgEmerAndTransitInfo   OPTIONAL,
    -- Info pertaining to emergency or transit vehicles
    v2xMsgRecption          CfgMsgRecepIndicators   OPTIONAL,
    -- V2X message reception: reception of any V2X message over the communications
    -- interface(s), identified by indicating the desired data
    -- dictionary (e.g. SAE J2735, ETSI and ISO data dictionary documents) and
    -- message IDs in the configuration.
    driverAlertsAndWarnings BOOLEAN                 OPTIONAL,
    ...
}
```

```
CfgKinematicEvents ::= SEQUENCE {
    events              CfgEvents,
    hysteresis          CfgHysteresis       OPTIONAL,
    ...
}

CfgEvents ::= SEQUENCE {
    absActivated            BOOLEAN         OPTIONAL,
    tractionCtlLoss         BOOLEAN         OPTIONAL,
    stabilityCtlActivated   BOOLEAN         OPTIONAL,
    hardBraking             BOOLEAN         OPTIONAL,
    swerveThreshold         INTEGER (1..50) OPTIONAL,
    -- Lateral acceleration exceeds a certain threshold
    -- e.g. 18 represents 1.8 m/s2, 36 represents 3.6 m/s2 (units = 0.1 m/s2)
    -- Measured in meters per second squared and the threshold value of comfort
    -- is 1.8 m/s2, with medium comfort and discomfort levels of 3.6 m/s2
    -- and 5 m/s2, respectively.
    ...
}

CfgHysteresis ::= SEQUENCE {
    hysSamples      INTEGER(1..10),
    -- Value indicates the number of samples before and after the event
    hysRate         INTEGER(1..10),
    -- In 100 mSecs, value indicates sampling interval for hysteresis
    ...
}

CfgEmerAndTransitInfo ::= CHOICE {
```

```
    emerVehLightBar         BOOLEAN,
    -- Emergency vehicle light bar turned on/off (reported by the emergency vehicle only)
    reqTspEvp               BOOLEAN,
    -- TSP/EVP requested (transit and emergency vehicles only)
    transitVehPassCnt       BOOLEAN,
    -- Transit Vehicle passenger count change and resulting number of occupants
    transitVehDoor          BOOLEAN,
    -- Transit vehicle door opened and number of passengers entering / exiting
    ...
}

CfgMsgRecepIndicators ::= SEQUENCE {
    msgDictionary   CfgMsgDictionary                    OPTIONAL,
    messages SEQUENCE (SIZE(1..8, ...)) OF DSRCmsgID    OPTIONAL,
    --DSRCmsgID imported from DSRC
    ...
}

-- Indicate which dictionary type
CfgMsgDictionary ::= ENUMERATED {
    sae     (1),
    etsi    (2),
    iso     (3),
    ...
}

-- The following are criteria by which the associated event will be reported
CfgRoadwayEvents ::= SEQUENCE {
    obstacleDetected        BOOLEAN,
    adverseRoadSurface      BOOLEAN,
```

```
-- Adverse road surface condition (non-weather related: potholes, road roughness).
trafficSigEncounters    CfgTrafficSigEncounters OPTIONAL,
-- Traffic signal related parameters
trfsigLightOut          BOOLEAN,
trfsigRoadGeoMismatch   BOOLEAN,
roadSignInfo            CfgRoadSignInfo         OPTIONAL,
lowLaneMarkReflect      INTEGER (1..100)        OPTIONAL,
-- Identify types of roadsigns and report back reflectivity
-- Low lane marking retro reflectivity (falls below a specified threshold
-- in % light returned)
roadsignIncnstncy       BOOLEAN,
-- Roadsign inconsistency or unexpected closure (posted sign inconsistent
-- with on-board map)
laneGeoIncnstncy        BOOLEAN,
-- Lane geometry inconsistency (difficult to interpret because of being covered
-- up or ambiguous, or different from on-board map)
incidentDetect          BOOLEAN,
-- Incident detection (car accident, wrong way driver, slowdown in
-- opposite direction)
workZoneCharDetect      BOOLEAN,
-- Detection of work zone characteristics: workers present, lane shifts and
-- lane closures
inclWeatherDetect       BOOLEAN,
-- Detection of inclement weather or weather-related road surface
-- condition (SAE J2945/3 - heavy rain, fog, wind, ice, snow)
railrdCrossActivated    BOOLEAN,
-- Railroad crossing activated
drawBridgeActivated     BOOLEAN,
-- Draw bridge activated
...
```

```
}

CfgTrafficSigEncounters ::= SEQUENCE {
    intersections           SEQUENCE (SIZE(1..100)) OF IntersectionID   OPTIONAL,
    -- Intersection IDs typically used in SPAT and MAP messsages
    trfcsigApproachDelay    INTEGER (1..3600)   OPTIONAL,
    -- In seconds, triggered if higher
    trfsigApproachSpeed     INTEGER (1..200)    OPTIONAL,
    -- In KPH, triggered if lower
    trfsigArrivalGreen      BOOLEAN             OPTIONAL,
    trfsigArrivalRed        BOOLEAN             OPTIONAL,
    trfsigPedDelay          INTEGER (1..300)    OPTIONAL,
    -- In seconds, triggered if higher
    trfsigSpatMismatch      BOOLEAN             OPTIONAL,
    trfsigSpatTimingError   BOOLEAN             OPTIONAL,
    ...
}

CfgRoadSignInfo ::= SEQUENCE {
        roadsignDetection       CfgRoadSignTypes,
        -- Road sign types
        lowRoadsignReflect1     INTEGER (1..250)    OPTIONAL,
        -- Min threshold for 1st color
        lowRoadsignReflect2     INTEGER (1..250)    OPTIONAL,
        -- Min threshold for 2nd color

        -- Low roadsign retroreflectivity (in cd/lx/m2 falls below a specified threshold)
        -- Reflectivity threshold is dependent on the type of roadsign
        -- Reference: U.S.DOT, FHWA, Manual on Uniform Traffic Control Devices for
        -- Streets and Highways, 2009 Edition
```

```
    ...
}

CfgRoadSignTypes ::= SEQUENCE {
    whiteOnGreen    BOOLEAN     OPTIONAL,
    blackOnYellow   BOOLEAN     OPTIONAL,
    blackOnOrange   BOOLEAN     OPTIONAL,
    whiteOnRed      BOOLEAN     OPTIONAL,
    blackOnWhite    BOOLEAN     OPTIONAL,
    octagon         BOOLEAN     OPTIONAL,
    eqlatTriangle   BOOLEAN     OPTIONAL,
    circle          BOOLEAN     OPTIONAL,
    pennant         BOOLEAN     OPTIONAL,
    pentagon        BOOLEAN     OPTIONAL,
    crossbuck       BOOLEAN     OPTIONAL,
    diamond         BOOLEAN     OPTIONAL,
    trapezoid       BOOLEAN     OPTIONAL,
    other           BOOLEAN     OPTIONAL,
    -- Reference: U.S.DOT, FHWA, Manual on Uniform Traffic Control Devices for
    -- Streets and Highways, 2009 Edition
    ...
}


CfgCommSysPerfEvents ::= SEQUENCE {
    j2945-1ChanBusyThresh   INTEGER (1..100)    OPTIONAL,
    -- Based on J2945/1 Channel busy percentage measured over last 100ms
    rfDataRsuInfo           BOOLEAN             OPTIONAL,
    numRsusObservedThresh   INTEGER (1..254)    OPTIONAL,
    -- Threshold for numOfRsusObserved
```

```
    -- RF Triggers:
    rfV2xJamDetectThresh    INTEGER (1..140)    OPTIONAL,
    -- 5.9 GHZ V2X Radio Jamming detection (if equipped)in -dBm
    j2945-1VehDensThresh    INTEGER (1..255)    OPTIONAL,
    -- J2945/1 Vehicle Density in range exceeds specified threshold (number of vehicles)
    j2945-1CqiBelowThresh   INTEGER (1..100)    OPTIONAL,
    -- J2945/1 CQI falls below a specified threshold (poor link quality)
    j2945-1TrackErrorThresh INTEGER (1..100)    OPTIONAL,
    -- J2945/1 Tracking Error estimate exceed a specified threshold in meters.

    -- GNSS Performance Triggers:
    gnssHdopExceedsThresh   INTEGER (1..20)     OPTIONAL,
    -- HDOP exceeds a specified threshold
    gnssSatsBelowThresh     INTEGER (1..20)     OPTIONAL,
    -- Satellites in view goes below a specified threshold
    gnssJammingDetect       BOOLEAN             OPTIONAL,
    -- Jamming detected
    ...
}

CfgAveragedAndSummaryTriggers ::= CHOICE {
    averagedTriggers        CfgAveragedTriggers,
    summaryTriggers         CfgSummaryTriggers,
    ...
}

CfgAveragedTriggers ::= SEQUENCE {
    avgSpeed            BOOLEAN OPTIONAL, -- in KPH
    avgStopDuration     BOOLEAN OPTIONAL, -- in Seconds
```

```
    avgFuelConsumption  BOOLEAN OPTIONAL, -- in Liters
    avgEmissions        BOOLEAN OPTIONAL,
    avgNumOfOccupants   BOOLEAN OPTIONAL,
    ...
}

CfgSummaryTriggers ::= SEQUENCE {
    regTravelTime           BOOLEAN                 OPTIONAL,
    -- Total travel time to traverse the region in seconds
    regVehDistTraveled      BOOLEAN                 OPTIONAL,
    -- Total vehicle distance traveled within the region (kilometers)
    regVehTimeTraveled      BOOLEAN                 OPTIONAL,
    -- Total vehicle time traveled within the region (seconds)
    fuelConsumption         BOOLEAN                 OPTIONAL,
    -- Total fuel consumption in liters
    totalVehEmissions       BOOLEAN                 OPTIONAL,
    -- Total vehicle emissions
    numOfLowSpeedEvents     CfgLowSpeedCriteria     OPTIONAL, -- Low speed threshold
    -- Number of times speed dropped below a low speed threshold (low speed threshold
    -- must be greater than 5 km/h)
    timeStopped             CfgStoppedCriteria      OPTIONAL, -- Stopped speed threshold
    -- Seconds spent at speed less than the specified stopped threshold
    numOfStopped            CfgStoppedCriteria      OPTIONAL,
    -- Number of times the speed fell below the specified stopped threshold
    locOfStops              BOOLEAN                 OPTIONAL,
    -- Each location and duration in seconds where the speed drops below the
    -- specified stopped threshold
    regNumOfVehPassed       BOOLEAN                 OPTIONAL,
    -- Number of vehicles passed over the configuration region
    regNumOfSurpassedVeh    BOOLEAN                 OPTIONAL,
```

```
    -- Number of vehicles that passed the recording vehicle over the configuration region
    totalMsgsReceived       CfgMsgRecepIndicators   OPTIONAL,
    -- Total messages received by the message type indicated in the configuration
    ...
}

CfgLowSpeedCriteria ::= SEQUENCE {
    lowSpeedThreshold   INTEGER (5..100),               -- In KPH
    lowSpeedTimeThresh  INTEGER (1..30)     OPTIONAL,   -- In seconds
    ...
}

CfgStoppedCriteria ::= SEQUENCE {
    stoppedSpeedThreshold   INTEGER (1..30),    -- in KPH
    amountOfTimeBelow       INTEGER (1..300),   -- in seconds
    ...
}


END
```

H.2 PROBE DATA REPORT ASN.1 MODULE

```
ProbeDataReport
{joint-iso-itu-t (2) country (16) us (840) organization (1) sae (114566)
v2x-communications (1) technical-committees (1) infrastructure-applications (6)
technical-reports (1) j2945 (2945) slash-c (12) asn1-module (1) probeDataReport (1)
version-1 (1)}

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--


DEFINITIONS AUTOMATIC TAGS ::=

BEGIN


IMPORTS

    DTime, DDateTime, IntersectionID, Speed, Heading, PositionalAccuracy, Position3D,

    RoadAuthorityID, VehicleSize, VehicleMass

    FROM Common {joint-iso-itu-t (2) country (16) us (840) organization (1)

    sae (114566) v2x-communications (1) technical-committees (1)

    v2x-core (5) technical-reports (1) j2735 (2735) part-0 (0)

    asn1-module (1) common (38) version-1 (1)}


    NtcipEssData

    FROM RoadWeatherMessage {joint-iso-itu-t (2) country (16) us (840) organization (1)

    sae (114566) v2x-communications (1) technical-committees (1)

    infrastructure-applications (6) technical-reports (1) j2945 (2945) slash-3 (3)

    asn1-module (1) roadWeatherMessage (0) version-2 (2)}


    ConfigId

    FROM ProbeDataConfig {joint-iso-itu-t (2) country (16) us (840) organization (1)

    sae (114566) v2x-communications (1) technical-committees (1)

    infrastructure-applications (6) technical-reports (1) j2945 (2945) slash-c (12)

    asn1-module (1) probeDataConfig (0) version-1 (1)}

;
```

```
ProbeDataReportMessage ::= SEQUENCE {
    configId            ConfigId,
    reportChar          ReportCharacteristics,
    roadAuthorityID     RoadAuthorityID             OPTIONAL,
    instantaneousRecs   RptInstantaneousRecords     OPTIONAL,
    avgAndSumRec        RptAveragedAndSummaryRecord OPTIONAL,
    ...
} (WITH COMPONENTS {..., instantaneousRecs PRESENT} |
   WITH COMPONENTS {..., avgAndSumRec PRESENT})

ReportCharacteristics ::= SEQUENCE {
    -- The next four data elements are mandatory in every report record
    timeStamp           DDateTime,
    position            Position3D,
    posAccuracy         PositionalAccuracy,
    velocity            RptVelocity,
    vehicleClass        RptVehicleClass     OPTIONAL, -- FHWA classes
    devType             RptDevType          OPTIONAL, -- OBU Type
    vehicleSize         VehicleSize         OPTIONAL,
    vehicleMass         VehicleMass         OPTIONAL,
    vehPassengerCount   INTEGER (1..255)    OPTIONAL,
    ...
}

-- The following are FHWA defined vehicle classes (types)
RptVehicleClass ::= ENUMERATED  {
    motorcycles                         (1),
    passengerCars                       (2),
    other2axle4tireSingleUnitVehs       (3),
    buses                               (4),
```

```
    twoAxle6TireSingleUnitTrucks        (5),
    threeAxleSingleUnitTrucks           (6),
    fourOrMoreAxleSingleUnitTrucks      (7),
    fourOrFewerAxleSingleTrailerTrucks  (8),
    fiveAxleSingleTrailerTrucks         (9),
    sixOrMoreAxleSingleTrailerTrucks    (10),
    fiveOrFewerAxleMultiTrailerTrucks   (11),
    sixAxleMultiTrailerTrucks           (12),
    sevenOrMoreAxleMultiTrailerTrucks   (13),
    ...
}

-- Device Types (OBU type)
RptDevType ::= SEQUENCE {
    oemOrAftermarket    BOOLEAN,
    canOrIvnConnected   BOOLEAN,
    mcoCapable          BOOLEAN OPTIONAL,
    ...
}

RptInstantaneousRecords ::= SEQUENCE (SIZE(1..255, ...)) OF RptInstantaneousRecord

RptInstantaneousRecord ::= SEQUENCE {
    timeOfInstantRec    DDateTime,
    locOfInstantRec     Position3D,
    accOfPosition       PositionalAccuracy,
    velOfInstantRec     RptVelocity,
    record              RptInstantaneousRecordData  OPTIONAL,
    ...
}
```

```
-- Heading and Speed imported from J2735
RptVelocity ::= SEQUENCE {
    speed       Speed,            -- in km/h
    speedStdDev StdDev  OPTIONAL, -- in km/h
    heading     Heading OPTIONAL,
    ...
}

RptInstantaneousRecordData ::= CHOICE {
    intervalEvents      RptIntervalEvents,
    vehEvents           RptVehicleEvents,
    roadwayEvents       RptRoadwayEvents,
    commSysPerfEvents   RptCommSysPerfEvents,
    ...
}

RptAveragedAndSummaryRecord ::= SEQUENCE {
    startTime       DDateTime,  --Time at the start of data capture
    startLoc        Position3D, --Position at startTime
    startAccOfPos   PositionalAccuracy, --Accuracy of starting position
    endTime         DDateTime,  --Time at the end of data capture
    endLoc          Position3D, --Position at endTime
    endAccOfPos     PositionalAccuracy, --Accuracy of ending position
    record          RptAvgAndSummaryRecordData,
    ...
}

RptAvgAndSummaryRecordData ::= CHOICE {
    averagedRecord      RptAveragedRecord,
```

```
    summaryRecord       RptSummaryRecord,
    ...
}

RptIntervalEvents   ::= SEQUENCE {
    wiperStatus     RptWiperStatus      OPTIONAL,
    vehCount        INTEGER (0..10000)  OPTIONAL,
    -- Number of V2V-equipped vehicles encountered
    weatherData     RptVehicleReport    OPTIONAL,
    transitVehData  RptTransitVehData   OPTIONAL,
    numOfOccupants  INTEGER (0..255)    OPTIONAL,
    -- 254 indicates > 253, 255 is reserved
    ...
}

RptVehicleReport ::= SEQUENCE (SIZE(1..32)) OF NtcipEssData
-- NtcipEssData is defined in RWM (J2945/3)

RptTransitVehData ::= SEQUENCE {
    currNumPasngers INTEGER (0..255)    OPTIONAL,
    avgNumPasngers  INTEGER (0..255)    OPTIONAL,
    trnstVehSchAdh  INTEGER (-200..55)  OPTIONAL,
    -- Neg nums indicates running behind,
    -- positive indicates running ahead of schedule, in minutes
    ...
}


-- For each below, set to TRUE if the correpsonding event occured (triggered)
RptVehicleEvents ::= CHOICE {
```

```
    headLights          NULL,
    fogLights           NULL,
    hazardLights        NULL,
    kinematicEvents     RptKinematicEvents,
    wiperStatusChange   NULL,
    lowSpeed            NULL,
    resumedSpeed        NULL,
    vehEntrsExitsRegion NULL,
    emerVehDetect       NULL,
    emerVehLightBar     NULL,
    reqTspEvp           NULL,
    transitVehPassCnt   NULL,
    transitVehDoor      NULL,
    v2xMsgRecption      NULL,
    -- Indicates reception of the V2X message identified in the configuration.
    driverAlertsAndWarnings     RptDriverAlertsAndWarnings,
    ...
}

RptDriverAlertsAndWarnings ::= CHOICE {
    j2945Slash1Eebl         NULL,
    -- Emergency Electronic Brake Lights
    j2945Slash1Fcw          NULL,
    -- Forward Crash Warning
    j2945Slash1BswLcw       NULL,
    -- Blind Spot Warning/Lane Change Warning
    j2945Slash1Ima          NULL,
    -- Intersection Movement Assist
    j2945Slash1Lta          NULL,
    -- Left Turn Assist
```

```
    j2945Slash1Clw          NULL,
    -- Control Loss Warning

    redLightViolationWarn   NULL,

    emerVehAlert            NULL,

    otherAlert              NULL,

    otherWarning            NULL,

    ...

}


RptKinematicEvents ::= SEQUENCE {

    events              RptEvents,

    hysteresis          RptHysteresisRecord OPTIONAL,

    ...

}


RptEvents ::= CHOICE {

    absActive           BOOLEAN,

    tractionCtlLoss     BOOLEAN,

    stabilityCtlActive  BOOLEAN,

    hardBraking         BOOLEAN, -- Defined in J2945/1

    swerve              BOOLEAN,

    ...

}


RptHysteresisRecord ::= SEQUENCE (SIZE(1..20)) OF RptHysteresis


RptHysteresis ::= SEQUENCE {

    time                DTime,

    position            Position3D,

    positionalAccuracy  PositionalAccuracy  OPTIONAL,
```

```
    velocity            RptVelocity,
    ...
}

RptRoadwayEvents ::= CHOICE {
    obstacleDetected        NULL,
    adverseRoadSurface      RptRoadRoughness,
    trfsigEncounters        RptTrafficSigEncounters,
    trfsigLightOut          NULL,
    trfsigRoadGeoMismatch   NULL,
    roadsignDetection       NULL,
    lowRoadsignReflect      NULL,
    lowLaneMarkReflect      NULL,
    roadsignIncnstncy       NULL,
    laneGeoIncnstncy        NULL,
    incidentDetect          NULL,
    workZoneCharDetect      NULL,
    inclWeatherDetect       NULL,
    railrdCrossActiv        NULL,
    drawBridgeActiv         NULL,
    ...
}

RptRoadRoughness ::= SEQUENCE {
    meanVerticalVariation       MeanVariation,
    verticalVariationStdDev     StdDev          OPTIONAL,
    -- Standard deviation in microns
    meanHorizontalVariation     MeanVariation   OPTIONAL,
    horizontalVariationStdDev   StdDev          OPTIONAL,
    -- Standard deviation in microns
```

```
    ...
}

MeanVariation ::= INTEGER (0..25000)
    -- Measured in microns (.001 mm)
    -- Range is 0 to 25 mm (0 to 25000 microns)
    -- Measured in microns (.001 mm)

StdDev ::= INTEGER (0..10000)



RptTrafficSigEncounters ::= SEQUENCE {
    intersectionID          IntersectionID  OPTIONAL, -- Imported from J2735
    -- Received by OBU in SPAT and MAP messages
    trafficMetrics          RptTrafficMetrics,
    ...
}

RptTrafficMetrics ::= CHOICE {
    trfsigApproachDelay     NULL,
    trfsigApproachSpeed     NULL,
    trfsigArrivalGreen      NULL,
    trfsigArrivalRed        NULL,
    trfsigPedDelay          NULL,
    trfsigSpatMismatch      NULL,
    trfsigSpatTimingError   NULL,
    ...
}

RptCommSysPerfEvents ::= CHOICE {
```

```
    j2945-1ChanBusy         NULL,
    rfDataRsuInfo           OCTET STRING (SIZE(6)),
    -- Report Source MAC / Layer 2 Source ID of any RSUs that we see/hear
    numOfRsusObserved       INTEGER (1..255),
    -- Count of encountered RSUs if count higher than threshold
    rfV2xJamDetect          NULL,
    j2945-1VehDens          NULL,
    j2945-1CqiBelow         NULL,
    j2945-1TrackingError    NULL,
    gnssHdopExceeds         NULL,
    gnssErrElipse           NULL,
    gnssSatsBelow           NULL,
    jammingDetect           NULL,
    ...
}

RptWiperStatus ::= ENUMERATED {off, low, medium, high, ...}

RptAveragedRecord ::= SEQUENCE {
    avgSpeed            Speed               OPTIONAL,
    -- in km/h
    speedStdDev         StdDev              OPTIONAL,
    -- in km/h
    avgStopDuration     INTEGER (1..36000)  OPTIONAL,
    -- in tenths of seconds up to an hour
    avgStopStdDev       StdDev              OPTIONAL,
    -- in tenths of seconds
    avgFuelConsumption  INTEGER (1..255)    OPTIONAL,
    avgEmissions        RptEmissions        OPTIONAL,
    avgNumOfOccupants   INTEGER (1..255)    OPTIONAL,
```

```
    ...
}

RptSummaryRecord ::= SEQUENCE {
    regTravelTime           INTEGER (1..3600)   OPTIONAL,
    -- Total travel time to traverse the region in seconds
    regVehDistTraveled      INTEGER (1..500)    OPTIONAL,
    -- Total vehicle distance traveled in kilometers
    regVehTimeTraveled      INTEGER (1..3600)   OPTIONAL,
    -- Total vehicle time traveled within the region (seconds)
    fuelConsumption         INTEGER (1..255)    OPTIONAL,
    -- Total fuel consumption in liters
    totalVehEmissions       RptEmissions        OPTIONAL,
    -- Total vehicle emissions
    numOfLowSpeedEvents     INTEGER (1..255)    OPTIONAL, -- Low speed threshold
    -- Number of times speed dropped below a low speed threshold
    timeStopped             INTEGER (1..36000)  OPTIONAL,
    -- Total Stopped time in tenths of seconds up to an hour
    numOfStopped            INTEGER (1..255)    OPTIONAL,
    -- Number of times the speed fell below the specified stopped threshold
    locOfStops              RptLocOfStops       OPTIONAL,
    -- Each location and duration in seconds where the speed drops below
    -- the specified stopped threshold
    regNumOfVehPassed       INTEGER (1..255)    OPTIONAL,
    -- Number of vehicles passed over the configuration region
    regNumOfSurpassedVeh    INTEGER (1..255)    OPTIONAL,
    -- Number of vehicles that passed the recording vehicle over the configuration region
    totalMsgsReceived       INTEGER (1..255)    OPTIONAL,
    -- Total messages received by the message type indicated in the configuration
    ...
```

```
}


RptEmissions ::= SEQUENCE {
    hydrocarbons    INTEGER (1..1000) OPTIONAL, -- in parts per million
    co              INTEGER (1..1000) OPTIONAL, -- in parts per million
    co2             INTEGER (1..1000) OPTIONAL, -- in parts per billion
    no              INTEGER (1..1000) OPTIONAL, -- in parts per million
    no2             INTEGER (1..1000) OPTIONAL, -- in parts per billion
    so2             INTEGER (1..1000) OPTIONAL, -- in parts per billion
    o3              INTEGER (1..1000) OPTIONAL, -- in parts per 100 billion
    -- Particulates of 10 micrometers or less in diameter
    pm10            INTEGER (1..1000) OPTIONAL, -- in micrograms per cubic meter
    -- Particulates of 2.5 micrometers or less in diameter
    pm25            INTEGER (1..1000) OPTIONAL, -- in micrograms per cubic meter
    ...
}


RptLocOfStops ::= SEQUENCE {
    locationOfStop      Position3D,
    locAccOfStop        PositionalAccuracy, -- Imported from J2735
    durationOfStop      INTEGER (1..36000), -- in tenths of seconds up to an hour
    ...
}


END
```

APPENDIX I - SAE J2735 EDITING INSTRUCTIONS [INFORMATIVE]

The following are instructions for updating SAE J2735 ASN.1 to include support for the ProbeDataConfigMessage and ProbeDataReportMessage. These additions to SAE J2735 ASN.1 will enable the encoding of PDUs of type MSG_MessageFrame which encapsulates the messages defined in this standard.

The first updates are to add the message type definitions to the file named J2735-MessageFrame.asn (see I.1), and the definition for RoadAuthorityID to the file named J2735-Common.asn (see I.2). Then update the SAE J2735 ASN.1 modules as specified in SAE J2945/3 (see I.3).

I.1 EDIT THE FILE J2735-MESSAGEFRAME.ASN

Add the following lines to the list of IMPORTS:

```
   ProbeDataConfigMessage
      FROM ProbeDataConfig {joint-iso-itu-t (2) country (16) us (840) organization (1)
      sae (114566) v2x-communications (1) technical-committees (1)
      infrastructure-applications (6) technical-reports (1)
      j2945 (2945) slash-c (12) asn1-module (1) probeDataConfig (0) version-1 (1)}

   ProbeDataReportMessage
      FROM ProbeDataReport {joint-iso-itu-t (2) country (16) us (840) organization (1)
      sae (114566) v2x-communications (1) technical-committees (1)
      infrastructure-applications (6) technical-reports (1)
      j2945 (2945) slash-c (12) asn1-module (1) probeDataReport (1) version-1 (1)}
```

Add the following lines to MessageTypes after the last defined SAE J2735 message, but before TestMessage00:

```
  { ProbeDataConfigMessage       IDENTIFIED BY probeDataConfigMessage       } |
  { ProbeDataReportMessage       IDENTIFIED BY probeDataReportMessage       } |
```

and then, in the list of DSRCmsgID, add the lines:

```
  probeDataConfigMessage            DSRCmsgID ::=   35 -- PDC
  probeDataReportMessage            DSRCmsgID ::=   36 -- PDR
```

I.2 EDIT THE FILE J2735-COMMON.ASN

Add the following lines after the definition of `RestrictionClassID`:

```
   RoadAuthorityID ::= CHOICE {
   -- This data frame defines the Object Identifier (OID) of the Road Authority.
      fullRdAuthID    FullRoadAuthorityID,
      relRdAuthID     RelativeRoadAuthorityID,
      ...
      }

   FullRoadAuthorityID ::= OBJECT IDENTIFIER
   -- This data element provides the identifier for the fully specified OID of the
   -- Road Authority.

   RelativeRoadAuthorityID ::= RELATIVE-OID
   -- This data element provides the identifier for the partially specified OID of the
   -- Road Authority. This may be used when the base portion of the OID is known.
```

I.3 IMPLEMENT EDITING INSTRUCTIONS AS SPECIFIED IN SAE J2945/3 APPENDIX J - SAE J2735 EDITING INSTRUCTIONS

Some data structures in this standard are dependent on structures defined in SAE J2945/3. The SAE J2735 editing instructions found in Appendix J of SAE J2945/3 must also be implemented in order for the ASN.1 specified in this standard to compile.

APPENDIX J - SAMPLE CONFIGURATION AND RESPONSE MESSAGES [INFORMATIVE]

This appendix provides a sample configuration as may be generated and transmitted by an IOO along with a response that is expected from a participating vehicle.

J.1 SAMPLE PROBE DATA CONFIGURATION

J.1.1 Probe Data Configuration Message Sample - UPER Encoded

The following is UPER encoding of ProbeDataConfig message. The hex representation of the UPER encoded message is shown first, followed by the corresponding human readable ASN.1. UPER-encoded messages are used when the ProbeDataConfig is send in a broadcast WAVE short message. The values used in this message are identical to the values used in the JER-encoded message in the next section.

```
00000000 00 2E F4 70 10 08 54 06 08 0A 28 E7 3A 86 00 11
00000010 3C 0C 5E D0 E6 E1 F5 74 00 A0

value ProbeDataConfigMessage ::=
{
  --TYPE INFORMATION: SEQUENCE (SIZE(1..255,...)) OF
  --OFFSET: 0,0
  --extension range: <.0>
  --length: <0000000.0> (decoded as 1)
  {
    --TYPE INFORMATION: SEQUENCE
    --OFFSET: 1,1
    --extension flag: <0>
    --preamble: <1>
      --bit #0 = 1: 'boundary' is present
    descriptor
    {
      --TYPE INFORMATION: SEQUENCE
      --OFFSET: 1,3
      --extension flag: <0>
      --preamble: <111>
        --bit #0 = 1: 'vehClass' is present
        --bit #1 = 1: 'roadAuthorityID' is present
        --bit #2 = 1: 'percentOfResp' is present
      identifier 123,
        --TYPE INFORMATION: INTEGER (1..255)
        --OFFSET: 1,7; LENGTH: 1,0
        --contents: <0.1111010>
      vehClass
      {
        --TYPE INFORMATION: SEQUENCE OPTIONAL
        --OFFSET: 2,7
        --extension flag: <0>
        motorcycles FALSE,
          --TYPE INFORMATION: BOOLEAN
          --OFFSET: 3,0; LENGTH: 0,1
          --contents: <.0>
        passengerCars TRUE,
          --TYPE INFORMATION: BOOLEAN
          --OFFSET: 3,1; LENGTH: 0,1
          --contents: <1>
        other2axle4tireSingleUnitVehs TRUE,
          --TYPE INFORMATION: BOOLEAN
          --OFFSET: 3,2; LENGTH: 0,1
          --contents: <1>
        buses TRUE,
```

```
      --TYPE INFORMATION: BOOLEAN
      --OFFSET: 3,3; LENGTH: 0,1
      --contents: <1>
    twoAxle6TireSingleUnitTrucks FALSE,
      --TYPE INFORMATION: BOOLEAN
      --OFFSET: 3,4; LENGTH: 0,1
      --contents: <0>
    threeAxleSingleUnitTrucks FALSE,
      --TYPE INFORMATION: BOOLEAN
      --OFFSET: 3,5; LENGTH: 0,1
      --contents: <0>
    fourOrMoreAxleSingleUnitTrucks FALSE,
      --TYPE INFORMATION: BOOLEAN
      --OFFSET: 3,6; LENGTH: 0,1
      --contents: <0>
    fourOrFewerAxleSingleTrailerTrucks FALSE,
      --TYPE INFORMATION: BOOLEAN
      --OFFSET: 3,7; LENGTH: 0,1
      --contents: <0>
    fiveAxleSingleTrailerTrucks FALSE,
      --TYPE INFORMATION: BOOLEAN
      --OFFSET: 4,0; LENGTH: 0,1
      --contents: <.0>
    sixOrMoreAxleSingleTrailerTrucks FALSE,
      --TYPE INFORMATION: BOOLEAN
      --OFFSET: 4,1; LENGTH: 0,1
      --contents: <0>
    fiveOrFewerAxleMultiTrailerTrucks FALSE,
      --TYPE INFORMATION: BOOLEAN
      --OFFSET: 4,2; LENGTH: 0,1
      --contents: <0>
    sixAxleMultiTrailerTrucks TRUE,
      --TYPE INFORMATION: BOOLEAN
      --OFFSET: 4,3; LENGTH: 0,1
      --contents: <1>
    sevenOrMoreAxleMultiTrailerTrucks FALSE
      --TYPE INFORMATION: BOOLEAN
      --OFFSET: 4,4; LENGTH: 0,1
      --contents: <0>
    ,
    --<unknown extension>
      --OFFSET: 4,5; LENGTH: 0,0
  },
  roadAuthorityID --choice value:
    --TYPE INFORMATION: CHOICE OPTIONAL
    --OFFSET: 4,5
    --extension flag: <0>
    --choice index: <0> (index = 0)
    fullRdAuthID : { 1 2 3 4 5 },
      --TYPE INFORMATION: OBJECT IDENTIFIER
      --OFFSET: 4,7; LENGTH: 5,0
      --length: <0.0000100> (decoded as 4)
      --contents: <0>.54.06.08.<0000101>
  percentOfResp 2
    --TYPE INFORMATION: INTEGER (1..10) OPTIONAL
    --OFFSET: 9,7; LENGTH: 0,4
    --contents: <0.001>
  ,
  --<unknown extension>
    --OFFSET: 10,3; LENGTH: 0,0
},
```

```
    triggers --choice value:
      --TYPE INFORMATION: CHOICE
      --OFFSET: 10,3
      --extension flag: <0>
      --choice index: <1> (index = 1)
      avgAndSumTriggers :
        --TYPE INFORMATION: CHOICE
        --OFFSET: 10,5
        --extension flag: <0>
        --choice index: <0> (index = 0)
        averagedTriggers :
        {
          --TYPE INFORMATION: SEQUENCE
          --OFFSET: 10,7
          --extension flag: <0>
          --preamble: <.11100>
            --bit #0 = 1: 'avgSpeed' is present
            --bit #1 = 1: 'avgStopDuration' is present
            --bit #2 = 1: 'avgFuelConsumption' is present
            --bit #3 = 0: 'avgEmissions' is absent
            --bit #4 = 0: 'avgNumOfOccupants' is absent
          avgSpeed TRUE,
            --TYPE INFORMATION: BOOLEAN OPTIONAL
            --OFFSET: 11,5; LENGTH: 0,1
            --contents: <1>
          avgStopDuration TRUE,
            --TYPE INFORMATION: BOOLEAN OPTIONAL
            --OFFSET: 11,6; LENGTH: 0,1
            --contents: <1>
          avgFuelConsumption TRUE
            --TYPE INFORMATION: BOOLEAN OPTIONAL
            --OFFSET: 11,7; LENGTH: 0,1
            --contents: <1>
          ,
          --<unknown extension>
            --OFFSET: 12,0; LENGTH: 0,0
        },
    maxAgeOfData 30,
      --TYPE INFORMATION: INTEGER (1..90)
      --OFFSET: 12,0; LENGTH: 0,7
      --contents: <.0011101>
    boundary --choice value:
      --TYPE INFORMATION: CHOICE OPTIONAL
      --OFFSET: 12,7
      --extension flag: <0>
      --choice index: <.1> (index = 1)
      geoAndDistBoundary :
      {
        --TYPE INFORMATION: SEQUENCE
        --OFFSET: 13,1
        --preamble: <0>
          --bit #0 = 0: 'extent' is absent
        direction { from067-5to090-0degrees, from090-0to112-5degrees },
          --TYPE INFORMATION: BIT STRING (SIZE(16)) {from000-0to022-5degrees(0),from022-
5to045-0degrees(1),from045-0to067-5degrees(2),from067-5to090-0degrees(3),from090-0to112-
5degrees(4),from112-5to135-0degrees(5),from135-0to157-5degrees(6),from157-5to180-
0degrees(7),from180-0to202-5degrees(8),from202-5to225-0degrees(9),from225-0to247-
5degrees(10),from247-5to270-0degrees(11),from270-0to292-5degrees(12),from292-5to315-
0degrees(13),from315-0to337-5degrees(14),from337-5to360-0degrees(15)}
          --OFFSET: 13,2; LENGTH: 2,0
          --contents: <000110>.00.<00>
```

```
        area --choice value:
          --TYPE INFORMATION: CHOICE
          --OFFSET: 15,2
          --choice index: <01> (index = 1)
          circle :
          {
            --TYPE INFORMATION: SEQUENCE
            --OFFSET: 15,4
            center
            {
              --TYPE INFORMATION: SEQUENCE
              --OFFSET: 15,4
              --extension flag: <0>
              --preamble: <00>
                --bit #0 = 0: 'elevation' is absent
                --bit #1 = 0: 'regional' is absent
              lat 425602740,
                --TYPE INFORMATION: INTEGER (-900000000..900000001)
                --OFFSET: 15,7; LENGTH: 3,7
                --contents: <1>.3C.0C.5E.<110100>
              long -831607970
                --TYPE INFORMATION: INTEGER (-1799999999..1800000001)
                --OFFSET: 19,6; LENGTH: 4,0
                --contents: <00>.E6.E1.F5.<011101>
              ,
              --<unknown extension>
                --OFFSET: 23,6; LENGTH: 0,0
            },
            radius 2,
              --TYPE INFORMATION: INTEGER (0..4095)
              --OFFSET: 23,6; LENGTH: 1,4
              --contents: <00>.00.<10>
            units kilometer
              --TYPE          INFORMATION:          ENUMERATED          {centimeter,cm2-
5,decimeter,meter,kilometer,foot,yard,mile}
              --OFFSET: 25,2; LENGTH: 0,3
              --contents: <100>
          }
      }
    ,
    --<unknown extension>
      --OFFSET: 25,5; LENGTH: 0,0
  }
}
--PDU padding: <000>
--TOTAL LENGTH: 26,0
```

J.1.2 Probe Data Configuration Message Sample - JSON Encoding Rules (JER) Encoded

The following JER-encoded message illustrates a probe data configuration with identifier 123 and requesting data collection from passenger/light duty vehicles and busses. The IOO requesting the data is identified by the roadRegulatorID 12345, and 20% of vehicles in the identified classes are requested to respond.

The data collected (triggers) include average speed, average stop duration and average fuel consumption. The max age of the data is 30 days, and the collection region is for headings between 67.5 degrees and 112.5 degrees (heading easterly, clockwise from north as specified in SAE J2735). The area of collection is a 2-km radius circle with a center at the location of SAE International offices in Troy, MI. This would result in data collection for east-bound vehicles along Big Beaver Rd starting 2 km before and ending 2 km after passing SAE International.

This PDC message would be downloaded using an HTTPS Response() to a query (HTTP Get (URI)) from a vehicle (the query is outside the scope of this document, and the vehicle would need to know the URI to use in the query in advance).


```
  {
    "descriptor":{
      "identifier":123,
      "vehClass":{
        "motorcycles":false,
        "passengerCars":true,
        "other2axle4tireSingleUnitVehs":true,
        "buses":true,
        "twoAxle6TireSingleUnitTrucks":false,
        "threeAxleSingleUnitTrucks":false,
        "fourOrMoreAxleSingleUnitTrucks":false,
        "fourOrFewerAxleSingleTrailerTrucks":false,
        "fiveAxleSingleTrailerTrucks":false,
        "sixOrMoreAxleSingleTrailerTrucks":false,
        "fiveOrFewerAxleMultiTrailerTrucks":false,
        "sixAxleMultiTrailerTrucks":true,
        "sevenOrMoreAxleMultiTrailerTrucks":false
      },
      "roadAuthorityID":{
       "fullRdAuthID":"1.2.3.4.5"
      },
      "percentOfResp":2
    },
    "triggers":{
      "avgAndSumTriggers":{
        "averagedTriggers":{
          "avgSpeed":true,
          "avgStopDuration":true,
          "avgFuelConsumption":true
        }
      }
    },
    "maxAgeOfData":30,
    "boundary":{
      "geoAndDistBoundary":{
        "direction":"1800",
        "area":{
          "circle":{
            "center":{
              "lat":425602740,
              "long":-831607970
            },
            "radius":2,
            "units":"kilometer"
          }
        }
      }
    }
  }
}
```

J.2 PROBE DATA REPORT MESSAGE SAMPLE - JER ENCODED

The following is a sample ProbeDataReport message uploaded in response to the ProbeDataConfig message in the previous section. The configID and roadRegulatorID match, and the ProbeDataReport shows an upload from a bus. The location, data and time of the upload, collection location and start time, and collection location and end time are all included in the message. This vehicle reported an average speed of 25 km/h (standard deviation of 5 km/h), average stop time of 61.9 seconds (standard deviation of 6.2 seconds), and average fuel consumption of 2 L/100 km. These measurements were taken as the vehicle traversed the circle defined in the ProbeDataConfig.

The PDR would be uploaded using an HTTPS Put() sent to the URI received in the certificate used to sign the PDC or to establish the TLS connection.


```
{
  "configId":123,
  "reportChar":{
    "timeStamp":{
      "year":2021,
      "month":4,
      "day":1,
      "hour":13,
      "minute":30
    },
    "position":{
      "lat":425602741,
      "long":-831607971
    },
    "posAccuracy":{
      "semiMajor":0,
      "semiMinor":0,
      "orientation":0
    },
    "velocity":{
      "speed":0
    },
    "vehicleClass":"buses"
  },
  "roadAuthorityID":{
    "fullRdAuthID":"1.2.3.4.5"
  },
  "avgAndSumRec":{
    "startTime":{
      "year":2021,
      "month":4,
      "day":1,
      "hour":13,
      "minute":25
    },
    "startLoc":{
      "lat":425602739,
      "long":-831607969
    },
    "startAccOfPos":{
      "semiMajor":0,
      "semiMinor":0,
      "orientation":0
    },
    "endTime":{
      "year":2021,
      "month":4,
      "day":1,
```

```
      "hour":13,
      "minute":35
    },
    "endLoc":{
      "lat":425602741,
      "long":-831607971
    },
    "endAccOfPos":{
      "semiMajor":0,
      "semiMinor":0,
      "orientation":0
    },
    "record":{
      "averagedRecord":{
        "avgSpeed":25,
        "speedStdDev":5,
        "avgStopDuration":619,
        "avgStopStdDev":62,
        "avgFuelConsumption":2
      }
    }
  }
}
```