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BSI Standards Publication

Intelligent transport systems – Cooperative ITS – Using V2I and I2V communications for applications related to signalized intersections (ISO/TS 19091:2019)

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee EPL/278, Intelligent transport systems.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Intelligent transport systems - Cooperative ITS - Using V2I and I2V communications for applications related to signalized intersections (ISO/TS 19091:2019)

Systèmes intelligents de transport - Coopérative ITS - Utilisation de communications V2I et I2V pour des applications relatives aux intersections signalées (ISO/TS 19091:2019)

Intelligente Transportsysteme - Kooperative ITS - Nutzung von V2I und I2V-Kommunikation für Anwendungen bezogen auf Signalanlagen an Kreuzungen (ISO/TS 19091:2019)

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European foreword

This document (CEN ISO/TS 19091:2019) has been prepared by Technical Committee ISO/TC 204 "Intelligent transport systems" in collaboration with Technical Committee CEN/TC 278 “Intelligent transport systems” the secretariat of which is held by NEN.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 204, *Intelligent transport systems*.

This second edition cancels and replaces the first edition (ISO/TS 19091:2017), which has been technically revised.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

Cooperative-ITS (C-ITS) is a promising and remarkable advancement of intelligent transport systems (ITS). Numerous cooperative applications are specified that open up new possibilities to make traffic safer, more efficient, and smarter. Technologies are developed and improved to realize and support those new services and applications. To enable those applications, information needs to be reliably communicated between the stationary infrastructure and mobile vehicles.

This document describes the use cases for several applications that address safety, mobility, and ecological sustainability. Each use case has information needs that communication between vehicles and the infrastructure facilitate. It then identifies the information needs for the applications and the requirements to satisfy them. In turn, it maps the requirements into data frames and data elements to fulfil the requirements within the specified message set.

ISO 22951 has a relationship to this document. PRESTO addresses its user needs through the implementation of a specific system architecture similar to that described in NTCIP 1211. This architecture includes traffic signals, message signs, routing systems, human machine interfaces, and fixed detection locations. Many of PRESTO's data value details are “left undefined to allow for discretional definition by each country.” The PRESTO architecture detects priority requesting vehicles by installing specific detection equipment at these locations.

This document uses a similar set of user needs to develop the message set between vehicles and the roadside equipment they interface. This document does not address the system architecture other than data needed to fulfil the user needs that will be managed elsewhere in the architecture. It details data values and structures in order to define the interface between these two devices. Routing information is supported in the architecture through other mechanisms and is not a need supported by the vehicle to roadside equipment information flows. The user needs also provide for priority by approach, a preconfigured strategy, and ingress/egress lane requests. This document is based on vehicles periodically broadcasting their location and trajectory information to other vehicles and the roadside infrastructure. This document complements ISO 22951 as it provides for vehicle location and request information directly from connected vehicles rather than the detection of the vehicles from other fixed sensing equipment. It does not address the architecture data flows and operations that are detailed within ISO 22951. In other terms, this document provides a connected vehicle alternative for request and status communication without impacting the back office or local intersection operations of priority management.

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Intelligent transport systems — Cooperative ITS — Using V2I and I2V communications for applications related to signalized intersections

1 Scope

This document defines the message, data structures, and data elements to support exchanges between the roadside equipment and vehicles to address applications to improve safety, mobility and environmental efficiency. In order to verify that the defined messages will satisfy these applications, a systems engineering process has been employed that traces use cases to requirements and requirements to messages and data concepts.

This document consists of a single document that contains the base specification and a series of annexes. The base specification lists the derived information requirements (labelled informative) and references to other standards for message definitions where available. Annex A contains descriptions of the use cases addressed by this document. Annexes B and C contain traceability matrices that relate use cases to requirements and requirements to the message definitions (i.e. data frames and data elements). The next annexes list the base message requirements and application-oriented specific requirements (requirements traceability matrix) that map to the message and data concepts to be implemented. As such, an implementation consists of the base plus an additional group of extensions within this document.

Details on information requirements, for other than SPaT, MAP, SSM, and SRM messages are provided in other International Standards. The focus of this document is to specify the details of the SPaT, MAP, SSM, and SRM supporting the use cases defined in this document. Adoption of these messages varies by region and their adoption can occur over a significant time period.

This document covers the interface between roadside equipment and vehicles. Applications, their internal algorithms, and the logical distribution of application functionality over any specific system architecture are outside the scope of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE As this document contains multiple profiles, the reference's associated profile(s) are listed within braces.

ISO 22951, *Data dictionary and message sets for preemption and prioritization signal systems for emergency and public transport vehicles (PRESTO) {A, B}*

ISO 26684, *Intelligent transport systems (ITS) — Cooperative intersection signal information and violation warning systems (CIWS) — Performance requirements and test procedures {B}*

SAE J2735:2016, *Dedicated Short Range Communications (DSRC) Message Set Dictionary {A, B, C}*

ARIB STD-T109, *700 MHz Band Intelligent Transport Systems {B}*

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ITS FORUM RC-010, *700 MHz Band Intelligent Transport Systems — Extended Functions Guideline, published on March 15, 2012 {B}*

ETSI/TS 102 894-2 V1.3.1, *Intelligent Transport Systems (ITS); Users and applications requirements; Part 2: Applications and facilities layer; common data dictionary {C}*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

NOTE This document requires the understanding of the terminology used in the context of C-ITS and the various devices involved in its implementation. As a result, the following terms contain important information to set the context of the discussions which follow in the remaining sections of this document.

3.1
active manoeuvre
traveller paths (vehicles, pedestrians, bicyclists, etc.) that are allowed and have the right of way to enter and move through the path

Note 1 to entry: This term supersedes allowed movements which means, in the context of this document, the directions of manoeuvre that are legally allowed at a specific point in time based upon the state of the intersection signals.

Note 2 to entry: Formerly known as active movement.

3.2
aftermarket safety device
ASD
connected device (3.8) in a *vehicle* (3.50) that operates while the vehicle is mobile, but which is not fully integrated into the vehicle systems (as opposed to an OEM device that is pre-installed into the vehicle systems)

3.3
allowed manoeuvre
traveller paths, e.g. vehicles, pedestrians, bicyclists, legally permitted to be performed when moving from/into a *lane* (3.21) or between lanes

3.4
application
software designed to help users perform particular tasks or handle particular types of problems, as distinct from software that controls the computer itself

Note 1 to entry: In the context of this document, it is a software program that provides functionality to realize safety, mobility, and environmental benefits.

[SOURCE: ISO/IEC 26514:2008, 4.5, modified – Term 'application software' changed to 'application' and Note 1 to entry added.]

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3.5
Barnes dance
signal phase that stops vehicular manoeuvres and allows pedestrian manoeuvres to exclusively occur across the *intersection* (3.17) including diagonally moving between corners

Note 1 to entry: Also referred to as a scramble, or "X" crossing. The term refers to Henry Barnes, a deceased traffic engineer.

3.6
commercial motor vehicle
self-propelled or towed motor *vehicle* (3.50) used on a highway in commerce to transport passengers or property when that vehicle is subject to regulations determined by the jurisdiction as to its use on the road system of the jurisdiction in regulated circumstances and

a) has a gross vehicle weight rating or gross combination weight rating, or gross vehicle weight or gross combination weight, of 4 536 kg (10 001 pounds) or more, whichever is greater,

b) is designed or used to transport more than 8 passengers (including the driver) for compensation,

c) is designed or used to transport more than 15 passengers, including the driver, and is not used to transport passengers for compensation

3.7
commercial motor vehicle on-board equipment
OBE (3.29) or *ASD* (3.2) mounted or in a *vehicle* (3.50) moving goods, heavy equipment, or people

Note 1 to entry: Vehicles include tractor-trailer combinations, panel trucks, and motor coaches.

3.8
connected device
device used to transmit to or receive messages from another device

Note 1 to entry: A connected device can be sub-categorized as an *OBE* (3.29), *ASD* (3.2), or *RSE* (3.39).

Note 2 to entry: In many cases, the connected device will be a *DSRC* (3.10) device, but other types of communications could be supported.

3.9
connected vehicle
vehicle that contains a *connected device* (3.8)

3.10
dedicated short range communications
DSRC
technology for the transmission of information between multiple *vehicles* (3.50) (V2V) and between vehicles and the transportation infrastructure (V2I and I2V) using wireless technologies

Note 1 to entry: It is characterized as having a limited distance (approximately 300 m) but is assumed to be low latency to establish a connection and exchange information.

Note 2 to entry: Alternative definition - means of effecting (short-range) transactions between fixed equipment and OBE(s) using an "air interface" comprising inductive or propagated signals between the fixed equipment and OBE(s).

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3.11
eco-driving
practice of driving in such a way as to minimize fuel consumption and emissions

3.12
eco-lane
dedicated *lane(s)* (3.21) optimized for *eco-driving* (3.11) similar to high-occupancy vehicle lanes

Note 1 to entry: However, these lanes are optimized for the environment using connected vehicle data.

Note 2 to entry: These lanes would be targeted toward low-emission, high-occupancy freight, public transport, and alternative-fuel vehicles (AFV).

Note 3 to entry: Drivers would be able to opt-in to these dedicated eco-lanes to take advantage of eco-friendly applications such as eco-speed limits, eco-cooperative adaptive cruise control, and connected eco-driving applications.

3.13
electronic on-board recorder
device on-board a commercial *vehicle* (3.50) used to record driver information such as hours of service

3.14
inactive manoeuvre
traveller paths, e.g. vehicles, pedestrians, bicyclists, that are allowed and do not have the right of way to enter and move through the path

3.15
intelligent transportation system
ITS
transport system in which advanced information, communication, sensor, and control technologies, including the Internet, are applied to increase safety, sustainability, efficiency, and comfort

Note 1 to entry: Another appropriate meaning of the ITS acronym is integrated transportation systems, which stresses that ITS systems will often integrate components and users from many domains, both public and private.

[SOURCE: ISO/TR 17465-1:2014, 2.3, modified – Note 1 to entry added.]

3.16
interoperability
ability of two or more systems or components to exchange information and to use the information that has been exchanged

[SOURCE: IEEE 610.12-1990]

3.17
intersection
nexus where two or more approaches (*links*) (3.26) meet and *vehicles* (3.50) and other type of users may travel between the connecting links

Note 1 to entry: Typically, this is a signalized intersection when considered by this document, and as such, the modes of allowed manoeuvre are reflected in the signal phases, the geometry of the intersection, and the local regulatory environment.

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Note 2 to entry: The messages of J2735™ convey some of this intersection information to the travelling public. Specifically, the *MAP message* (3.28) conveys the relevant road geometry, while the *SPaT* (3.44) message conveys the current allowed manoeuvres and timing which control movements within the intersection.

Note 3 to entry: Alternative definition - GDF level 2 representation of a crossing which bounds a road or a ferry as a complex feature composed of one or more GDF level 1 junctions, road elements and enclosed traffic areas.

3.18
interval
part of a traffic signal cycle during which *signal indications* (3.43) are stable and do not change

Note 1 to entry: In the *SPaT* (3.44) message, the current timing value for the remaining interval time estimate, as well as the anticipated interval for yellow change (clearance) interval, is provided for each lane.

Note 2 to entry: Because signal interval times commonly change based on triggering events in many types of signalling systems, the value provided in the SPaT message may represent a minimal value that is extended and updated as the message is re-transmitted in real time.

3.19
interval sequence
order of appearance of *signal indications* (3.43) during successive periods of a traffic signal cycle

3.20
international traveller information system
ITIS
standard for incident phrases developed by the SAE ATIS Committee in conjunction with ITE TMDD and other standards

Note 1 to entry: The ITIS documentation contains a wide variety of standard phrases to describe incidents and is expected to be used throughout the *ITS* (3.15) industry. The codes found there can be used for sorting and classifying types of incident events, as well as creating uniform human readable phrases. In the capacity of classifying incident types, ITIS phrases are used in many areas. ITIS phrases can also be freely mixed with text and used to describe many incidents.

3.21
lane
portion of the transportation network (typically a section of roadway geometry) which is being described (its paths and various attributes about it) or referred to

Note 1 to entry: In the DSRC message set, the lane object is widely used. Lanes consist not only of sections of drivable roadway traversed by motor vehicles, but other types of lanes including pedestrian and bicycle walkways, trains and public transport lanes, and certain types of dividers and barriers.

Note 2 to entry: When used in describing an intersection, a lane is defined for each possible path into and out of the intersection (in the MAP message). The current allowed manoeuvres applicable to the lane or its approach are provided in the *SPaT* (3.44) message.

3.22
lane-use control signal
signal face displaying *signal indications* (3.43) to permit or prohibit the use of specific *lanes* (3.21) of a roadway or to indicate the impending prohibition of such use

Note 1 to entry: Typically, these are arrow displays of varying colours.

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Note 2 to entry: This document does not attempt to use signal colours/indications to reflect the allowed vehicle operation, rather, the permitted movements are indicated and the state of the movement as explained later herein. Each region has unique mechanisms for using the display signals to indicate the movement(s) allowed.

3.23
latency
<system> time interval between the instant at which an instruction control unit issues a call for data and the instant at which the transfer of data is started

Note 1 to entry: The reader is advised to select the appropriate definition based on the context.

[SOURCE: ISO/IEC IEEE 24765:2017, 3.2187, modified – "<system>" added at beginning of definition.]

3.24
latency
<communication> time delay between sending a signal from one device and receiving it by another device

Note 1 to entry: The reader is advised to select the appropriate definition based on the context.

[SOURCE: ISO/IEEE 11073-10201:2004, 3.31, modified – Note 1 to entry.]

3.25
link
<radio frequency> communications channel being used in support of application data transfer needs

3.26
link
<traffic> segment of a road network

Note 1 to entry: While highway links are generally separated by one data collection node (such as an RSE or a vehicle detector station), local road links tend to be limited by intersections with cross streets.

Note 2 to entry: Other common usages of the word "link," such as those used in telecommunications, may also appear in this document.

3.27
low-emissions zone
geographically defined area that seeks to restrict or deter access by specific categories of high-polluting *vehicles* (3.50) to improve the air quality within the geographic area

Note 1 to entry: The low-emissions zone can be dynamic, allowing the operating entity to change the location, boundaries, or time of the low-emissions zone.

3.28
MAP data message
MAP
data elements and frames comprising a message, the contents of which describe the geometry of a roadway *intersection* (3.17)

Note 1 to entry: In the context of USDOT J2735™ SE Candidate, the MAP message provides the road geometry at an intersection.

Note 2 to entry: It is broadcast from the infrastructure to the vehicle.

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Note 3 to entry: The MAP message contains geographic intersection description (GID) data.

3.29
on-board equipment
OBE
complement of equipment located in the *vehicle* (3.50) for the purpose of supporting the vehicle side of the C-ITS applications

Note 1 to entry: It is likely to include the DSRC radios, other radio equipment, message processing, driver interface, and other applications to support the use cases described herein.

Note 2 to entry: It is also referred to as the vehicle ITS station.

Note 3 to entry: Alternative definition - device on board or attached to the vehicle/equipment to perform the functionality of AVI/AEI.

3.30
prohibited manoeuvre
traveller paths, e.g. vehicles, pedestrians, bicyclists, legally disallowed from being performed when moving from/into a *lane* (3.21) or between lanes

3.31
traffic signal phase
set of manoeuvres being allowed by the roadside traffic signal controller

Note 1 to entry: This term is commonly used in North America to refer to a specific manoeuvre that is allowed, e.g. main street left turn to a side street, main street north bound through manoeuvre, side street pedestrian walk.

3.32
platoon
collection of vehicles travelling together, coordinating their operation, e.g. speed, headway, using V2V communications

Note 1 to entry: Platoons may consist of a mixture of *vehicle types* (3.51) or in special circumstances, a single vehicle type such as freight vehicles (e.g. lorries), public safety vehicles, or *public transport vehicles* (3.35).

3.33
precondition
condition that must exist or be established before something can occur or be considered

3.34
public safety on-board equipment
PSOBE
OBE (3.29) or *ASD* (3.2) mounted or in an authorized public safety *vehicle* (3.50)

Note 1 to entry: It may be designed to transmit at a higher power to allow its messages to be received from a greater distance to provide more time to complete appropriate clearance intervals at signalized intersections.

3.35
public transport vehicle
PTV
vehicle (3.50) specifically designed to carry multiple passengers, e.g. a bus

Note 1 to entry: Does not refer to taxis or similar vehicles.

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3.36
queue jump
operation where *public transport vehicles* (3.35) are provided an advantage over adjacent *vehicles* (3.50) through signal operations that allow the public transport vehicle to enter an *intersection* (3.17) in advance of the adjacent vehicles

3.37
road surface condition
environmental measures of a pavement's running surface including temperature and moisture condition

EXAMPLE Dry, wet, snowy, icy, chemical concentration, oil, etc.

Note 1 to entry: This information may also include information regarding surface conditions that could be used to compute stopping distances for selected use cases.

3.38
road sign
physical traffic control device intended to communicate specific information to road users through a word, symbol, and/or arrow legend

Note 1 to entry: Road signs do not include highway traffic signals, pavement markings, delineators, or channelization devices.

3.39
roadside equipment
RSE
complement of equipment located at the roadside that prepares and transmits messages to *vehicles* (3.50) and receives messages from vehicles for the purpose of supporting the V2I and I2V applications

Note 1 to entry: This is intended to include the DSRC radio, traffic signal controller, where appropriate, interface to the backhaul communications network necessary to support the applications, and support such functions as data security, encryption, buffering, and message processing.

Note 2 to entry: It may also be referred to as the roadside ITS station.

3.40
roadway segment
section of a highway improved, designed, or ordinarily used for vehicular travel and parking lanes, or that portion of a highway improved, designed, or ordinarily used for vehicular travel and parking lanes, but exclusive of the sidewalk, berm, or shoulder even though such sidewalk, berm, or shoulder is used by persons riding bicycles or other human-powered *vehicles* (3.50)

[SOURCE: MUTCD, 2009, Section 1A.13]

3.41
signal control zone
geo-physical area of an *intersection* (3.17) used for an approaching *vehicle* (3.50) to request a pre-empt or priority request of a traffic signal

3.42
signal group
set of traffic signals providing a *signal indication* (3.43) that governs the vehicle/pedestrian/bicycle manoeuvres possible for a set of one or more *lanes* (3.21)

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3.43
signal indication
illumination of a signal lens or equivalent device

Note 1 to entry: The signal face of a signal indication is an assembly of one or more signal sections that is provided for controlling one or more traffic manoeuvres on a single approach.

[SOURCE: MUTCD, 2009, Section 1A.13]

3.44
signal phase and timing
SPaT
SAE J2735™ message from the infrastructure to the C-ITS device that describes the current state of a traffic signal system (at one or more intersections) and its phases and relates this to the specific *lanes* (3.21) (and therefore to manoeuvre and approaches) in the *intersection* (3.17)

Note 1 to entry: It is used along with the *MAP message* (3.28) to allow describing an intersection and its current allowed manoeuvres and timing of same.

3.45
signal request message
SRM
SAE J2735™ message from a C-ITS device to the infrastructure by which the *vehicle* (3.50) asks for priority treatment by an intersection's traffic signal controller

3.46
signal status message
SSM
SAE J2735™ message from the infrastructure to the C-ITS device that contains the infrastructure's response details to a *signal request message* (SRM) (3.45) for requesting priority from an intersection's traffic signal controller

Note 1 to entry: This is a broadcast message in this document; this is not a unicast message.

3.47
speed
rate of progress, or change in position, usually without regard to direction

Note 1 to entry: The distance travelled divided by time (if speed is constant). A scalar quantity which refers to how fast an object is moving.

3.48
traffic signal phase overload
proceed manoeuvre that has been terminated while demand for the manoeuvre continues

Note 1 to entry: Repeated phase overloads indicate that the signal phase timing is not adequate to satisfy the demand.

3.49
public transport vehicle on-board equipment
PTVOBE
OBE (3.29) or *ASD* (3.2) mounted or within a *public transport vehicle* (3.35)

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3.50
vehicle
self-propelled transport device, along with any attachments, e.g. trailers, that is a legal user of the transportation network

Note 1 to entry: Alternative definition — Object subject to being navigated or tracked.

Note 2 to entry: Alternative definition — Machine for the transportation of goods and people on land.

3.51
vehicle type
classification scheme used to identify *vehicles* (3.50) for appropriate services by various crosscutting C-ITS applications

Note 1 to entry: Observe that this definition differs from the (multiple other) vehicle types defined elsewhere in other International Standards used in *ITS* (3.15). The specific vehicle type (i.e. classification) used for an application may not satisfy the needs of other applications.

Note 2 to entry: Alternative definition - type (i.e. classification) of vehicle based on the nature of its construction or intended purpose.

Note 3 to entry: See SAE J1100.

3.52
work zone
area of a highway with construction, maintenance, or utility work activities

Note 1 to entry: A work zone is typically marked by signs, channelizing devices, barriers, pavement markings, and/or work vehicles.

Note 2 to entry: A work zone extends from the first warning sign or high-intensity rotating, flashing, oscillating, or strobe lights on a vehicle to the END ROAD WORK sign or the last Temporary Traffic Control device.

[SOURCE: MUTCD 2009, Section 6C.02]

4 Abbreviated terms

AEI	Automatic Equipment Identification
AERIS	Applications for the Environment: Real-Time Information Synthesis
ASD	Aftermarket Safety Device
ATIS	Advanced Traveller Information System
AVI	Automatic Vehicle Identification
BOPC	Back Office Processing Centre (also known as Traffic Management Centre)
BSM	Basic Safety Message (J2735™)
CAM	Cooperative Awareness Message (ETSI)
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CV	Connected Vehicle
DSRC	Dedicated Short Range Communications
ETSI	European Telecommunications Standards Institute

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EVP	Emergency Vehicle Pre-emption
FrVOBE	Freight Transport Vehicle On-Board Equipment
FSP	Freight Signal Priority
GHG	Green House Gas
GID	Geographic Intersection Description
GNSS	Global Navigation Satellite System
GPS	Geographic Positioning System (by use of GNSS)
HDOP	Horizontal Dilution of Precision
HOV	High Occupancy Vehicle
I2V	Infrastructure to Vehicle
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITE	Institute of Transportation Engineers
ITIS	International Traveller Information System
ITS	Intelligent Transport Systems
MMITSS	Multi-Modal Intelligent Traffic Signal System (a project within the US)
MPR	Minimum Performance Requirements
MUTCD	Manual on Uniform Traffic Control Devices (a US Department of Transportation technical document)
NMEA	National Marine Electronics Association
OBE	On-Board Equipment
PRESTO	Data Dictionary and Message Sets for Pre-emption and Prioritization Signal System for Emergency and Public Transport Vehicles
PSOBE	Public Safety On-Board Equipment
PTV	Public Transport Vehicle
RF	Radio Frequency
RSE	Roadside Equipment
RTCM	Radio Technical Commission for Maritime Services
SAE	Society of Automotive Engineers International
SPaT	Signal Phase and Timing (J2735™)
SRM	Signal Request Message (J2735™)
SSM	Signal Status Message (J2735™)
TMC	Traffic Management Centre (also known as Back Office Processing Centre)
TMDD	Traffic Management Data Dictionary
PTVOBE	Public Transport Vehicle On-Board Equipment
TSC	Traffic Signal Controller

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TSP	Public transport Signal Priority
USC	United States Code
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VRU	Vulnerable Road User (typically, a pedestrian may include bicycle rider)

5 General description (informative)

5.1 Overview

This clause describes the actors, needs, and models requiring the services provided by the message set. It describes how the connected vehicle (CV) obtains the data needed from the infrastructure to perform its on-board processing and decision making within the context of the use cases.

It also describes the assumptions and operational issues associated with delivering the services.

The use cases are organized into three areas: safety, mobility/sustainability, and priority/pre-emption for specific vehicle types (public safety, public transport, freight, etc.) and are shown in Annex A. Each area is identified using an alpha-numeric identification consisting of a use case category and a number. The use case categories are PR for priority/pre-emption, SA for safety, and MS for mobility/sustainability. Table A.1 lists the use cases by their identification and name.

Each use case comprises 16 descriptive characteristics ranging from simple identification information through data/process flow sequences and outstanding issues. These are presented in tabular form with each use case beginning on a new page. An illustration is included with each use case to provide a visual reference when discussing the operation.

Three types of travellers are supported by this document: general motorized vehicles, non-motorized (e.g. pedestrians, bicyclists), and specialized motor vehicles. Vehicular lanes are lanes for motorized vehicles, pedestrian lanes (cross walks) are for pedestrians, including non-motorized vehicles such as bicycles, while special lanes are for lanes for a specific type of motorized vehicle such as trains or public transport vehicles.

5.2 Functional model

5.2.1 Description

The use cases described in this document utilize the following functional working model, which describes at a high level the relevant vehicle equipment, roadside infrastructure, and traffic management functionality to support the use cases. While the focus is on the communications between the vehicle and roadside infrastructure, selected use cases involve interaction with traffic/fleet management functions beyond the roadside. The precise details of these interactions are not defined herein, but rather are described in general terms. While DSRC communications media has been assumed for message exchanges, the focus of this document is to identify the specific data elements needed for the exchanges over the V2I/I2V link to meet the needs of the use cases described herein. The message content is intended to be media-independent. However, it is likely that performance requirements for certain applications will dictate the type of media capable of supporting the intended functionality.

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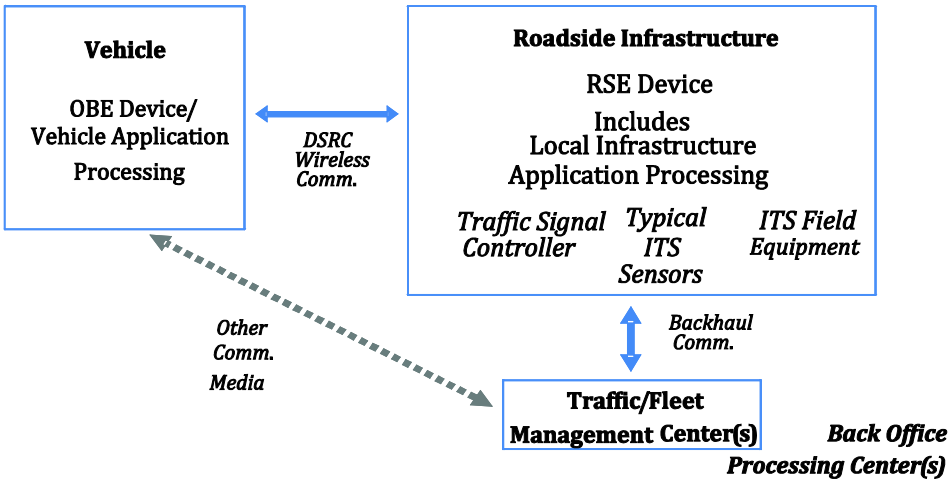

Figure 1 — Working model for use cases (functional)

Vehicle role. The connected vehicle includes the basic functionality needed to implement transmission of basic safety messages (BSM) [or cooperative awareness messages (CAM)], and signal request messages (SRM), where applicable, as well as receiving and processing incoming signal phase and timing (SPaT) messages, MAP messages, signal status messages (SSM), and other infrastructure-to-vehicle messages. The following assumptions apply.

— An OBE device provides for DSRC communications with the field infrastructure.

— Vehicle application processing may be provided by the OBE device and/or separately.

— Other communications may exist to communicate with the traffic/fleet management center.

— Vehicles are assumed to make all safety-related decisions and determine what, if any, advisory, alert, or warning to provide to the driver.

The vehicle transmits to the infrastructure (V2I) and receives from the infrastructure (I2V). These transmissions are also received by other vehicles (V2V) since they are broadcast messages. While the data flows between vehicles could be utilized within the use cases identified herein, they exist only to indicate data availability and these data flows are outside the scope of this document.

Roadside infrastructure role. The roadside infrastructure incorporates the communications and processing functionality to send, receive, and process messages to and from the vehicle and, as applicable, provides for traffic signal control, sensing/detection using traditional ITS devices, and other field-related functions. It also includes backhaul communications capability to support management functions such as traffic management. The following assumptions apply.

— RSE devices provide for DSRC communications with vehicles.

— Local infrastructure application processing may be provided by the RSE device and/or separately (in combination, the RSE may be referred to as roadside equipment).

— RSE device, traffic signal controller, and other ITS field equipment are connected via backhaul network to one or more back office processing centres (BOPC).

— Traffic signal controller and other ITS field equipment are typically connected to the RSE device via local wireline communication.

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— Roadside equipment can provide limited control and performance management over a specific geographic area, i.e. at an intersection and its approaches.

— The use cases typically identify or separate functions within the roadside infrastructure as the RSE and the TSC to be separate devices. Hence, selected processing is assigned to the RSE while other processing is assigned to the traffic signal controller. This is an arbitrary separation; the reader should assume that the functions specified at the roadside can be performed by any of the roadside devices, thus all processing could take place within the traffic signal controller if it has sufficient processing power and memory, or such processing could be assigned to other devices within the cabinet. This document only addresses the message content exchanged between the vehicle and the roadside.

Traffic management center (TMC) role. The traffic management centre, also known as the back office processing centre (BOPC), provides for management of field ITS equipment including traffic signal controllers, RSE devices and associated processing capabilities, as well as managing information such as policies and rules, the geometric database, regional (section, arterial) signal timing data, and performance management. The following assumptions apply.

— Traffic management center (TMC) manages traffic signal controllers and ITS field equipment.

— TMC incorporates other back-office functions.

— Backhaul communication exists between field infrastructure components and TMC.

— Other communications may exist to communicate with vehicles and other centres.

— Traffic management is assumed to provide for higher-level control and coordination for area-wide (network) and corridor-level functions and performance. This includes arterial progression, adaptive control, and timing pattern/plan selection.

— Multiple facilities could be represented by the single centre shown in the diagram.

5.2.2 Architecture

The conceptual architecture for the use cases is shown below. This generalizes the overall distribution of equipment. The roadside equipment (RSE) will contain a DSRC radio transceiver that hears the broadcasts from the vehicles (BSM/CAM) and uses this information to provide the applications to support use cases. The RSE includes the traffic signal controller responsible for controlling the traffic signals, and it uses the infrastructure-based sensors along with the information provided from the BSM to regulate the right of way at the signalized intersection.

NOTE The term BSM and CAM are used in this document to refer to the basic safety message and cooperative awareness message which is broadcast by the vehicles to provide data regarding the position, trajectory, and other data for each vehicle within range of the signal.

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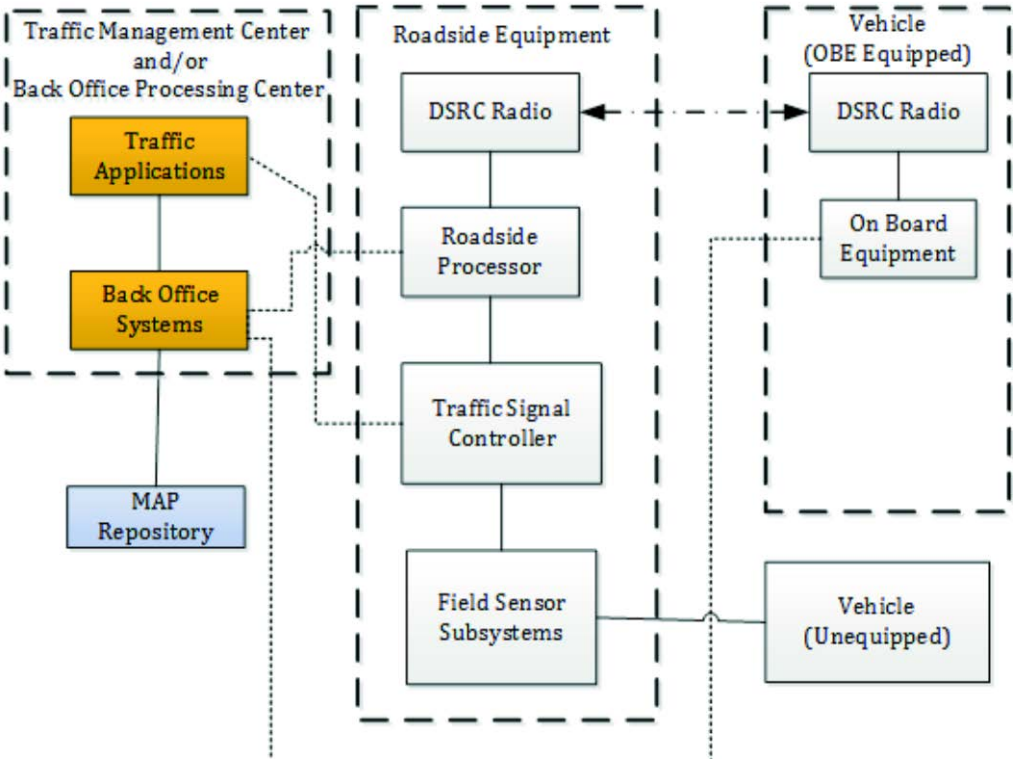

Figure 2 — General architecture for V2I/I2V communications

Some of the key concepts are the connection to the back-office systems where the RSE will obtain its local configuration information, which will include the security certificates, GNSS augmentation information, and the detailed static geometric information for the intersection (MAP). The connection to the BOPC (in this specific case, the traffic management centre) is used for the management of the traffic controller database which includes timing patterns, schedules, etc. The BOPC is also involved in the selection of timing plans and adaptive signal timing to accommodate special timing plans, platoon management, etc.

There is a connection shown from the vehicle to the BOPC which is recognition that some of the information may be exchanged directly with the BOPC if there is a wide area network available. This connection may also include the back-office systems and could be used for such tasks as the distribution of the MAP information, regional status, and route pre-emption (green wave). While a single TMC/BOPC is logically shown in the figure, it represents one or more physical locations where various processes/functions may be resident, such as traffic, public transport, and/or emergency services operations.

Note that the exchanges between the RSE and the OBE may also be used to directly impact the signal timing and will be used to provide the approaching connected vehicle with the real-time information regarding the currently permitted manoeuvres and timing such as the remaining "green" time and the remaining "red" time. Note that signal colours have been used; it is the intent of these use cases that the RSE provides information to the OBE that indicates the permitted manoeuvres for the specific location of the vehicle. In some cases, this may be lane by lane, while in other cases, it may be by approach only. Since different countries/regions use different displays to indicate the permitted manoeuvres and the time point of their change, they will be dealt with as information concepts termed movement states rather than specific displays.

This document focuses on the messages exchanged over the interface between the vehicles and the roadside equipment. Since these are message specifications, using broadcast messages, the role of the

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ITS station is not addressed. It is assumed that the roadside equipment (RSE) and the on-board equipment (OBE) could be constructed in any manner using any architecture including the ITS station as described in other standards, or other hardware and software constructs of a proprietary nature. It is important that the messages adhere to the structure, dialogues, and content specified herein and this content identified for the specific regions in the subsequent additional annexes (e.g. Annex E for North America). This approach allows an intermix of proprietary and open devices to be used to implement the various elements of the C-ITS infrastructure and remain interoperable with equipment constructed by a variety of vendors.

As noted below, security issues (e.g. authentication, encryption, privacy protection, misbehaviour detection, etc.) are assumed to be addressed in the implementation of the message exchanges as required but are outside the scope of this document. The use cases assume that the communications among all parties is secure.

5.2.3 Message interactions

The messages which support the use cases described herein are based on the concept of "broadcast" messages where the appropriate device (OBE or RSE) broadcasts the message content to all entities (e.g. vehicles and infrastructure) within range of the DSRC radio signals. The messages to support these use cases are not based on the concept of an interactive information exchange between two or more specific entities.

Given the nature of the DSRC communications, the applications described herein (safety, mobility/sustainability, priority/pre-emption) rely on the replication of messages and the probability that the target entity will receive the message in time to take appropriate action, such as warning the driver of an impending intersection violation or that a specific vehicle is requesting priority treatment. Each entity in turn cannot assume that its request(s) have been received and honoured unless it confirms such a situation based on a broadcast message from the target entity. Even in such cases, conditions can change instantaneously; for example, a priority treatment can be immediately terminated to accommodate an emergency vehicle of higher priority pre-emption. Thus, the entity should continuously monitor the messages received and act accordingly whether it is to modify signal timing or provide driver warnings.

Where the application described uses wide area communications (e.g. 3G/4G/LTE), then the exchanges may be point to point exchanges using other protocols such as TCP/IP, where a specific unit to unit interaction is required.

5.2.4 Common operational assumptions

The use cases described herein are based on the following general assumptions.

a) It is assumed that all OBE equipped vehicles are broadcasting the basic safety message (BSM) or cooperative awareness message (CAM) message continuously at some repetition rate which has yet to be determined and may vary depending on the saturation of active vehicles. The commonly assumed rate is 10 times per second; however, the exact latency necessary for such use cases has not been determined at this time. It is likely that the rate of less than 10 Hz will be adequate for these applications.

b) The use cases described below are based on the assumption that the vehicles within range of the intersection will all be broadcasting the BSM or CAM, which includes information regarding the vehicle's location, speed, heading, and directional signals as a minimum. This information will be used by the applications supporting these use cases as described herein.

c) These use cases are also based on the use of DSRC communications from the vehicle to the RSE with a range of approximately 300 m under "normal" conditions. While different conditions and locations may extend this, the applications should only be designed to work with this range in

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mind. It is likewise possible that infrastructure (buildings) and weather conditions restrict the range to significantly less than 300 m.

d) The RSE at the traffic signal controller (TSC) is continuously broadcasting the signal phase and timing (SPaT) message to indicate the current (and future) signal state information to vehicles in the vicinity. Vehicles approaching the intersection become aware of the traffic signal when they "hear" this message.

e) The RSE at the traffic signal controller (TSC) is periodically broadcasting information that describes the geometrics of the intersection, which defines the approach lanes, the departure lanes, and the permitted manoeuvres (the MAP message). A set of performance requirements are included to establish a framework for the periodic broadcast of the MAP message. At this time, these performance requirements are subject to additional analysis as the repetition rate will be determined in part by the RF propagation characteristics and the speed of the approaching vehicles. Note that it is assumed that the vehicle "knows" its position and can judge the relevant intersection it is approaching. Since it may be possible for the OBE to "hear" multiple RSE's at any point in time, the responsibility of determining which intersection ID it is approaching and hence how to react to the messages.

f) It is assumed that the priority requesting vehicles and other OBE equipped vehicles have some sort of on-board map database that they can use for identifying a route through the street network. The map database will contain information regarding the identification of the intersections along the route such that the vehicle "knows" its current location and "knows" what type of signal priority request (scenario) to make at a given intersection it is approaching. It will also be able to determine when it will arrive at the intersection and when the required priority manoeuvre is needed.

g) The MAP information will include base geometric information and other related information (e.g. manoeuvres permitted). Generally, MAP information is static in nature. There are times when the MAP information changes (e.g. when access to a side road or a turn is not permitted). Therefore, the MAP information shall contain both the base geometry and changes to the other MAP information. A vehicle receiving the MAP information message need only process the changes unless the base geometric information has changed (e.g. the version for the base geometric is different from what is currently stored in the vehicle). If the base geometric information has changed, the vehicle shall process the base geometric information. If the vehicle does not contain a base geometric for the intersection in question, then the vehicle process the base geometric information and other changes contained in the MAP.

h) Vehicles will be assigned a type that will be used by the intersection control logic to determine the nature of the priority request that may be supported for that vehicle. This shall identify such vehicle types as public transport vehicles, freight vehicles (lorry), emergency vehicles, etc.

i) Where route pre-emption or platoon support is desired over multiple intersections (for example, along an arterial), interaction with a central system or interaction between traffic controllers will be necessary to manage signal timing along a route (arterial) and route priority or pre-emption rather than an isolated intersection interaction.

j) Security is a global requirement for all SPaT/MAP, SRM and SSM transmissions found in these use cases. The use cases assume that security will be in place and is therefore not mentioned in the respective use cases.

k) While the message sets are intended to be media-independent, their application should address the chosen media's bandwidth limitations and propagation latencies for a successful implementation.

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5.3 Safety use cases

5.3.1 Intent

The safety related use cases for V2I/I2V are intended to provide vehicles with information regarding the current condition of the traffic signal it is approaching (permitted manoeuvre) and the time point for the manoeuvre to change. Using this type of information, the approaching vehicle should be able to determine the appropriate actions to avoid violating the right of way and a subsequent crash.

It is also possible for the traffic controller to use the information regarding impending violations of the stop-bar to alter the signal timing to reduce the probability of a crash under such circumstances.

The safety use cases are related to the concept of using the connected vehicle (CV) message exchanges (V2I, I2V) for the purpose of modifying the traffic signal operation and/or providing warning information to OBE equipped vehicles. These use cases are based on the use of DSRC communications, although some of them could be supported with other media that meet the appropriate performance characteristics such as latency, reliability, and range. It is important to keep in mind that the SPaT and MAP are intended to be media-independent such that they could be handled with alternatives to DSRC.

The details of the safety use cases are provided in Annex A.

5.3.2 Additional assumptions

There are no safety specific assumptions contained within these use cases.

5.3.3 Architecture implications

The conceptual architecture for the use cases for general safety applications is shown in Figure 2. This generalizes the overall distribution of equipment. The roadside equipment (RSE) will contain a DSRC radio transceiver that hears the broadcasts from the vehicles (BSM/CAM) and uses this information to provide the applications to support use cases. The RSE includes the traffic signal controller responsible for controlling the traffic signals, and it uses the infrastructure-based sensors along with the information provided from the BSM to regulate the right of way at the signalized intersection.

One of the key concepts is the connection to the back-office systems where the RSE will obtain its local configuration information which will include the security certificates, GNSS augmentation information, and the detailed static geometric information for the intersection (MAP). The connection to the BOPC (in this specific case, the traffic management centre) is used for the management of the traffic controller database which includes timing patterns, schedules, etc. The BOPC is also involved in the selection of timing plans and adaptive signal timing to accommodate special timing plans, platoon management, etc.

Note that the exchanges between the RSE and the OBE may also be used to directly impact the signal timing and will be used to provide the approaching connected vehicle with the real-time information regarding the currently permitted manoeuvres and timing such as the remaining “green” time and the remaining “red” time. Note that signal colours have been used here; it is the intent of these use cases that the RSE provides information to the OBE that indicates the permitted manoeuvres for the specific location of the vehicle and not the specific signal display. In some cases, this information may be on a lane-by-lane basis, while in other cases, it may be provided by approach only. Since different countries/regions use different displays to indicate the permitted manoeuvres and the time points when they will change, the information will be dealt with in this document as movement states rather than specific displays.

Several use cases involve non-signalized intersections. These use cases assume that one of two situations exist. Either the non-signalized intersection has an RSE located at the intersection or a near-by RSE equipped intersection provides the MAP data for the non-signalized intersection. This means that the vehicle has sufficient information to navigate the intersection's geometrics. The remaining issue is whether there is a SPaT message to indicate the allowable manoeuvres or whether the

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allowable manoeuvres are completely described within the MAP message. If the manoeuvres are static, then there is no need for a SPaT transmission from the non-signalized intersection. If the manoeuvres change due to circumstances or time-of-day, then it is assumed that the updates will be distributed through an updated MAP message and will be available to all vehicles approaching the intersection.

5.4 Mobility/sustainability use cases

5.4.1 Intent

The mobility/sustainability use cases are related to the concept of using the connected vehicle (CV) message exchanges (V2I, I2V) for the purpose of modifying vehicular operations to improve travel and reduce environmental impacts within a roadway network. These use cases are based on the use of DSRC communications, although some of them could be supported with other media that meet the appropriate performance characteristics such as latency, reliability, and range. It is important to keep in mind that the SPaT and MAP are intended to be media-independent such that they could be handled with alternatives to DSRC.

The overall operation and architecture is identical to that described in 5.3 for the safety applications. While 5.3 dealt primarily with the use cases and requirements to support intersection safety, the use cases in this subclause deal with the additional information needed to promote more efficient use of the roadway network and, more specifically, improved efficiency of the individual intersections. For example, for ECO driving, knowing how much green remains or when the green will appear allows the vehicle/driver to better modulate the vehicle's speed to minimize the production of green house gases (GHG) and allow more efficient driving. It is also possible for the intersection to track the location of all approaching vehicles and to improve the efficiency of the overall system operation through optimal intersection and arterial timing to accommodate platoons.

The information needed is virtually identical. The vehicles need to know what manoeuvre is currently permitted for their specific lane (approach) and how long it will remain active. If their desired manoeuvre is not currently permitted, the vehicle needs to know when it will be permitted such that it can make efficient use of the time before "green" for such applications as vehicle charging and engine shutdown and startup. This information can also be used in conjunction with other on-board sensors to modulate the vehicle speed through the intersection or roadway network to minimize the hard braking or startup costs. A modulated speed can create a safer environment and minimize pollution and fuel consumption, as well as reduce congestion.

The details of the mobility/sustainability use cases are provided in Annex A.

5.4.2 Additional assumptions

It should be noted that the mobility/sustainability use cases include applying these operational concepts to vehicular platoons in addition to single vehicles. The definition and operations involving platoons have yet to be established for these applications. The uses cases do not address these ongoing needs and therefore requirements for platoon operations will be addressed in a future version of this document.

The inductive charging use case assumes that any financial transaction involving the use of the facility is provided outside the scope of this document. The location of the facility and the time available for the operation are the only aspects of the use case that are within the scope of this document.

5.4.3 Architecture implications

The mobility use cases exist within the architecture outlined in 5.2.2. Otherwise, there are no additional architecture implications.

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5.5 Priority/pre-emption use cases

5.5.1 Intent

The priority/pre-emption use cases are related to the concept of using the connected vehicle (CV) message exchanges (V2I, I2V) for the purpose of modifying the traffic signal operation, for one or more intersections, to better serve the needs of public transport, freight, and emergency service vehicles. These use cases are based on the use of DSRC communications, although some of them could be supported with other media that meet the appropriate performance characteristics such as latency, reliability, and range. It is important to keep in mind that the SRM and SSM are intended to be media-independent such that they could be handled with alternatives to DSRC.

The details of the priority/pre-emption use cases are provided in Annex A.

This is a vehicle to infrastructure message set, typically sent from an emergency vehicle, public transport vehicle, or freight transport vehicle to request priority treatment at a signalized intersection. The priority vehicle message set consists of two distinct messages, as outlined below.

— Signal request message (SRM) is used to request a pre-emption or priority signal state (preferential treatment) from a signalized intersection. This message is broadcast from the vehicle to the infrastructure.

— Signal status message (SSM) is used to relate the current pre-emption or priority signal state(s) that a signalized intersection may be in. This message is broadcast from the infrastructure to the vehicle.

These two messages are used to request and acknowledge priority "service" at a signalized intersection during emergency or priority response operations. The first message is transmitted by an approaching vehicle and is used by the traffic controller of a signalized intersection. The second message is transmitted by the local RSE (with content created by the signal controller) if a pre-emption or priority request is granted, causing a change to the signal state status data of the SPaT message stream being sent. This message provides emergency vehicles and priority public transport/freight vehicles information regarding the internal state of the controller and may include specific information with respect to servicing the request.

The scenarios are built on the assumption that such communications will be directly between the vehicle(s) and the RSE and intersection equipment, but these messages are broadcast in nature with no specific vehicle interaction with the intersection/RSE.

Restating the sequence of operations in greater detail is as follows.

a) When the vehicle "knows" that it is in the vicinity of the intersection for which priority treatment is desired, the OBE equipped vehicle transmits a signal request message (SRM) to the RSE at the identified intersection which then passes the request to the TSC equipment. This message is sent after the vehicle has received and processed the intersection MAP message.

   NOTE This presupposes a specific approach to identifying the actions desired by the approaching vehicle. This will be examined later when the detailed requirements are established for each message.

b) The alternative to requesting a predetermined (and configured) scenario at the intersection the vehicle is approaching is for the vehicle to use the MAP information and to request priority treatment to support a specific manoeuvre. In this situation, the vehicle could identify its intended approach (and lane) and request a specific manoeuvre along with the expected time of arrival or other relevant information. In this situation, the RSE and traffic controller would need to evaluate all such requests, prioritize these requests and establish the optimal sequence and timing to accommodate the approaching vehicle(s). It is anticipated that both techniques for priority

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requests should be supported by the RSE/TCS. Different requirements are needed for each mechanism.

c) The RSE will transmit a signal status message (SSM) if there is one or more active or pending pre-emption or priority events to report. This message is transmitted by the local intersection RSE in a broadcast style. The RSE should include sufficient information such that the vehicles approaching the intersection can determine if their specific request is being serviced. However, the SPaT message will always indicate the state of the signal and thus the approaching vehicle can determine if and when the movements required will be available.

d) There is a potential that multiple local vehicles will be simultaneously sending signal request messages as they approach the intersection and receive the RSE/TSC generated signal status message in this time interval. The required logic to decode the "winner" in such a conflict is outside the scope of this of document and resides in the combination of the RSE and TSC. The outcome of that process is reflected in the SSM. These two messages (along with the SPaT and MAP message discussed elsewhere) are considered part of the intersection control message set.

5.5.2 Additional assumptions

The priority/pre-emption use cases described herein are based on the following additional assumptions that are specific to this set of use cases.

a) Vehicles will be assigned a priority that will be used by the intersection to determine the priority of this vehicle relative to the priority structure for all vehicle types and the operation to be supported. For both vehicle type and priority, these attributes shall be developed for each region as it is likely that the rules of engagement may vary by region and the actions to be taken by the intersection control algorithms are likely to vary as well.

b) In general, use cases associated with a single intersection are not based on real-time interaction with a central traffic management system to support priority treatment at the specific intersection.

c) Public transport vehicles, freight vehicles, and emergency vehicles are assumed to have consistent, non-changing IDs for the duration of all interactions described for pre-emption and priority as described herein. That is, the randomization present for light vehicles to maintain anonymity does not apply to this class of vehicle for these applications.

d) The use cases herein do not reflect the user needs or use cases that are intended to optimize traffic signal operation based on receipt of BSM/CAM messages from all vehicles approaching the intersection. The assumption is that priority/pre-emption is of greater importance than operation of other vehicles. It is also assumed that the traffic management centre (TMC) is responsible for configuring the RSE and TSC and for enabling and disabling priority operation at the intersection. Hence, the link to the TMC is critical, although its active role is limited to a few of the scenarios that deal with signal priority along an arterial or string of intersections.

5.5.3 Architecture implications

When an emergency vehicle and other surrounding vehicles are equipped with an OBE, the vehicles can establish communication when they are within range of each other and share information relative to their location and direction. A special application (PSOBE) may be used in emergency vehicles and is not available to standard OBEs. This PSOBE limits ID changes and may be implemented as a high-powered application to extend the range. It is expected that the surrounding private vehicle OBEs will receive BSM and SRM messages from the high-powered PSOBE well before they begin to receive the normal BSM/CAM transmission from the same vehicle. From calculations resulting from this information, the private vehicle can first notify its driver of the situation, after which it may offer

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suggestions to avoid path interference. While it is difficult to make this function robust and precise, enough information can be made available to the driver that improvements over a non-equipped system can be significant.

NOTE This presumes that the DSRC 5,9 GHz license allows certain emergency vehicle applications to transmit at a power higher than that of the normal OBE and RSU, thus extending the range.

The message content for the V2V use case will not be developed here since this concept is completely within the V2V domain and not the V2I and I2V domain space.

The basic architecture for the connected vehicle system for the discussion of priority and pre-emption is illustrated in Figure 2. The major components are the roadside equipment (RSE) and the vehicle systems. To simplify the interface discussion in this document, the vehicle systems will be called the on-board equipment (OBE). Traffic management and fleet management systems are designated as back office processing centres (BOPC). This basic physical architecture will be used for the discussion of the use cases.

These use cases focus on the message exchanges between the connected vehicle and the intersection traffic controller with the intent to modify the operation of the traffic controller and the vehicle to support the operational scenarios described. Although DSRC is assumed, the message content could be routed through a public transport centre, fleet management centre, and a traffic management centre which may also affect its operation. Examples might include the need to suspend priority operation due to special events or road construction or to change priority strategy based on environmental conditions.

While a separate roadside processor is shown in Figure 1, this could be a function included in the traffic signal controller depending on the age and capabilities of that device. Many of today's traffic controllers include encryption processors and processor speeds that are more than adequate to handle the functions described herein. Likewise, the use cases describe interactions between the RSE and the TSC that imply that there is a layered decision-making process. Again, these may be combined into a single processor unit such that the only external element is the DSRC radio and all algorithms and interactions take place within the TSC.

5.5.4 Public transport signal priority application

There are several use cases associated with public transport and while they are shown as separate here, they are similar in operation. They have the common characteristic of requiring specific actions by the traffic controller to facilitate the progression through the intersection.

However, there are different needs associated with each; therefore, they will be represented separately as follows:

a) providing preferential "through" manoeuvre to allow a public transport vehicle (PTV) to proceed through the intersection by truncating conflicting manoeuvres and returning to the required manoeuvre "early" or by extending the required manoeuvre to allow the public transport vehicle more time to get through the intersection;

b) preferential "turning" manoeuvre at the intersection, for example, a protected left (or right) that may normally be prohibited or a permissive turn. In this instance, the traffic controller shall determine the need for advancing the green phase to clear the queue in front of the public transport vehicle to allow the vehicle to enter the left-turn pocket, and manages coordinated priority timing between the through and left-turn manoeuvres;

c) "clearing a queue" to enable a vehicle to get to a near side passenger stop. This could be combined with additional actions as described below;

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d) providing a leading public transport vehicle "green" (queue jump) to allow the public transport vehicle to "jump" out into traffic after the completion of passenger pickup/discharge at a near side public transport stop.

Operational constraints

The desired "action" from the TSC is embodied in the configuration of the scenario at the intersection and is requested in the SRM. The action taken by the TSC will depend on the priority manoeuvre requirements and current conditions and the rules for signal operation within the roadway and region.

There are two mechanisms that could be used by the public transport vehicle to identify the preferential treatment needed.

— The intersection is "pre-configured" to support specific actions (scenarios) requested by the vehicle. In this case, the vehicle would indicate the required "scenario" (based on their route) and the traffic controller would respond accordingly based on current conditions and conflicting requests. This approach requires that the vehicle be programmed to know which scenario is required based on its "route" and the intersection ID.

If the public transport vehicle is required to deviate from its route due to such situations as roadway construction, a crash, a special event, or other blockage, then scenarios should be developed for those possibilities and intersections as well.

— The vehicle is "pre-configured" to request that the traffic controller provides preferential treatment for its approach in a specific lane and exit in a specific lane, i.e. "I am arriving in lane X and departing in lane Y". This requires that the vehicle "know" the intersection geometrics (MAP) and is able to translate its route information into the "X" and "Y" parameters indicated above. The use cases indicated below are based on the concept of "pre-configured" intersection scenarios.

5.5.5 Freight vehicle signal priority application

This subclause describes the use cases for heavy vehicles (assumed to be carrying freight) with characteristics that include a slower start-up and greater stopping distance/time than light vehicles. The term freight vehicle, truck, and lorry (EU) are used synonymously. The freight signal priority use cases are similar in nature and support the following concepts:

a) priority treatment for an individual truck at a signalized intersection;

b) priority treatment for a fleet (platoon) of trucks at a signalized intersection;

c) priority treatment for a fleet (platoon) of trucks travelling along an arterial of signalized intersections.

There are advantages to keeping the platoon moving where possible to avoid unnecessary stops. This makes trucks different from public transport vehicles which must stop to pick up and discharge passengers.

One of the issues with attempting to move a platoon through an arterial or even an isolated intersection is the identification of the existence of such a platoon with the limited range of the DSRC communications. It would be important if the platoon could identify itself with a lead and end such that the TSC and BOPC could adjust the complete arterial to pass a limited number of vehicles. Knowing the length and speed of the platoon, the TSC can determine how to best accommodate the platoon through the arterial or intersection. If the platoon is to be identified as an entity, then there needs to be V2V propagated communications where the vehicles identify if there is another vehicle "behind" them and how many vehicles are behind them. It would also be useful to know the overall length of the platoon.

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For these use cases, it will be assumed that the RSE/TSC will continuously monitor the BSM/CAM for the identified truck(s) and monitor their locations through the intersection(s).

Figure 3 demonstrates the normal FSP interaction where a group of vehicles is involved.

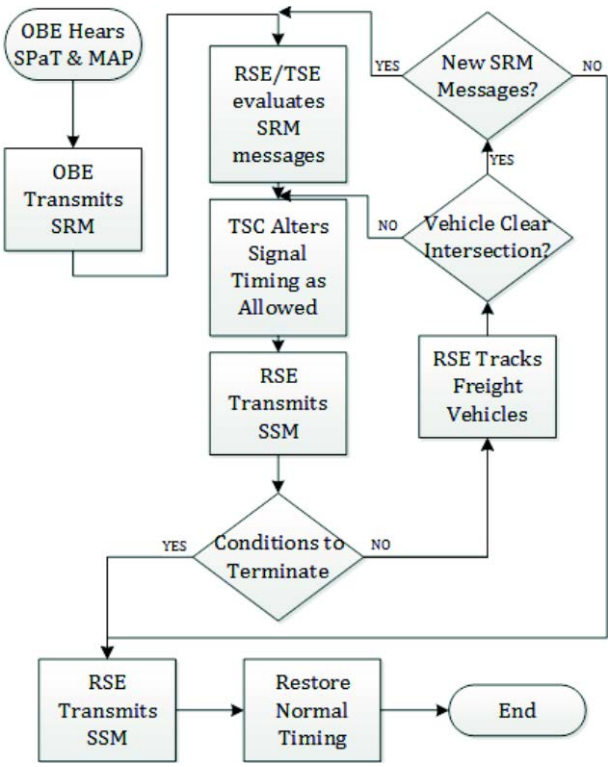

Figure 3 — FSP flow for a platoon of vehicles

The FSP operation is largely intended to improve the efficiency of freight transport through a signalized intersection, arterial, and ultimately, a corridor with the benefit of improved safety, travel time reliability, reduced fuel consumption, and reduced GHG production. One concept is to develop a "green band" for connected freight vehicles that requires that the platoon be constructed and limited, and that members of the platoon be tracked and notified when the green period is about to close and they will need to stop and wait until the next "green wave" of freight vehicles. The platoon cannot be infinite in length; therefore, some criteria need to be invoked to determine when a platoon must stop for the next green band.

Many of the use cases described above are similar in nature and it is likely that they can be combined during the development of the requirements and the design of the dialogues and message content to support these applications. It will be up to the developers of the detailed requirements to determine which of these use cases can be combined.

Ultimately, it will be the responsibility of the TSC to make the priority decision as to which manoeuvres are serviced next, the duration of manoeuvre(s), and how the intersection responds to specific and competing priority requests. Some priority requests such as FSP and TSP are not "mission critical", whereas emergency vehicle pre-emption is considered critical such that it will take over the normal operation of the intersection. However, the exact operation of the intersection will depend on the geometrics and specifics of the request including the vehicle type and priority.

The rules that must be enforced are likely to vary by region; hence, the detailed requirements need to be open and consider that different regions may establish different priorities for each type of vehicle.

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5.5.6 Emergency (public safety) vehicle pre-emption application

Emergency vehicle pre-emption (EVP) is different from priority treatment in that it is expected that the intersection will react and immediately take steps to terminate all conflicting manoeuvres and grant a "green" that will both clear vehicles that may be "in the way", as well as facilitate the emergency vehicle path through the intersection(s). However, most of the exchanges with the RSE/TSC devices are similar to that for TSP and FSP. The use case is presented separately, but ultimately, the messaging is anticipated to be identical to the TSP or FSP with changes only to the vehicle type and priority. The TSC equipment, however, will take much more dramatic and immediate action for this type of priority.

Two different pre-emption use cases are presented in Annex A. The first, PR4, assumes a standard OBE and is based on the concept that the emergency vehicle should first "hear" the intersection RSE before reacting and initiating an EVP request. Under these circumstances, there is a provision for the intersection to "tell" the vehicle what type of pre-emption is supported and the full geometrics for the intersection such that the vehicle can either make a specific request or indicate entry and exit.

The second use case, PR5, depends on the implementation of a "high-powered" OBE radio that is presumed to have a much greater range than a standard OBE, and hence, it can provide information regarding its location, heading, speed, lane, type, etc. long before it can actually receive data from the intersection. It is uncertain at this time as to which approach will be supported so both are covered here.

These two use cases cover "on-the-fly" pre-emption at intersections as encountered by a public safety vehicle. Another pre-emption scenario involves a "green wave" or route pre-emption concept such that pre-emption is requested at a series of intersections in sequence in anticipation of the public safety vehicle(s) arrival. This third possibility allows a platoon of PSOBE-equipped vehicles to travel through closely spaced signalized intersections and provides time for the traffic signals to clear traffic in advance of the platoon. The mechanism for implementing the green wave varies as it may involve operations at the TMC/BOPC or be triggered by the first PSOBE-equipped vehicle as it requests priority at the first intersection of a pre-defined emergency route. In such a case, the request can be transmitted from RSE to RSE along a route based on the content of the SRM. This scenario is discussed in the above use cases under the issues topic as route pre-emption.

6 Function description (informative)

This clause is informative as it documents a portion of the system engineering process used in the development of this document. It identifies requirements based on the information flows that move data from sources to destinations as needed to implement solutions on geographically fixed and mobile devices. They address the interface between the infrastructure's roadside equipment (RSE) and the vehicle's on-board equipment (OBE). It also identifies system implementation requirements for deployment under various communication solutions reflecting various bandwidth and media constraints.

Each use case assumes that there is at least a single connected vehicle broadcasting its basic vehicle information using the basic safety message (BSM), cooperative awareness message (CAM), or decentralized environmental notification message (DENM). These messages are beyond the scope of this document; therefore, they are only referenced in the requirements where utilized by special vehicles.

All of the use cases include the collection of "performance measures" with the intent to provide a tool for analysis to improve operations; however, these are not necessary for the operation of the use cases. The exact details of the data to be collected are not identified in the requirements contained herein. It is expected that future revisions will provide these details and will be related to the specific needs of a project or technology.

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The requirements are organized into sections based on the device or message to which they apply. Information as to whether the requirement is mandatory or optional and details regarding the type of information required are provided in the requirements traceability matrix in Annex C or as defined in the selected annex for additional group requirements. Note that selecting an optional requirement for a given project means that selected requirement shall be implemented for the project to conform to this document.

6.1 Public safety vehicle

In addition to the generic vehicle requirements in SAE J3067™:2014, 3.5.1, there are several safety-related requirements specific to public safety vehicles. For example, while travelling to the scene of an incident, public safety connected vehicles need to make other road users aware of their presence and also may need to request preferential priority at signalized intersections.

The detailed requirements for a properly authorized public safety connected vehicle to respond to an incident and broadcast incident response and emergency alert messages are listed below.

6.1.1 Broadcast public safety vehicle information

Each public safety vehicle shall broadcast information about its location to other connected devices.

6.1.2 Broadcast emergency response indication

A public safety connected vehicle needs to identify itself as an authorized public safety vehicle travelling to or at the scene of a service call. This identification is included as part of vehicle information broadcast to connected devices (see SAE J3067™:2014, 3.5.1.1.4.6.19).

6.2 Signal pre-emption

While travelling to the location of an incident, a public safety connected vehicle needs to request preferential treatment when approaching a signalized intersection.

The detailed requirements for a properly authorized public safety connected vehicle to request preferential treatment at a signalized intersection are listed below. Note that the requirements support priority requests using the operational concepts discussed in the previous section for normal or high-power transmissions.

6.2.1 Signal pre-empt request (normal power)

An authorized public safety vehicle shall begin transmitting SRM to an intersection using a normal power OBE transmission when the following conditions are met.

a) The authorized vehicle is on the intersection's approach or moving toward the intersection.

b) The vehicle has the intersection's roadway geometric information available or has received one or more MAP message(s) from the intersection.

c) The authorized vehicle has a need for priority services.

d) The vehicle has received one or more SPaT message(s) from the intersection.

6.2.2 Signal pre-empt request (high power)

An authorized public safety vehicle shall begin transmitting SRM to an intersection using a high-power OBE transmission when the following conditions are met.

a) The vehicle is on the intersection's approach or moving toward the intersection.

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b) The vehicle has sufficient intersection roadway geometric data available to identify its approach in the request.

c) The authorized vehicle has a need for priority services.

6.2.3 Request signal pre-empt — Message identifier

A public safety connected vehicle shall include an identifier for each signal request message transmitted to an RSE. The message identifier is used to identify a sequence number within a stream of messages (of the same message type) from a connected vehicle. The message identifier increments by one whenever the contents of the message has changed. This identifier is used by the RSE to distinguish between requests from the same connected vehicle.

6.2.4 Request signal pre-empt — Intersection identifier

A public safety connected vehicle shall include the unique identifier of the intersection that is the target of the signal request broadcast.

Each intersection shall have a unique identifier which is used for all requests and navigation functions. The intersection identifier shall be included in the roadway geometric message broadcast by the RSE located at or near the intersection.

6.2.5 Request signal pre-empt — Approach lane

A public safety connected vehicle shall include the identifier of the lane, approach, or connection to be used to approach the intersection as part of the signal request message transmitted to an RSE. The lane numbering is identified as part of a roadway geometrics message broadcast by the RSE at the signalized intersection.

6.2.6 Request signal pre-empt — Egress lane

In addition to identifying the approach lane, a public safety connected vehicle shall include the lane number to be used to exit the intersection as part of the signal request message transmitted to an RSE. The lane number is assigned as part of the roadway geometrics information broadcast by the RSE at the signalized intersection. The egress lane information is needed to determine which pre-emption strategy may be appropriate for the public safety connected vehicle.

6.2.7 Request signal pre-empt — Vehicle class

A public safety connected vehicle shall include its vehicle type and request level as part of the signal request message transmitted to an RSE. Signalized intersections can use the vehicle type and request level to determine which vehicle receives priority in the event multiple conflicting requests are received by the same signalized intersection. Examples of vehicle types are public safety vehicle, public transport vehicles, military vehicles, commercial motor vehicles carrying freight, and private vehicles. A signal request from a higher vehicle class type may take priority over another signal request from a lower vehicle class type. In addition, within each vehicle class type, a vehicle may also be assigned a vehicle class level. For example, with a public safety vehicle class type, an emergency services vehicle may have a higher vehicle class level than a law enforcement vehicle. A signal request with a higher vehicle class level will take priority over another signal request from a lower vehicle class level. The order of precedence for the signal request priority is by signal priority vehicle class type and then class level. How these are assigned and how the intersection traffic control equipment reacts may vary by jurisdiction and is not standardized here.

6.2.8 Request signal pre-empt — Time of service

A public safety connected vehicle shall include the time when the signal pre-empt is requested to start as part of the signal request message transmitted to an RSE. This is the estimated time (point), in

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minutes and seconds past midnight that the connected vehicle expects to arrive at the intersection's stopping point (e.g. stop bar). The time is assumed to be a future time and is based on the current local time.

6.2.9 Request signal pre-empt — Vehicle identity

A connected public safety vehicle shall include its vehicle identifier as part of the signal request message transmitted to an RSE. The vehicle identifier may be a permanent identifier assigned by the public safety agency and used to track the service performance for that vehicle, or it may be a random number to ensure the overall anonymity of the connected device. The vehicle identifier is used to allow the RSE to distinguish requests from different connected vehicles and to distinguish different requests from the same connected vehicle. Where the pre-empt request is for one or a sequence of intersections (e.g. an arterial), then the vehicle ID shall remain constant throughout the navigation of the intersection/arterial such that the traffic management systems can track the progress of the vehicle and manage the coordination between intersections where appropriate.

6.2.10 Request signal pre-empt — Vehicle location and speed

A public safety connected vehicle shall include its current location, speed, and heading as part of the signal request message transmitted to an RSE. This information may be used by the traffic signal controller to determine what operational strategy it will perform (service) in the event there are more than one conflicting request for preferential treatment from different connected vehicles.

6.2.11 Request signal pre-empt — Cancellation

A public safety connected vehicle shall transmit to an RSE a signal request message to cancel (clear) a previously transmitted signal request. The combination of the vehicle identifier and the transaction identifier for the initial signal request message are used to identify the signal request to be cancelled.

6.2.12 Request signal pre-empt — Transaction identifier

Each signal request message shall also include a unique identifier for the specific request and use that same identifier for all subsequent changes related to that same request. For example, if the expected arrival time were to change, then the vehicle could transmit a new arrival time (in the SRM) using that same request identifier. Further, the intersection shall assume the request remains active until the RSE receives a clear request from the same vehicle or the request "times out" based on a "time to live" transmitted by the vehicle as part of the signal request message.

6.2.13 Request signal pre-empt — Duration

Each signal request message shall include a "duration" value as calculated by the requesting vehicle. The duration value shall be the time as seconds that the request may remain active after the time of service (see 6.2.8) occurs.

6.3 Public transport and commercial vehicle

In addition to the generic vehicle requirements in SAE J3067™:2014, 3.5.1, there are several requirements specific to public transport vehicles (PTV) and commercial freight transport vehicles. These requirements include providing preferential treatment to PTVs to improve the throughput of travellers through the transportation network.

The detailed requirements for a connected PTV or freight vehicle to exchange priority request and status information are listed below.

6.3.1 Broadcast priority requesting vehicle information

Each public transport or commercial vehicle shall broadcast information about its location to other connected devices.

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6.4 Signal priority requirements

A connected public transport vehicle (PTV) or commercial vehicle approaching a signalized intersection may wish to send a priority request to stay on schedule. For example, a public transport connected vehicle with a passenger load in revenue service and behind schedule may send a signal priority request to maintain its schedule.

The detailed requirements for a connected PTV or commercial vehicle to transmit requests for signal priority at an intersection are listed below.

6.4.1 Signal priority request

An authorized PTV or commercial vehicle shall begin transmitting SRM to an intersection using a normal power OBE transmission when the following conditions are met.

a) The authorized vehicle is on the intersection's approach or moving toward the intersection.

b) The authorized vehicle has received one or more SPaT message(s) from the intersection.

c) The authorized vehicle has the intersection's MAP content available or has received one or more MAP message(s) from the intersection.

d) The authorized vehicle has a need for priority services.

6.4.2 Request signal priority — Message identifier

A connected PTV or commercial vehicle shall include an identifier for each signal request message transmitted to an RSE. The message identifier is used to identify a sequence number within a stream of messages (of the same message type) from the connected PTV or commercial vehicle. The message identifier increments by one whenever the contents of the message has changed. This identifier is used by the RSE to distinguish between requests from different connected devices and to distinguish different requests from the same connected vehicle.

6.4.3 Request signal priority — Intersection identifier

A connected PTV or commercial vehicle shall include the unique identifier of the intersection that is the target of the signal request message transmitted to an RSE. The intersection identifier is assigned as part of a roadway geometric message broadcast by an RSE at or near the intersection.

6.4.4 Request signal priority — Approach lane

A connected PTV or commercial vehicle shall include the lane, approach, or connection number to be used to approach the intersection on as part of the signal request message transmitted to an RSE. The lane numbers and lane information are assigned by the RSE at the signalized intersection as part of the roadway geometrics information broadcast by the RSE.

6.4.5 Request signal priority — Egress lane

In addition to identifying the approach lane, a connected PTV or commercial vehicle shall include the lane number to be used to exit the intersection as part of the signal request message transmitted to an RSE. The lane numbers and lane information may be provided by the RSE at the signalized intersection as part of the roadway geometrics information broadcast by the RSE. The egress lane information is needed to determine which priority strategy or signal timing pattern may be the most appropriate to provide the requested service.

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6.4.6 Request signal priority — Vehicle class

A connected PTV or commercial vehicle shall include its vehicle type and request level as part of the signal request message transmitted to an RSE. Signalized intersections may use the vehicle type and request level to determine which vehicle receives priority in the event multiple requests are received by the same signalized intersection. Examples of vehicle types may be public safety vehicle, public transport vehicles, or commercial motor vehicles carrying freight.

A signal request message from a higher vehicle class type may take priority over another signal request from a lower vehicle class type. In addition, within each vehicle class type, a vehicle may also be assigned a vehicle class level. For example, in public transport vehicle class type, a bus rapid public transport vehicle may have a higher vehicle class level than a local public transport vehicle. A signal request message with a higher vehicle class level may take priority over another signal request from a lower vehicle class level. The order of precedence for the signal request priority is by signal priority vehicle class type and then class level. However, the operation of the local intersection is left to the local agency.

6.4.7 Request signal priority — Time of service

A connected PTV or commercial vehicle shall include the time when the signal service is requested to start as part of the signal request message transmitted to an RSE. This is the estimated time point representing minutes and seconds that the connected vehicle arrives at the intersection's stopping point (e.g. stop bar). The time is assumed to be a future time and is based on the current local time.

6.4.8 Request signal priority — Vehicle identity

A connected PTV or commercial vehicle shall include its vehicle identifier as part of the signal request message transmitted to an RSE. The vehicle identifier may be a permanent identifier assigned by the owning public transport agency or commercial organization and used to track the service performance for that vehicle or it may be a random number to ensure the overall anonymity of the connected device. The vehicle identifier is used to allow the RSE to distinguish requests from different connected vehicles and to distinguish different requests from the same connected vehicle. Where the priority request is for one or a sequence of intersections (e.g. an arterial), then the vehicle ID shall remain constant throughout the navigation of the intersection/arterial such that the traffic management systems can track the progress of the vehicle and manage the coordination between intersections where appropriate.

6.4.9 Request signal priority — Vehicle location and speed

A connected PTV or commercial vehicle shall include its current location, speed, and heading as part of the signal request message transmitted to an RSE. This information may be used by the traffic signal controller to determine what operational strategy it will perform (service) in the event there are more than one request for preferential treatment from different connected vehicles. It may also be used to optimize the signal timing to accommodate the vehicle for an ad hoc request.

6.4.10 Request signal priority — Service information

A connected PTV shall include its public transport service status as part of the signal request message transmitted to an RSE. Such status information may include the passenger load of the PTV, if the PTV is stopped, if the PTV vehicle door is open, and if the PTV is in the process of loading a mobility device (e.g. wheelchair) or bicycle (device that needs to be racked). The passenger load information may be used by the traffic signal controller to determine what operational strategy to service in the event there are more than one conflicting request for preferential treatment from different connected vehicles. The other status information may be used to help the traffic signal controller to determine when to provide preferential treatment if a public transport vehicle is stopped to load/unload before reaching the intersection.

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6.4.11 Request signal priority cancellation

A connected PTV or commercial vehicle shall transmit to an RSE a message to cancel a previously transmitted signal request message. The transaction identifier combined with the vehicle ID shall be sufficient to cancel the request. See 6.4.13.

6.4.12 Request signal priority — Priority request level

A connected PTV or commercial vehicle shall include a priority request level as part of the signal request message transmitted to an RSE. The priority request level shall be configurable with 1 being lowest and 10 being highest. The default request shall be set to 5.

6.4.13 Request signal priority — Transaction identifier

Each signal request message shall also include a unique identifier for the specific request and use that same identifier for all subsequent changes related to that same request. For example, if the expected arrival time were to change, then the vehicle could transmit a new arrival time (in the SRM) using that same request identifier. Further, the intersection shall assume the request remains active until the RSE receives a clear request from the same vehicle or the request “times out” based on a “time to live” transmitted by the vehicle as part of the signal request message.

6.4.14 Request signal priority — Duration

Each signal request message shall include a “duration” value as calculated by the requesting vehicle. The duration value shall be the time as seconds that the request may remain active after the time of service (see 6.4.7) occurs.

6.4.15 Request signal priority — Transit schedule

When PTV transmit a signal priority request, the signal request message shall include the time difference between the PTV's current location and its scheduled location with a positive value indicating that the PTV is in advance of its schedule and a negative value indicating that the PTV is behind its schedule with the value in minutes.

6.5 Broadcast area's geometrics

An area's geometric information is used to provide connected devices with information about the roadway geometry, including intersection descriptions, speed curve outlines, and roadway segment information. For example, roadway geometric data can be used by a connected vehicle to support warnings to drivers for accident prevention.

The detailed requirements for providing roadway geometric information from the infrastructure to connected devices are as follows herein. Note that this information is broadcast to all devices within range. There is not any point to point or individual communications directed to specific vehicles implied.

6.5.1 Broadcast roadway geometrics

An RSE shall broadcast a message with information about the roadway geometrics to connected devices. The following sub-requirements identify the types of information needed to support the use cases described herein with respect to roadway geometrics.

6.5.2 Broadcast roadway geometrics — Message identifier

An RSE shall include a message identifier as part of the roadway geometrics information broadcast. The message identifier is used to identify a message within a stream of messages (of the same message type) from the RSE. The message identifier increments by one whenever the contents of the message has changed. This requirement allows a receiving connected device to ignore (not process) messages from

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an RSE when the content has not changed. This is required to support the concept of updating the roadway geometric information related to construction activities or other permanent or transient (semi-static) situations.

6.5.3 Broadcast intersection — Identifier

An RSE shall include the unique identifier of the intersection as part of the geometric information broadcast. This identifier is used to uniquely define an intersection within a country or region.

6.5.4 Broadcast intersection — Reference point

An RSE shall include the geographic location (latitude, longitude, elevation) of a reference point for the intersection as part of the geometric information. This reference point will be used to determine the offset for other data points. The latitude and longitude are measured in units of 1 cm. The elevation represents the intersection's geographic position above or below the reference ellipsoid (WGS-84) in units of 1 cm.

6.5.5 Broadcast intersection — Lane/approach default width

An RSE shall include the default lane/approach width for the intersection as part of geometric information broadcast. The default lane/approach width, measured in one centimeter units, is used such that a lane/approach width does not have to be transmitted for each lane/approach at the intersection. For each lane/approach at an intersection, the intersection's default lane/approach width is used unless the lane/approach width is specified or adjusted at points along the specific lane/approach.

6.5.6 Broadcast intersection — Egress lanes/approach

An RSE shall include all the vehicular lanes/approach that are leaving the intersection as part of the geometric information broadcast. These lanes/approach, known as egress lanes/approach, allow vehicles that have entered into the intersection to exit out of the same intersection.

6.5.7 Broadcast intersection — Ingress lanes/approach

An RSE shall include all the vehicular lanes/approach that are approaching the intersection as part of the geometric information broadcast. These lanes/approach, known as ingress lanes/approach, allow vehicles to enter into an intersection.

6.5.8 Broadcast intersection — Lane/approach number

For each lane/approach at an intersection, the RSE shall include a lane/approach number as part of the geometric information. Each lane/approach number shall be unique for that intersection.

A number convention should be established for consistency of the lane numbering but is not requried for the use cases described herein.

6.5.9 Broadcast intersection — Lane/approach centerline coordinates

For a lane/approach at an intersection, an RSE shall include a sequence of node locations that together describe the path of the lane's/approach centre line, as part of the geometric broadcast information. Each node location (based on the WGS-84 coordinate system and its reference ellipsoid) shall be referenced from the previous node's location with an accuracy of ±1 cm. The number (and location) of nodes needed to represent the path of a lane shall be selected such that the perpendicular distance between the lane centre line and the straight line connecting the two consecutive nodes is less than 1 m. For example, two nodes may be sufficient to represent a straight lane, while for a curved roadway segment, more nodes will be needed. The first node location should be the node that is closest to the geometric centre of the intersection, and is typically at the stop line of the lane, and the values should be the offset from the intersection's reference point (see 6.5.4).

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NOTE The specific choice for the accuracy specified herein is based on previous versions of the SAE J2735™ data dictionary standard and can be subject to change as more research is performed.

6.5.10 Broadcast intersection — Vehicle lane/approach manoeuvres

For each vehicular lane at an intersection, an RSE shall include the allowed (valid) manoeuvres from the lane as part of the geometric information broadcast. The allowed manoeuvres indicate the types of manoeuvre(s) permitted through the intersection and the type(s) of vehicles that are allowed to perform those manoeuvres. Valid manoeuvre types are as follows:

— no data available;

— straight;

— left;

— right;

— U-turn;

— turn on red after stop;

— shared opposing turns.

Valid vehicle types are as follows:

a) general vehicles;

b) HOV;

c) commercial vehicles;

d) emergency vehicles (public safety);

e) bus (public transport vehicles);

f) taxi;

g) tracked vehicle;

h) undefined.

The shared lane represents a lane, generally in the centre of the roadway, that can be used as a turn lane for both directions of traffic to cross opposing through traffic. Shared lanes can be represented as a single lane or multiple uni-directional lanes that overlay one another with each lane supporting left turns.

A lane may allow more than one valid manoeuvre value, for example, a lane may have straight, left, right, and U-turn as valid manoeuvre types.

A lane may allow more than one valid vehicle type.

6.5.11 Broadcast intersection — Pedestrian crossing lane/approach manoeuvres

For each pedestrian lane at an intersection, an RSE shall include the allowed (valid) manoeuvres from the lane as part of the geometric information. The allowed manoeuvres for a pedestrian lane are related to the type of crosswalk, bicycle-crossing, or non-motorized lane and, as a minimum, shall include no

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data available, straight, and proceed after stopping. Valid user types for these lanes are pedestrians, bicycles, other.

6.5.12 Broadcast intersection — Special lane/approach manoeuvres

For each special lane at an intersection, an RSE shall include the allowed (valid) manoeuvres from the lane as part of the geometric information broadcast to connected devices. The allowed manoeuvres indicate the allowed navigational manoeuvres through the intersection and any other restrictions. Valid manoeuvre values for special lanes are no data available, straight, and proceed after stopping. Valid traffic types for special lanes are no data available, heavy rail, commuter rail, light rail trains, buses, HOV. Each special lane may have more than one manoeuvre and more than one vehicle type.

6.5.13 Broadcast intersection — Version identifier

An RSE shall include a version identifier as part of the geometrics information broadcast. This version identifier is used to identify the version of the roadway geometrics currently being broadcast from the RSE. A map version identifier should be assigned whenever the roadway geometrics change. For example, an intersection may have an approach with two reversible lanes, which are used as egress lanes in the morning, and allows vehicles to enter the intersection at all other times. This intersection may have a version identifier of “2” during the weekday morning peak hours and a version identifier of “3” all other times. If the intersection geometrics were to change, for example, a new lane was added to the approach, it would be assigned a new version identifier.

This requirement allows a receiving connected device to ignore (not process) the intersection's geometric information if the geometric information has not changed. A connected device may also have the capability to store the intersection's geometric information in its memory - if that connected device already has that version of the geometric information stored, the device may ignore the remainder of the geometric information being transmitted, if the version identifier has not changed.

6.5.14 Broadcast intersection — Crossings

An RSE shall include lane information about all the crossings in the intersection as part of the geometric information broadcast. Crossings can generally be considered bi-directional and do not have approaches or egresses. The users of crossings are typically not vehicles but include pedestrians, bicyclists, or railroad cars (including light rail).

6.5.15 Broadcast intersection — Lane/approach width

For each lane/approach at an intersection, an RSE shall include its lane/approach width as part of the geometric information broadcast. This is the lane width, in one centimeter units, at each offset value defining the path of the lane. A non-zero value will take precedence over the default lane/approach width for the intersection; otherwise, the default lane/approach width for the intersection (see 6.5.5) should be used. To support regional interests, the lane can be defined as an approach or parts of an approach.

6.5.16 Broadcast intersection — Node lane/approach width

For a lane/approach at an intersection, an RSE shall establish its lane/approach width at each point location describing the path of the lane/approach as part of the geometric information broadcast. This requirement allows an RSE to establish the width of the lane/approach at each node for lanes/approach when the width of the lane/approach varies. An absolute lane width value or a delta lane width from previous values are acceptable approaches to establishing the lane/approach width. A non-zero value will take precedence over the default lane/approach width for the intersection (see 6.5.5) and any lane/approach width defined for length of the lane/approach (see 6.5.15). It is expected that if the lane/approach width at each node is broadcast, a lane/approach width for the length of the lane/approach will not be broadcast.

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6.5.17 Broadcast intersection — Egress connection

For each lane/approach entering an intersection, an RSE shall identify the lanes/approaches that the subject lane/approach connects to, called the egress lanes/approach, as part of the geometric information broadcast. The egress lane/approach information is needed to help identify potential pedestrian/cyclist/special vehicle crossing conflicts that affect the turning manoeuvre times for that vehicle.

The egress connection also needs to identify the vehicle manoeuvre needed to turn into the egress lane. Valid manoeuvre information are unknown (or not applicable), uTurn, leftTurn, rightTurn, straightAhead, and lane change.

6.5.18 Broadcast intersection — Traffic control

An RSE shall broadcast intersection geometric and manoeuvre information for intersections controlled by signs, beacons, crossing gates, pedestrian hybrid beacon (e.g. HAWK), rectangular rapid flashing beacons (RRFB), or ramp signals. This requirement enables connected vehicles to navigate intersections controlled by other types of traffic control devices. An RSE will utilize a “psuedo-signal” to broadcast the movement phase states that are consistent with the intersection's traffic control devices and their states.

6.5.19 Broadcast intersection — Traffic control by lane/approach

An RSE shall broadcast intersection geometric and manoeuvre information for each lane/approach at intersections controlled by signs, beacons, crossing gates, pedestrian hybrid beacon (e.g. HAWK), rectangular rapid flashing beacons (RRFB), ramp signals. This requirment enables connected vehicles to navigate intersection lanes/approaches controlled by other types of traffic control devices. An RSE will utilize a “psuedo-signal” to broadcast each lanes/approaches manoeuvres and the movement phase states that are consistent with the intersection's traffic control devices and the device's states.

6.5.20 Broadcast road conditions

The RSE shall broadcast environmental information to connected devices regarding pavement conditions. This information enables OBEs to calculate stopping distances based on the current conditions in order to properly predict the stopping distance and time.

6.5.21 Broadcast intersection — Signal group

An RSE shall broadcast the signal group identifier, the lanes/approaches associated with the signal group, and the lanes/approaches' allowable manoeuvres. This association enables connected devices to associate broadcast signal phase and timing information with the lanes/approaches in which it is travelling.

6.6 Broadcast GNSS augmentation details

Connected devices need information to improve its positional accuracy estimate. These differential GPS corrections allow a mobile GPS receiver, such as a GPS system in a connected vehicle, to achieve a greater absolute positional accuracy, compensating for errors that exist in satellite positioning. GPS receivers use the differential GPS corrections to improve the accuracy of their positioning by comparing its position with the RSE’s location, which is known.

The detailed requirements for transmitting differential GPS corrections are as follows.

6.6.1 Broadcast GNSS augmentations

An RSE shall broadcast GNSS augmentation details using one of the following GNSS augmentation messages.

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6.6.2 Broadcast GNSS augmentation detail — NMEA

The RSE shall broadcast Marine Electronics Association (NMEA) 0183 differential GPS correction messages. NMEA 0183 is a standard that defines the interface between two different devices, generally marine devices. NMEA 0183 includes support for a GPS receiver to provide its real-time position information, such as position, velocity and time as computed by the GPS receiver.

6.6.3 Broadcast GNSS augmentation detail — RTCM

The RSE shall broadcast Radio Technical Commission for Maritime Services (RTCM) 10402.3 and RTCM 10403.1 messages to connected devices. These standards support very high accuracy navigation and positioning through a broadcast to mobile global navigation satellite system (GNSS) receivers, which allows the receivers to compensate for errors that exist in satellite positioning without augmentation. RTCM 10403.1 is a later edition of RTCM 10402.3 and more efficient.

6.7 Signalized intersection requirements

Signal phase and timing information is used to provide connected vehicles with information to safely and efficiently pass through the intersection. For example, signal phase and timing information can be used by the connected vehicles to determine imminent signal changes, and hence alert the driver in the event it appears that the vehicle will enter the intersection when such movements are not allowed.

It is assumed that the signal phase and timing (SPaT) information is periodically broadcast to all devices within range of the RF signal in a timely manner such that the information can be used by the vehicle to avoid violating the permitted manoeuvres that might cause a crash or to manage its operation to more efficiently navigate an arterial network, thus reducing fuel consumption.

6.7.1 Broadcast signal phase and timing information

An RSE shall broadcast a message with signal phase and timing information. Signal phase and timing information may be used to provide connected devices with the current status of a signalized intersection. Together with the intersection geometric information, connected vehicles can determine what manoeuvres are currently permitted by lane/approach, and when their permitted manoeuvre may end.

6.7.2 Broadcast signal phase and timing — Message identifier

An RSE shall include a message identifier as part of the signal phase and timing message broadcast. A change in the message identifier indicates a change in the message content. This requirement allows a connected device to ignore (not process) messages from an RSE when the content has not changed.

6.7.3 Broadcast signal phase and timing — Intersection identifier

An RSE shall include the unique identifier for the intersection as part of the signal phase and timing message broadcast. The intersection identifier is provided as part of a roadway geometric message broadcast by an RSE at or near the intersection.

Note that it is assumed that the vehicle will use information about its current position and the interesection geometrics (MAP message) to determine its relative position with respect to the lanes, intersection stop lines, etc. and the SPaT information to determine the manoeuvres permitted and the time at which such manoeuvres will no longer be allowed in order to improve the efficiency and safety of its navigation through the roadway network.

6.7.4 Broadcast signal phase and timing — Intersection status

An RSE shall include the operational status of the intersection's traffic signal controller as part of the signal phase and timing message broadcast. Valid operational status includes operating normally (i.e. fixed time, traffic dependent as in actuated or semi-actuated, standby), intersection is in conflict flash

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mode, pre-empt is active, priority is active, manual control is enabled, and stop time is activated and all counting/timing has stopped.

6.7.5 Broadcast signal phase and timing — Timestamp

An RSE shall include a timestamp as part of the signal phase and timing message broadcast. The timestamp indicates when the message was generated. This time, indication allows detection and correction of different rates and offsets between the clocks and latency of message transmission.

6.7.6 Broadcast manoeuvre — Signal group

For each active manoeuvre at a signalized intersection, an RSE shall include the signal group at the intersection for which this manoeuvre is permitted as part of the signal phase and timing message broadcast. The signal group is assigned as part of a roadway geometrics message broadcast by the RSE at the signalized intersection for each lane and its manoeuvres.

6.7.7 Broadcast manoeuvre — Manoeuvre state

For each active manoeuvre at a signalized intersection, an RSE shall indicate the state and signal indications pertaining to that manoeuvre.

6.7.8 Broadcast manoeuvre — Vehicular state

For each vehicular manoeuvre at a signalized intersection, an RSE shall include the current movement's state pertaining to that manoeuvre as part of the signal phase and timing message broadcast. The valid movement phase states are unavailable, stop then proceed, stop and remain, permissive movement allowed, protected movement allowed, permissive clearance, protected clearance, and caution conflicting traffic.

6.7.9 Broadcast manoeuvre — Pedestrian state

For each pedestrian manoeuvre at a signalized intersection, an RSE shall include the movement state of the manoeuvre as part of the signal phase and timing message broadcast. The valid states for pedestrian movements are unavailable, stop then proceed, stop and remain (i.e. don't walk), permissive movement allowed (i.e. walk), protected movement allowed (i.e. exclusive walk), permissive clearance (i.e. flashing don't walk), protected clearance (i.e. exclusive flashing don't walk), and caution conflicting traffic.

6.7.10 Broadcast manoeuvre — Special state

For each manoeuvre for specialized vehicles at a signalized intersection, an RSE shall include the movement state of that manoeuvre as part of the signal phase and timing message broadcast. Special signal states are needed for traffic in non-vehicular (special) lanes, such as fixed guideways for trains. The allowable states for the special movement states are unknown, the special lane/approach is empty (no traveller) or not in use (closed), the special lane/approach is about to be occupied, the special lane/approach is occupied, and the special lane/approach is about to be empty.

NOTE This information is intended to notify the vehicles in the area about the condition of the special lane(s)/approach(es) and is not intended to provide instructions to the vehicles that use the special lane/approach.

6.7.11 Broadcast manoeuvre — Time of change — Minimum

For each manoeuvre at a signalized intersection, an RSE shall include the earliest time point when the manoeuvre state is predicted to change as part of the signal phase and timing message broadcast. This is the earliest time that the manoeuvre's signal indication will change. For example, with this information, connected devices can calculate if it has sufficient time to safely pass through the intersection before the manoeuvre state changes.

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For actuated traffic signal controllers, since the actuation on a side street can occur at any time, this earliest time will be equal to the time that the minimum green or pedestrian times have been satisfied, whichever is later. The same earliest time value will continue to be transmitted by the RSE even after the minimum green and pedestrian time have been satisfied. Note that the earliest time is subject to and could be overridden by pedestrian manoeuvre actuations depending on the local intersection control algorithms. It is essential that the traffic controller always indicates the soonest the movement can terminate such that any vehicle approaching the stop line can make an appropriate descision.

For traffic signal controllers operating fixed time, where the time of change is known, the earliest time of change will be equal to the latest time of change (see requirement in 6.7.12).

6.7.12 Broadcast manoeuvre — Time of change — Maximum

For each manoeuvre at a signalized intersection, an RSE shall include the latest time for when the manoeuvre state is predicted to change as part of the signal phase and timing message broadcast. This is the latest time that the manoeuvre's signal indication will change. For example, with this information, connected vehicles can calculate if it has sufficient time to safely pass through the intersection before the manoeuvre state changes.

For actuated traffic signal controllers, since the actuation on a side street can occur at any time, this latest time will be equal to the time that the manoeuvre state will reach the maximum allowable green or pedestrian duration, whichever is later. Once this time is reached, the manoeuvre state will change. Note that the latest time is subject to and could be overridden by pedestrian actuations and signal pre-emption or priority activity.

For traffic signal controllers operating fixed time, where the time of change is known, the latest time of change will be equal to the earliest time of change (see requirement in 6.7.11).

6.7.13 Broadcast manoeuvre — Succeeding signal indications

For each manoeuvre at a signalized intersection, an RSE shall include the next expected movement states pertaining to that manoeuvre (the succeeding manoeuvre) as part of the signal phase and timing message broadcast. The movement states after an allowed vehicle manoeuvre is usually a clearance state, such as a yellow or red state. Local regulations determine permitted actions during clearance conditions. Typically, vehicles are allowed to enter during the "yellow" clearance state but not on a "red" state and typically, an intersection may include a red clearance time before the conflicting manoeuvres are permitted (receive a "green"). Valid movement states for vehicle and pedestrian manoeuvres are identical to those required in 6.7.8 and 6.7.9.

The SPaT message shall indicate the currently permitted movement(s) for the subject lane(s)/approaches and the time points when each movement will terminate (assumed with a clearance interval).

For each manoeuvre which is not currently permitted, the SPaT message shall indicate the time point when the manoeuvre will next be permitted.

Rationale: the former is to support the intersection violation warning and the latter is to support the ECO driving applications. This is based on the following premise. The OBE will take steps to either notify the driver or other automated means to keep the vehicle from entering the intersection (violating the stop line for the movement for the lane).

For example, if the current movement state for a vehicle manoeuvre is a proceed (protected) and a protected left turn, the next expected movement state for the manoeuvre may be a proceed (permissive) and a left turn clearance. This indicates to connected vehicles continuing straight through the intersection that the next clearance state does not apply to them, while connected vehicles intending to make a left turn at the intersection are now aware when a clear or stop left turn signal indication is expected so the vehicle should approach the intersection with caution.

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6.7.14 Broadcast manoeuvre — Succeeding signal indication time of change

For each manoeuvre at a signalized intersection, an RSE shall include the time point for when the succeeding manoeuvre state is predicted to change as part of the SPaT message broadcast. The succeeding manoeuvre state is generally a clearance state, such as a yellow indication. Thus, this time generally defines the time the clearance state will end. With this information, travellers with connected devices can calculate if it has sufficient time to clear an intersection before the clearance manoeuvre state changes.

6.7.15 Broadcast manoeuvre pending manoeuvre start time

An RSE shall transmit the start time for each pending (i.e. currently stopped) manoeuvre at a signalized intersection. The time shall be broadcast as a time point and is subject to change based on pedestrian actuations, priority treatment, pre-emption, vehicle actuations for opposing manoeuvres, and adaptive signal timing algorithms. Intersections running a pretimed timing pattern can provide the exact time subject to priority and pre-emption actions.

6.7.16 Broadcast manoeuvre — Pedestrian detect

As part of the signal phase and timing message broadcast, for each manoeuvre at a signalized intersection, an RSE shall indicate if one or more pedestrians have been detected in the pedestrian crossing. Valid types are pedestrians detected (one or more) or no pedestrians detected. This requirement can be used to warn turning vehicles at an intersection, e.g. public transport vehicles, that a pedestrian may be in its blind spot. The message content is considered to represent the condition at the time of transmission.

6.7.17 Broadcast manoeuvre — Pedestrian call

As part of the signal phase and timing message broadcast to connected devices, for each manoeuvre at a signalized intersection, an RSE shall transmit an indication if a pedestrian call (request) has been detected in the pedestrian crossing. Valid types are no call detected, pedestrian call detected, and unavailable. This requirement can be used to warn turning vehicles at an intersection, e.g. public transport vehicles, that a pedestrian may be present in the pedestrian crosswalk. Note that the presence of a pedestrian call is only valid if the “walk” signal is not being displayed. The presence of a “call” indicates that a pedestrian has requested pedestrian service that has not or is not being serviced by a “walk” signal.

6.7.18 Broadcast manoeuvre — Optimal speed information

An RSE shall transmit information about the optimal speed for vehicles on each lane.

6.7.19 Broadcast manoeuvre — Signal progression information

An RSE shall transmit information about the signal timing progression speed along the roadway. This speed may be the signal progression’s “green wave” speed or speed associated with another progression algorithm.

6.7.20 Broadcast manoeuvre — Egress lane queue

An RSE shall transmit the length of the queue on each egress lane. The queue length shall be limited to the range from 0 to the length of the egress lane’s roadway segment.

This information is useful where there are regulations regarding blocking the intersection (“do not block the box”) due to down stream queue lengths.

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