Development of Wireless Message for Vehicle-to-Infrastructure Safety Applications

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Abstract

This paper summarizes the development of a wireless message from infrastructure-to-vehicle (I2V) for safety applications based on Dedicated Short-Range Communications (DSRC) under a cooperative agreement between the Crash Avoidance Metrics Partners, LLC (CAMP) and the Federal Highway Administration (FHWA). During the development of the Curve Speed Warning (CSW) and Reduced Speed Zone Warning with Lane Closure (RSZW/LC) safety applications [1], the Basic Information Message (BIM) was developed to wirelessly transmit infrastructure-centric information. The Traveler Information Message (TIM) structure, as described in the SAE J2735, provides a mechanism for the infrastructure to issue and display in-vehicle signage of various types of advisory and road sign information. This approach, though effective in communicating traffic advisories, is limited by the type of information that can be broadcast from infrastructures. The new BIM provides additional infrastructure data needed to support dynamic vehicles based safety applications and also leverages existing SAE J2735 data elements. By including data containers specific to other applications, the proposed BIM framework can be extended to support additional safety applications without compromising on backward compatibility to other connected vehicle infrastructure systems.

Keywords: Connected vehicles, infrastructure-to-vehicle (I2V), dedicated short range communications (DSRC), safety applications, Basic Information Message (BIM)

Introduction

Real-time Vehicle-to-Infrastructure (V2I) systems are the next generation of Intelligent Transportation Systems (ITS). V2I systems facilitate information exchanges between infrastructures and in-vehicle systems to enhance automotive vehicle collision avoidance while enabling a wide range of other safety, mobility, and environmental benefits [2].

Infrastructure-based communications to enhance road safety can be communicated to vehicle operators via static or dynamic road signs. However, this limits the amount of information communicated and signs may not be able to inform the vehicle systems of impending hazards. For the use cases described in this paper, information needs to be provided to connected vehicles so the vehicles can determine whether to warn the operator to take corrective action. For example, as a vehicle approaches a work zone, it may be beneficial to the driver to know of lane closures and the presence of on-site workers. This information could be embedded in the broadcast message from the road infrastructures.

Similarly, when a vehicle approaches a curve, the vehicle needs to be able to determine the safe speed for the curve. The vehicle can use information about the curve geometry, road material and surface conditions. Information needed to support the I2V safety applications was the main motivation for developing the BIM. At CAMP, BIM was developed and tested for Curve Speed Warning (CSW) and Reduced Speed Zone Warning with Lane Closure (RSZW/LC) I2V safety applications.

Curve Speed Warning Application

The CSW application informs the driver of an approaching curve and warns when the vehicle speed may be too high for safe travel through the curve. The in-vehicle application receives curve-related information from the infrastructure and combines it with vehicle dynamics parameters to calculate speed thresholds (centripetal and stability / roll-over) for the curve as illustrated in Figure 1.

Source: Satellite map images from Google. Used with permission. Plotted data from CAMP – V2I Consortium

Figure 1: Illustration of CSW Application

The On-board Equipment (OBE) in-vehicle system receives curve-related message from the infrastructure from the Road Side Unit (RSU) over Dedicated Short Range Communications (DSRC) as shown in Figure 2. The infrastructure parameters, such as the minimum radius of curvature, surface coefficient of friction, and superelevation, or bank angle of the road, are combined with vehicle dynamics parameters to calculate speed thresholds (centripetal and stability / roll-over) for the curve.

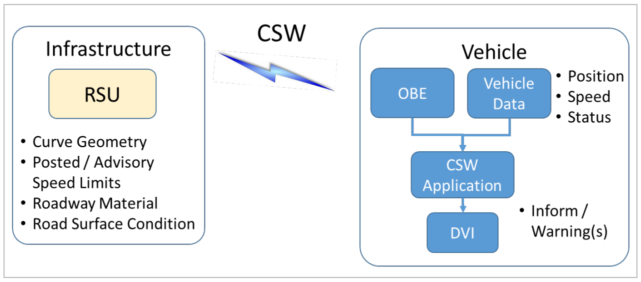

Figure 2: CSW Application Information Flow

The minimum radius of curvature, if known, can be specified in the message. Otherwise, it is computed using the curve geometry specified in the message using the Sagitta (also known as versine) [3] method.

Similarly, superelevation and road surface coefficient of friction, if known, can be specified in the message. When these data elements are not specified in the message for speed computation, appropriate values for superelevation are obtained from the Road & Bridge Standard Plans published by the Michigan Department of Transportation (MDOT) (p. 238 in [4]), and common road surface friction coefficient values for car tires obtained from Engineering Analysis of Vehicular Accidents [5].

Reduced Speed Zone Warning / Lane Closure (RSZW/LC) Application

The RSZW/LC application informs the driver of an approaching work zone and warns the driver when either of the following conditions occurs.

- Speeding in a work zone
- Lane closures that necessitate lane changing maneuvers

The in-vehicle application receives work zone related information from the infrastructure and combines it with vehicle dynamics parameters to warn the driver, if appropriate. Figure 3 shows an illustration of RSZW/LC application, while the information flow for the RSZW/LC application is shown in Figure 4.

Source: Satellite map images from Google. Used with permission. Plotted data from CAMP – V2I Consortium

Figure 3: Illustration of RSZW/LC Application

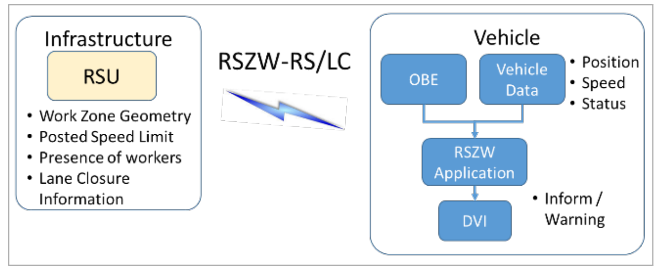

Figure 4: RSZW/LC Application Information Flow

Traveler Information Message

Per SAE J2735 [6], the Traveler Information Message (TIM) "is used to send various types of messages (advisory and road sign types) over the WAVE Short Message (WSM) stack to vehicles. It makes heavy use of the Intelligent Traveler Information System (ITIS) encoding (refer to SAE J2540-2 [7]) system to send well known phrases, but allows limited text for local place names."

The TIM framework provides the relevant mechanisms and data elements to support in-vehicle signage use cases (e.g., for display to the driver). Also, the TIM enables the transmission of advisories that were calculated either by the roadside equipment or at the Traffic Management Center (TMC) to the vehicle using predetermined ITIS codes. This approach, however, assumes that all relevant information to generate the advisory was available at the infrastructure. This inappropriate assumption has the potential to limit the performance of many V2I safety applications. The novel BIM framework proposed in this paper addresses these limitations.

As an example, not incorporating in-vehicle information into the advisory calculation would yield suboptimal results for the Curve Speed Warning (CSW) application. Using TIM, one could only issue advisories for an approaching curve with the speed limit and location information.

The in-vehicle system then can only decide whether to display the advisory or not. On the other hand, if additional data elements such as superelevation of the curve, road material and maybe weather information are available, then the vehicle system can generate the appropriate level of warning based on vehicle class. This is of paramount importance when it comes to user acceptance and driver response. While encoding additional information in TIM text fields may provide a technical solution for a short-term demo project, it does not represent a viable long term solution and consistent deployment across the U.S.

Furthermore, the mechanisms to describe an event location in TIM are limited. The message supports up to 16 valid regions which can be used to create event regions such as describing a curve of an off-ramp. This limitation restricts describing complex curves or a road work zone that could be several kilometers long. Select limitations of existing TIM to design V2I safety applications are listed below.

- Limited to 16 valid regions to represent road geometries
- Lack of additional attributes for lanes can be specified
- Inability to specify restrictions of road access for type of vehicles
- No provision to include road parameters (e.g., coefficient of friction, superelevation)
- Lack of message extensibility to cover additional V2I use cases

Basic Information Message Design

This section describes the design of the BIM. Keeping in mind the need to develop message structures in a harmonized way globally, it was decided to adopt the mature Decentralized Environmental Notification Message (DENM) [8] from the European Telecommunications Standards Institute (ETSI). Furthermore, BIM leveraged aspects from three different standards for messaging as described in Figure 5. BIM was developed and thoroughly tested for two applications – RSZW/LC and CSW. Required data elements pertaining to these two applications will be discussed in detail first.

As shown in Figure 5, BIM utilizes existing standards for event types from Transport Protocol Experts Group Traffic Event Compact (TPEG2 – TEC) [9], message structure from DENM, and data elements from SAE J2735.

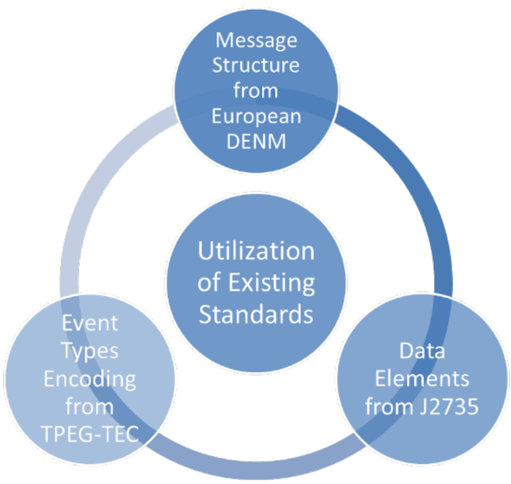

Figure 5: Basic Information Message Design Concept

BIM consists of a generic and a use case-specific container as illustrated in Figure 6. While the *mandatory* common container provides information about the type of event and information about the event location, the *optional* use case-specific container provides additional real-time information to achieve the desired performance of the V2I safety application. The number of *application* containers is not fixed and can be extended without compromising backward compatibility with non-BIM implementations. In other words, the in-vehicle application would still be able to decode the basic information from the common container even though it is not updated for a newer application container.

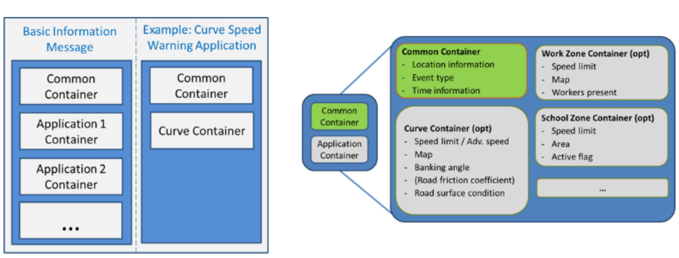

Figure 6. Basic Information Message Structure – Generic and Use Case-Specific Container

Message Data Elements

This subsection describes data elements for the different containers in the BIM. A list of the Common Container data elements is provided in Appendix A with data types along with whether the corresponding element is optional, mandatory or conditional. In addition to the common container, optional event containers may be added to the message. Such containers include information specific to the use case or event being described, enabling the corresponding application. In this paper two containers, Curve Container and Work Zone Container, developed and implemented for two safety applications - Curve Speed Warning (CSW) and Reduced Speed Zone Warning with Lane Closure (RSZW/LC) - are presented.

Curve Container

The Curve Container is intended to represent roadway curves that may be hazardous for vehicles to negotiate at certain speeds. The container can represent complex curve geometry including varying radii of curvature. Additional information about the curve may be conveyed using this container (e.g., bank angle, coefficient of friction, and indicator for reduced visibility on curve). These data elements enable the receiving vehicle with the on-board CSW application to make an accurate assessment of the situation for the vehicle and alert the driver if appropriate. The data elements for the Curve Container for BIM are described in Appendix B.

Work Zone Container

The BIM for the RSZW/LC application enables representation of complex work zone geometry. Additionally, it supports data elements for number of lanes, open and closed lanes, offset for closed lanes in the work zone, work zone length, presence of workers and speed limits. The application informs and warns the driver based on the vehicle speed and the lane in which the vehicle is traveling. The data elements of the Work Zone Container for BIM are described in Appendix C.

In addition to the data elements for the common, curve and work zone containers as described for the CSW and RSZW/LC safety applications and corresponding Abstract Syntax Notation One (ASN.1) data structure for the containers was developed and implemented for the applications is described in Appendix D.

One of the main characteristics of the BIM is extensibility. The message framework is built with the assumption that additional use cases can be represented without impacting the overall structure or breaking backward compatibility. An example of a BIM container is described for a Queue Warning (Q-Warn) application.

Q-Warn notifies drivers of traffic congestion on the route based on real-time traffic detection. Q-Warn enables drivers to have enough time to adjust speed and get ready to stop to avoid rear-end crashes. This application would need data from the infrastructure about the lane status (number of lanes and affected lanes) and queue offset (queue length) from the start of the formation of the queue. In this example, in addition to the common container, the Q-Warn container can provide specific data including dynamic queue offset information from the infrastructure for queue length determination for each lane by the on-board application.

Summary/Conclusions

A novel messaging format, the BIM, was presented in the paper. The paper described the rationale and design of the BIM, and presented the development and validation of application-centric containers for two safety applications. Based on testing in real-world settings, it was observed that the proposed BIM was sufficient to broadcast real-time information at 1 Hz to achieve the desired performance of the V2I safety applications. Furthermore, the implemented BIMs for the CSW and RSZW/LC applications conveyed complex curve and work zone information in a single message. For example, Unaligned Packed Encoding Rules (UPER)-encoded BIM for a multi-radii curve was represented in single message of 160 bytes, and a 5.5 mile four-lane work zone with lane closure and lane shifts was represented in a single message of 1261 bytes.

In excess of 100 tests were conducted for the two safety applications in controlled test settings and on public roads and live work zones using the developed BIMs. The flexible message structure provided representation for all required data elements from infrastructure for varying layouts of CSW and RSZW/LC applications.

Currently, the Crash Avoidance Metrics Partners, LLC (CAMP) V2I consortium in cooperation with the Connected Vehicle Pooled Fund Study for V2I Safety Applications is working with the SAE DSRC Technical Committee to standardize and harmonize the BIM to support V2I deployments around the U.S.

A BIM design for Q-Warn was presented to illustrate the simplicity of the message design format to extend to other use cases. One could design BIMs for other safety applications such as Spot Weather Inform Warning in which real-time information from the infrastructure will enhance road safety. Development and validation of BIMs for these applications are possible directions for future work.

References

1. Parikh, J.S., Adla R., Kailas A., "Validating Prototype Connected Vehicle-to-Infrastructure Safety Applications in Real-World Settings," submitted to SAE World Congress 2018 in AE503, Vehicle to Infrastructure, Paper # 18AE-0102.
2. FHWA-JPO-10-028, ITS Strategic Research Plan, 2010-2014: Executive Summary, Research and Innovative Technology Administration, Department of Transportation, p. 10.
3. Valentin E. Brimkov, Reneta P. Barneva, "Digital Geometry Algorithms: Theoretical Foundations and Applications to Computational Imaging." Springer Science & Business Media, 2012.
4. Michigan Department of Transportation, "Superelevation and Pavement Crowns, Standard Plan No. R-107-H," Road and Bridge Standard Plans. [Online]. Available: http://mdotcf.state.mi.us/public/design/files/englishstandardplans/files/standard_plan_book.pdf. [Accessed: 31-Oct-2015].
5. R. Noon, Engineering Analysis of Vehicular Accidents. Boca Raton: CRC Press, 1994.
6. SAE Surface Vehicle Standard – DSRC Message Set Dictionary J2735 MAR2016.
7. SAE J2540-2_200911: Advanced Traveler Information Systems (ATIS) Family of Standards for Coding of Messages and Phrase Lists
8. Final draft ETSI EN 302 637-3 V1.2.1 – "Intelligent Transport Systems (ITS); Part 3: Specifications of Decentralized Environmental Notification Basic Service." ETSI, Sep-2014.
9. TPEG2-TEC (2013): Intelligent Transport Systems (ITS) — Traffic and Travel Information (TTI) via Transport Protocol Experts Group, Generation 2 (TPEG2) -Part 15: Traffic Event Compact (TPEG2-TEC_3.2/002); TISA SP13001 (in publication, to potentially become ISO/TS 21219 Part15).

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Appendix A – Common Container Overview

Common Container Contents	Mandatory / Optional / Conditional	Type	Notes
DSRCmsgID	M	As 'DSRCmsgID' in J2735	Message ID for this message type
eventID	M	As 'DE_TemporaryID' in J2735	Unsigned 32-bit integer randomly generated at the time of event
segmentID	O	As 'DE_TemporaryID' in J2735	For linking multiple messages transmitted by multiple stations
dateTime	M	As 'DF_DDateTime' in J2735	Time of detection of the event
duration	M	As 'DF_DDateTime' in J2735	Time duration from dateTime before which the event is unlikely to change
causeCode	M	An unsigned 8bit integer representing seconds	Identifies type of event based on codes from the ETSI/ISO DENM standard
subCauseCode	O	An unsigned 8bit integer representing event types	Provides more detailed information of the event related to the causeCode, based on codes from the ETSI/ISO DENM standard
referencePoint	M	As 'DF_Position3D' in J2735 including Latitude, Longitude, Elevation	Reference position of the beginning of the event
applicableHeading	M	Data Frame consisting of unsigned integers for both heading and tolerance (both in increments of 1 degree)	Identifies applicable direction of travel
speedLimit	O	As 'DF_RegulatorySpeedLimit' in J2735	Speed limit at the reference position
roadWidth	C (approachLanes)	As 'DE_LaneWidth' in J2735	Road width at the reference position
approachLanes	M	A sequence of lane numbers (DE_LaneID), or a sequence of genericLane (DF_GenericLane) in J2735	Sequence of up to 10 lane numbers assigned to the corresponding affected approach lanes (from left-most – lane 1, to right-most lane)
eventLength	O	Unsigned 16-bit integer	Length of the event in meters

Appendix B – Curve Container Overview

Curve Container Contents	Mandatory / Optional / Conditional	Type	Notes
frictCoef	O	An unsigned 7bit integer 0..100 with a unit of 0.01, effectively representing values between 0..1	Coefficient of (kinetic) friction for a reference tire sliding over the surface under dry conditions
advisorySpeed	O	As 'DE_SpeedAdvice' in J2735	Advisory speed that may be displayed if the vehicle cannot calculate the warning speed
geometry	O	As 'DF_GenericLane' in J2735.	A sequence of genericLane. LaneIDs are carried over from approachLanes in the common container. Either minRadius or geometry must be present in the CWS container.
surfaceCondition	O	An enumerated value	[Consider using] ITIS codes (need dry, moist, wet, flowing, ice, snow, frost)

material	M	An enumerated value	Enumeration containing material type (e.g., asphalt, concrete, brushed concrete)
minRadius	O	Radius	Minimum radius of the curve (in meters). Either minRadius or geometry must be present in the CWS container.
bankAngle	M	A signed 7 bit integer representing positive and negative degrees (-63..64)	Bank angle of the curve at the minimum radius
obstacle	O	Activity	Binary flag.
reducedVisibility	O	Activity	Binary flag.

Appendix C – Work Zone Container Overview

Work Zone Container Contents	Mandatory / Optional / Conditional	Type	Notes
laneStatus	M	An 11-bit field	A sequence of laneIDs (from approachLanes) and their corresponding status (open or closed)*
laneCloseOffset	M	A list of up to 10 as 'DE_ObstacleDistance' in J2735	A list of offset distances from reference point that describe start of lanes closures in the work zone lanes
geometry	C (eventLength)	Sequence of genericLane (DF_GenericLane)	A sequence of GenericLane. Must be present if eventLength is not present in the common container.
workersPresent	O	Activity	Binary flag indicating workers are present or not

* - Bit field describes the number of lanes the road has and which lanes are open and which are closed. The leftmost '1' in the field is a delimiter to specify the number of lanes the road has. '00000010000' means that the road has four lanes and all are open. Every '1' right of that first '1' on left indicates that the corresponding lane is closed. For example, 00000010001 indicates lane 1 is closed. (Note: this limits the number of lanes to 10.)

Appendix D – ASN.1 Representation

```
BIM DEFINITIONS AUTOMATIC TAGS::=

BEGIN

IMPORTS

DSRCmsgID, TemporaryID, DDateTime, DirectionOfUse, Position3D, PositionalAccuracy,
Heading, HeadingConfidence, SpeedLimitList, LaneWidth, NodeListXY, Speed,
SpeedConfidence, PathHistory, RoadSegmentList, ObstacleDistance FROM DSRC {

};
BasicInformationMessage ::= SEQUENCE {
    commonContainer      CommonContainer,
    mobileContainer      MobileContainer       OPTIONAL,
    workzoneCont         WorkZoneContainer     OPTIONAL,
    schoolZoneCont       SchoolZoneContainer   OPTIONAL,
    curveContainer       CurveContainer        OPTIONAL,
... -- # LOCAL_CONTENT
```

```
}

CommonContainer ::= SEQUENCE {
    msgID           DSRCmsgID,
    stationID       TemporaryID               OPTIONAL,
    eventID         EventID,
    segmentedID     EventID                   OPTIONAL,
    detTime         DDateTime                 OPTIONAL,
    validityDur     ValidityDuration          OPTIONAL,
    causeCode       CauseCodeType,
    subCauseCode    SubCauseCode,
    refPos          Position3D,
    posAcc          PositionalAccuracy        OPTIONAL,
    heading         Heading                   OPTIONAL,
    headingConf     HeadingConfidence         OPTIONAL,
    speedLimit      SpeedLimitList            OPTIONAL,
    traffDir        DirectionOfUse            OPTIONAL,
    width           LaneWidth                 OPTIONAL,
    approach SEQUENCE (SIZE(1..10)) OF NodeListXY OPTIONAL,
... -- # LOCAL_CONTENT
}

MobileContainer ::= SEQUENCE {
    speed           Speed,
    speedConf       SpeedConfidence           OPTIONAL,
    path            PathHistory               OPTIONAL,
... -- # LOCAL_CONTENT
}

WorkZoneContainer ::= SEQUENCE {
    laneStatus      LaneStatus                OPTIONAL,
    laneClosOffsets       LaneClosOffsets     OPTIONAL,
    geometry        RoadSegmentList           OPTIONAL,
    length          Length                    OPTIONAL,
    workersPresent  Activity                  OPTIONAL,
... -- # LOCAL_CONTENT
}

CurveContainer ::= SEQUENCE {
   frictCoeff      BIMCoefficientOfFriction  OPTIONAL,
   advisorySpeed   Speed                     OPTIONAL,
   geometry        RoadSegmentList           OPTIONAL,
   surfaceCondition  SurfaceCondition        OPTIONAL,
   material        RoadwayMaterial           OPTIONAL,
   radius          Radius                    OPTIONAL,
   bankAng         BankingAngle              OPTIONAL,
   obstacle        Activity                  OPTIONAL,
   reducedVis      Activity                  OPTIONAL,
... -- # LOCAL_CONTENT
}

BankingAngle ::= INTEGER(-63..64)
EventID ::= INTEGER (0..65535)
CauseCodeType ::= INTEGER {
```

```
    reserved (0),
    trafficCondition (1),
    accident (2),
    roadworks (3),
    adverseWeatherCondition-Adhesion (6),
    hazardousLocation-SurfaceCondition (9),
    hazardousLocation-ObstacleOnTheRoad (10),
    hazardousLocation-AnimalOnTheRoad (11),
    humanPresenceOnTheRoad (12),
    wrongWayDriving (14),
    rescueAndRecoveryWorkInProgress (15),
    adverseWeatherCondition-ExtremeWeatherCondition (17),
    adverseWeatherCondition-Visibility (18),
    adverseWeatherCondition-Precipitation (19),
    slowVehicle (26),
    dangerousEndOfQueue (27),
    vehicleBreakdown (91),
    postCrash (92),
    humanProblem (93),
    stationaryVehicle (94),
    emergencyVehicleApproaching (95),
    hazardousLocation-DangerousCurve (96),
    collisionRisk (97),
    signalViolation (98),
    dangerousSituation (99)
} (0..255)


SubCauseCode ::= INTEGER (0..255)
ValidityDuration ::= INTEGER (0..131072)
LaneStatus ::= INTEGER (0..2047)
LaneClosOffsets ::= SEQUENCE (SIZE(1..10)) OF ObstacleDistance
Length ::=INTEGER (0..32767)
Activity ::= INTEGER (0..1)
BIMCoefficientOfFriction ::= INTEGER (0..127)
SurfaceCondition ::= ENUMERATED {
    dry(0),
    moist(1),
    wet(2),
    flowing(3),
    ice(4),
    snow(5),
    frost(6),
...
}


RoadwayMaterial ::= ENUMERATED {
    asphalt(0),
    concrete(1),
    gravel(2),
...
}

Radius ::= INTEGER (0..1023)

END
```