BASIC INFRASTRUCTURE MESSAGE DEVELOPMENT AND STANDARDS SUPPORT FOR CONNECTED VEHICLES APPLICATIONS

The MAP Message – Beyond Intersections
White Paper

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Connected Vehicle Pooled Fund Study

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1. INTRODUCTION

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

- An overview of the existing geometric representations including the MAP message
- An overview of use cases for geometric representation
- Identification of gaps and recommendations for improvements

1.1 Project Background

In a Connected Vehicle (CV) environment, vehicles which are equipped with Dedicated Short Range Communication (DSRC) devices (based on IEEE 802.11p) broadcast Basic Safety Messages (BSMs). A standard that defines the message content and behavior (SAE J2735) is in wide use. On the other hand, from the infrastructure side, which infrastructure information will be or needs to be broadcasted is relatively unknown and has not received the same level of scrutiny. While some of the infrastructure related information, i.e. a Signal Phase and Timing (SPaT) message, and a MAP message (including intersection ID, reference point, orientation, lane width, type, etc.), are already included in the current standards, there are other pieces of infrastructure information that may benefit CV applications; such as speed limit (particularly where that might be variable), standard signage in the area, presence of school zones, work zones and lane closures, messages displayed on variable messages signs or highway advisory radios, etc.

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

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

1.2 Project Goals

The overall goals of this project are:

- Evaluate current SAE messages to see if any are sufficient to provide the infrastructure dialogs needed to support the addition of CV applications.
- If existing messages are not sufficient, develop a Basic Infrastructure Message (BIM)
- Establish a means to collaborate with the relevant standards development organizations

1.3 Purpose of This Document

This white paper was developed under Task 3 of the project: “Standards and Related Activities Review”. This paper is intended to provide an overview of existing geometric representations, describe potential use cases, identify potential gaps and finally provide recommendations to address the gaps.

2. MAP OVERVIEW

The following sections will provide information regarding existing map information including:

- Background
- Standards
- Usage
- Data Gathering

2.1 Background

2.1.1 Standards

The J2735 standard (version 2016-03 issued March 2016)[1] defines the MAP message. Additionally, a cut down of J2735 was provided to the MAP_SPaT Task Force (TF) of the DSRC Technical Committee (TC) and contains a sub-set of Section 11 pertaining to MAP and SPaT message uses. The standard provides context and usage recommendations for the MAP message and all related elements.

In the definition of the MAP_Msg, it is noted that the primary use is for lane-level geometry for intersections. Specifically, the details for the MAP message indicate (emphasis added):

> "The MapData message is used to convey many types of geographic road information. At the current time its primary use is to **convey one or more intersection lane geometry maps** within a single message. The map message content includes such items as complex intersection descriptions, road segment descriptions, high speed curve outlines (used in curve safety messages), and segments of roadway (used in some safety applications). A given single MapData message may convey descriptions of one or more geographic areas or intersections. The contents of this message involve defining the details of indexing systems that are in

[1] https://saemobilus.sae.org/content/j2735_201603

turn used by other messages to relate additional information (for example, the signal phase and timing via the SPAT message) to events at specific geographic locations on the roadway."[2]

One example of the visual representation of the information contained in the MAP message is shown below. This highlights the applicability of the message to an intersection (Figure 1):

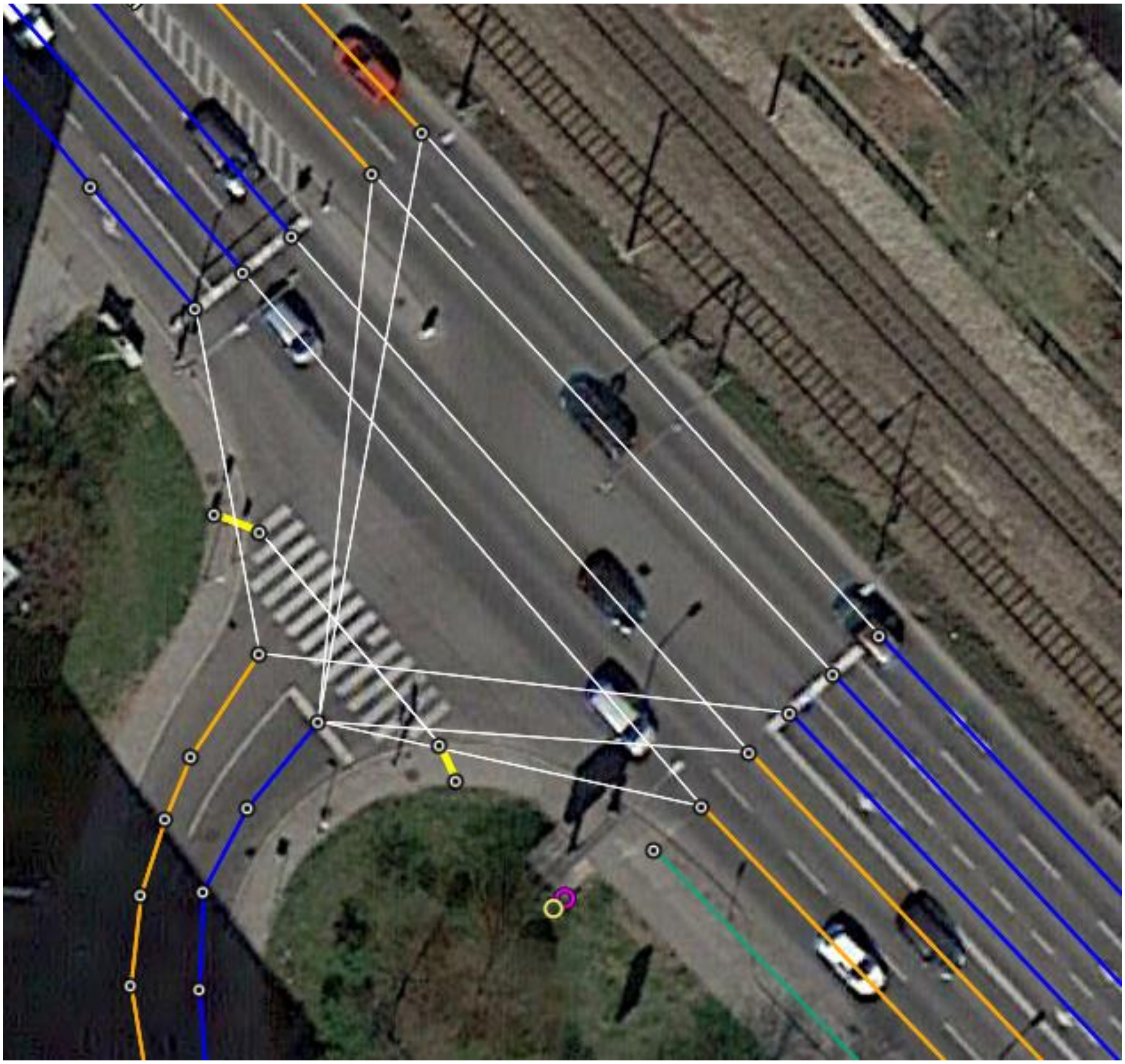

Figure 1: A visual representation of an example intersection.

This focus on intersections poses a risk when attempting to apply the MAP to use-cases that are not associated with intersections such as large stretches of freeways or work zones. See Section 4.3 below for possible improvements.

[2] https://saemobilus.sae.org/content/j2735_201603

Section 11.10 of J2735 notes that the data provided in the MAP_Msg may be tailored to the application that is using the data. This poses a risk in the ambiguity of the usage of information provided by the MAP_Msg and the usage in a safety application. The standard states:

> "…the MAP and SPAT messages are not intended to be used "as transmitted" but to be translated into whatever local data model the end device application requires."[3]

This creates ambiguity with regards to the way that the data is treated by the receiving application. Additionally, (also in section 11.10) the standard notes that a globally unique ID will require registration with a global process, which is outside of the scope of the J2735 standard and poses a risk for overlap. This risk could be addressed through global registration of geometric data (see recommendations in Section 4.3) or continued standardization regarding the generation and application of MAP_Msg data.

2.2 Tools

New York's Connected Vehicle Pilot proposal incorporates more than 200 intersections for just one of the four planned deployment sites[4]. With almost 13,000 signalized intersections with advanced traffic controllers, this is only a small subset of the effort needed to provide information over DSRC to CVs. New York's proposal includes supporting Intersection Movement Assist (IMA), Red Light Violation Warning (RLVW) and Pedestrian in Signalized Intersection Warning (PEDINXWALK). Each of these intersections will need extensive data (lane level as well as pedestrian crosswalk details).

Considering the vast numbers of intersections that could be encoded into MAP messages, there are a few tools that are designed to make MAP messages. The ISD Builder Tool for J2735 3/2016[5] offers a web-based interface that allows a user to define intersection features and encode the features into an ASN.1 or UPER message. This tool provides the ability to create detailed MAP messages based on a visual overlay (satellite images) and the user's understanding of the particular lanes and intersection (Figure 2).

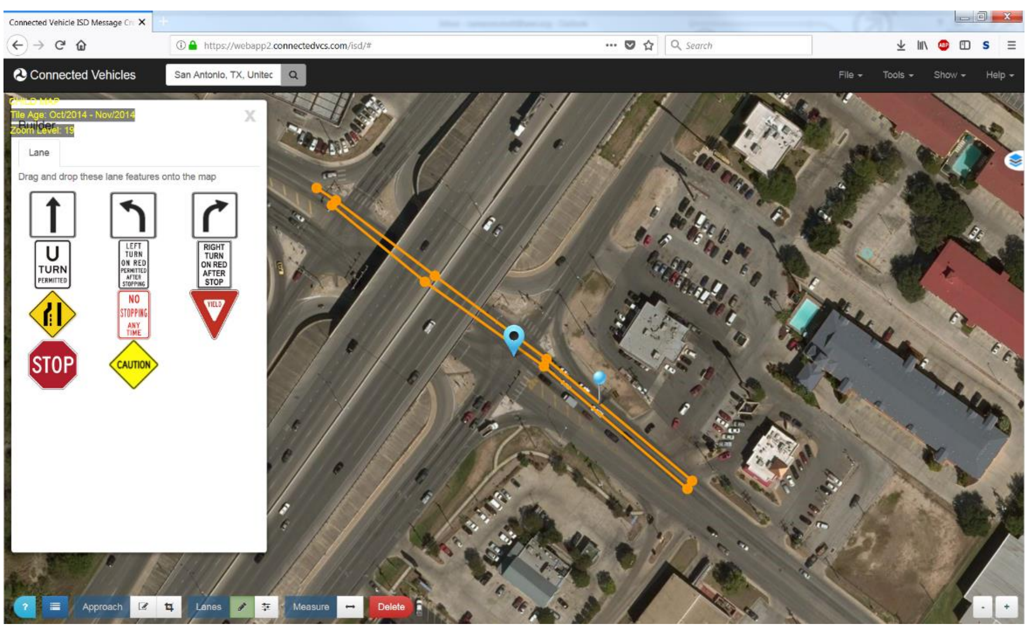

Figure 2: The ISD Builder Tool web app with lane level feature definitions.

[3] https://saemobilus.sae.org/content/j2735_201603
[4] https://www.its.dot.gov/pilots/pdf/NYC_ConOpsWebinar.pdf
[5] https://webapp2.connectedvcs.com/

It requires extensive effort (both generation of the data and verification of the data) in order for a tool like the ISD Builder to provide enough information to represent the details associated with just one intersection. Figure 3 provides an indication of the amount of data that needs to be generated for a full intersection to be encoded in the MAP message[6]:

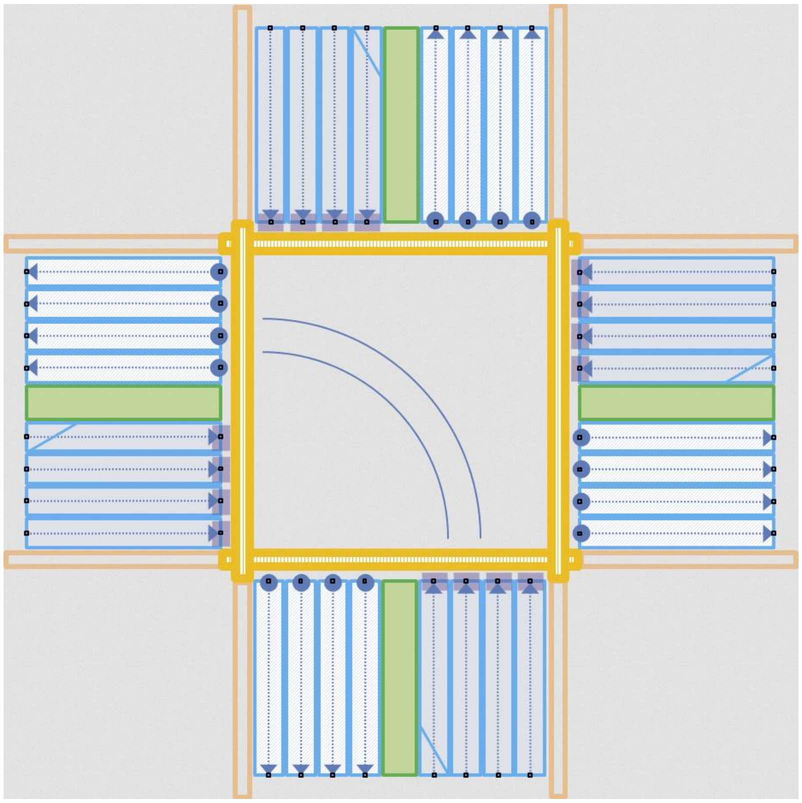

Figure 3: An example image of a fully-detailed intersection including ingress/egress lanes, crosswalks, medians, sidewalks and lane stripes.

Through a variety of efforts, there are intersections that have been encoded into a MAP message[7]. This provides insight into the complexity of the effort (Figure 4).

[6] http://dsrc-tools.com/map-spat/index.php/knowledge-base/common-map-style-choices/

[7] Source: DSRC Technical Committee

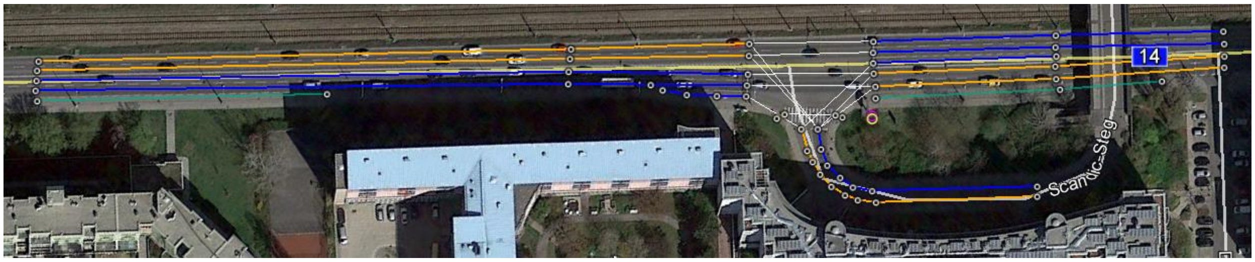

Figure 4: An overview of an intersection with MAP information plotted. Note the level of detail involved in the definition of this intersection.

For this example, almost 100 different elements needed to be defined. Each of these elements has multiple corresponding geometric coordinates and meaning. Additionally, the accuracy of each point is subject to multiple sources for potential error such as picking the wrong point, changes to the intersection after the satellite image was taken and features that are obscured in the satellite imagery. The connections between lanes through the intersection are also detailed (Figure 5).

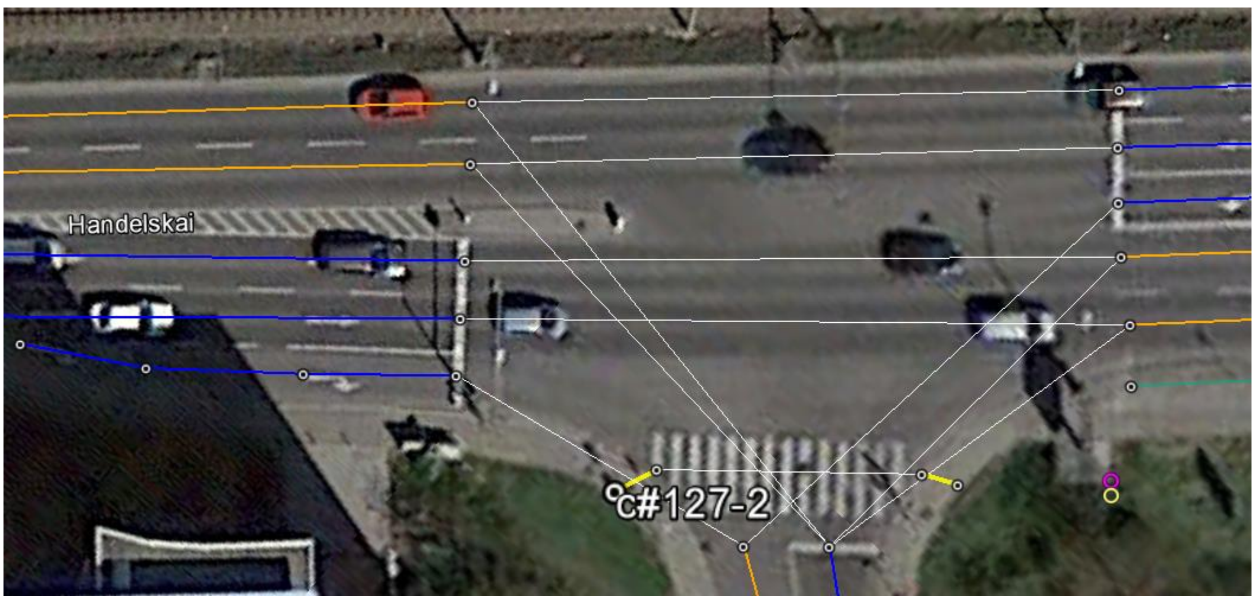

Figure 5: Zoomed in view of the intersection. Connecting lanes are indicated as straight white lines.

The level of detail included in this example highlights the level of complexity in order to enable a variety of applications.

Some of the difficulties in creating this level of detail for intersections include:

1. Level of complexity – large number (hundreds) of elements per intersection
2. Accuracy – Satellite imagery may not be accurate
3. Tedious – Encoding large numbers of intersections will be difficult

See section 4.3 for recommendations to address some of these difficulties.

There are also tools to help organize CV data, including a tool offered by USDOT to visualize BSMs that have been received as a part of the Advanced Messaging Concept Development (AMCD) field testing program[8]. Through this tool, data can be visualized as well as downloaded for offline use and analysis (see Figure 6).

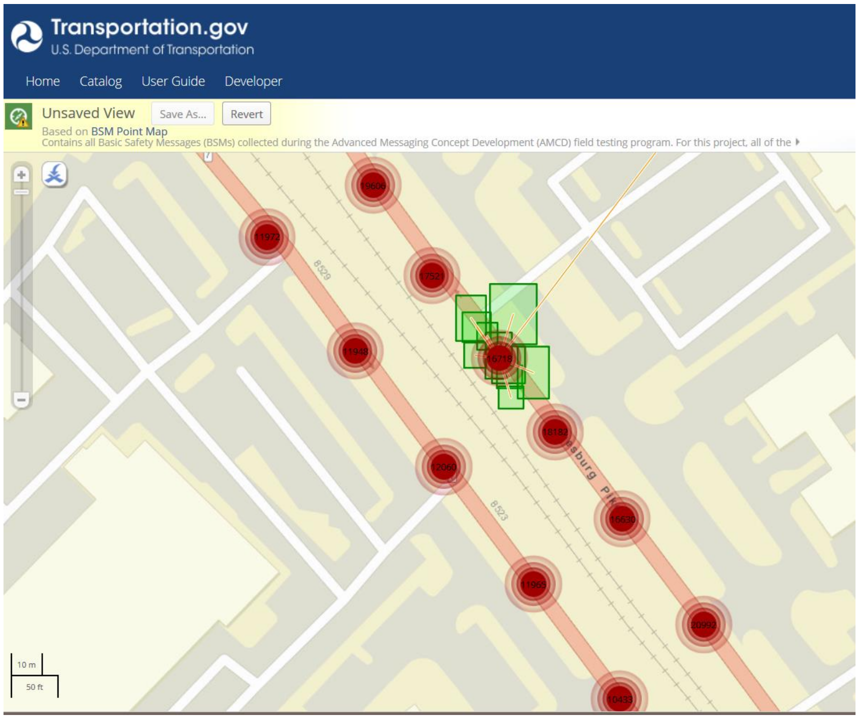

Figure 6: Visualization of BSM data available from USDOT.

2.3 Data Gathering

The MAP message must provide lane-level resolution of roadways and intersections, which requires data with that level of accuracy. To date, this is accomplished by other businesses through a wide variety of strategies:

1. Open-source community
    a. Open street maps[9] allows anyone to adjust map data, similar to wiki. The community self-regulates and contributors (currently over 3 million registered users) use data available to them through personal experience, public domain and data publically released by commercial agencies. As such, the data integrity is subject to limitations with regards to the accuracy of the data. Language is included that indemnifies everyone such as No warranties, guarantees, use at your own risk, the data is worth the weight of the bits used to represent it, subject to change without notification, user assumes all risk, etc.
        i. This data is global in nature and is quite extensive. Open street maps has addressed the issue of a global registry that assigns and tracks unique IDs for

[8] https://data.transportation.gov/Automobiles/BSM-Point-Map/fgbu-uats
[9] https://www.openstreetmap.org/

every identifiable feature. Additionally, the roadway features include lane information with center-line geometry (see Figure 7).

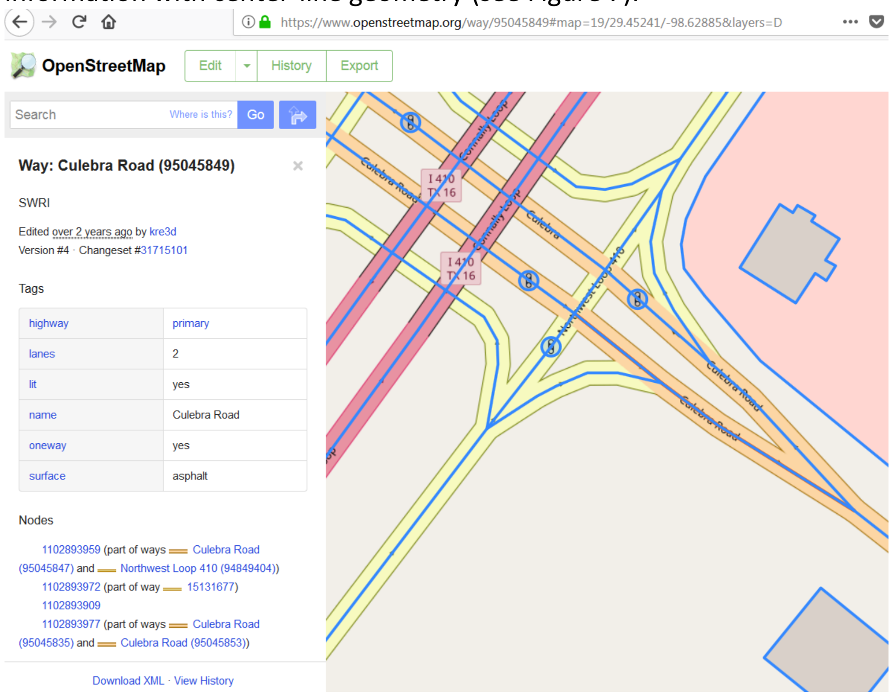

Figure 7: Screenshot from OpenStreetMap indicating the level of information for any roadway section. Of particular interest is the history, number of lanes, roadway name and connecting nodes.

2. Closed-source community
   a. Through the Google Map Maker, Google provides the capability for users to make adjustments to their underlying map data. Such changes are (supposed to be) extensively reviewed by Google staff prior to being incorporated. This feature was subsequently retired and rolled into Google Maps. This feature was not without some controversy, as users contributed content that was not related to navigation or mapping.
   b. Through image processing techniques, it is possible to use satellite images and learning algorithms to create digital representations of roadways[10]. In the paper "Best Practices for Surveying and Mapping Roadways and Intersections for Connected Vehicle Applications," advanced sensors mounted on a vehicle and image processing techniques were used to generate J2735 MAP messages for intersections that were driven by the UC Riverside engineers (see Figure 8 and Figure 9). This required an extensive sensor suite mounted on a vehicle that drove each intersection but similar mechanisms could be further expanded and simplified as technology improves.

[10] https://escholarship.org/uc/item/4f88m75k

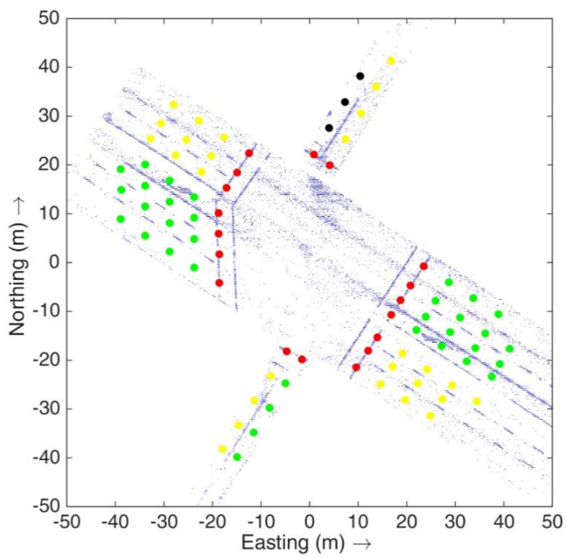

Figure 8: Point cloud data with MAP features superimposed as yellow, red and green dots.

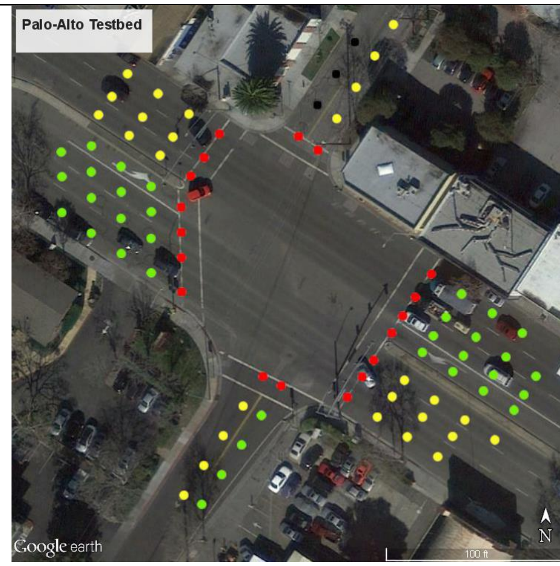

Figure 9: An overlay of the points on a satellite image from Google Earth.

3. Commercial solutions
    a. Some solution providers and even DOTs are using commercial surveying companies to get the data that is needed. Especially in downtown urban canyon areas, this is a concern. Additional concern surrounds the use of GPS-reliant DSRC units in urban canyons. The accuracy of the mapping data and the accuracy of the OBUs using the data are independent problems that will need to be investigated in order to determine the severity of each problem.

2.4 Data Maintenance

The data within the MAP message will need to be properly maintained, in order to retain the capability for addressing safety-related use-cases. This digital representation of the physical characteristics of the roadway will need to be verified and kept up to date by a responsible party.

3. OVERVIEW OF USE-CASES

The following sections will provide information regarding the use cases for transmitting geometric map information, including:

- Use-Cases
- Application of Use-Cases within Pilot Projects

As an examination of the technology will be provided in additional detail in the **Error! Reference source not found.** section, these sections will be covered at a high level.

3.1 Use-Cases

This section identifies use cases and the data that would be transferred over DSRC.

Known use-cases that utilize the MAP message (as identified by US DOT Message Lexicon Final Report issued December 2016)[11]. These use cases are now referenced in ISO 19091 standard:

SA2: Red Light Violation Warning

SA3: Stop Sign Violation Warning

SA4: Turning Assistant – Oncoming Traffic

SA5: Turning Assistant – Vulnerable Road User Avoidance

SA6: Non-signalized Crossing Traffic Warning

SA7: Crossing Vulnerable Road User Advisory (Non-signalized)

MS4: Traffic Signal Optimal Speed Advisory

MS5: Signalized Corridor Eco-Driving Speed Guidance

MS6: Idling Stop Support

MS7: Start Delay Prevention

MS9: Inductive Charging at Signals

MS10: Don't Block the Box

Additionally, there are connected vehicle applications that do not require MAP information but could benefit (increased true positives, decreased false negatives, decreased false positives) from utilizing the information:

Intersection Movement Assist (IMA)

Left Turn Assist (LTA)

Pedestrian in Signalized Intersection Warning (PED-X / PCW)

3.2 Application of Use-Cases within Pilot Projects

Applications of potential use-cases for map information that are ongoing include:

New York City DOT (NYCDOT) CV Pilot

[11] https://rosap.ntl.bts.gov/view/dot/32033

Intersection Movement Assist

Pedestrian in Signalized Intersection Warning

Curve speed warnings[12]

Tampa-Hillsborough Expressway Authority (THEA)[13]

Intelligent Traffic Signal System (I-SIG)

Intersection Movement Assist (IMA)[14]

Wyoming (WY) DOT Pilot[15]

Variable Speed Limits

Curve speed warnings[16]

12 https://www.its.dot.gov/pilots/pilots_nycdot.htm
13 https://www.its.dot.gov/pilots/pilots_thea.htm
14 https://www.its.dot.gov/pilots/pdf/03_CVPilots_Tampa.pdf
15 https://www.its.dot.gov/pilots/pilots_wydot.htm
16 https://www.its.dot.gov/pilots/pdf/04_CVPilots_Wyoming.pdf

4. IDENTIFICATION OF GAPS AND RECOMMENDATIONS

The following sections summarize gaps in the use cases based on utilizing only the existing MAP message.

4.1 Missing Use-Cases

4.1.1 Large stretches of roadways with lane-level resolution

One notable gap in the design is the lack of support for long stretches of road, especially roads that cross over multiple regions. While most DSRC applications are restricted to regions, a mechanism for representing long stretches of roads with lane-level resolution will be an important factor for success. See Section 4 for more details.

4.1.2 Large scale MAP data

Consider the use case of generating MAP data for hundreds of intersections for a stretch of roadway that will be outfitted with DSRC infrastructure equipment. Many of the intersections may be similar, with a few special features or geometries. In order to create MAP data with appropriate lane-level data, each of the approach lanes and connecting points needs to be mapped. In addition, to incorporate pedestrian crosswalks, medians and bike lanes requires additional data.

4.2 Use-Cases That Need Additional Information

While CV safety applications such as IMA and LTA are capable of providing value without map data, incorporating geometric information can improve the functionality.

4.3 Recommendations

The authors identify the following as opportunities to address the gaps and assist with the efficiency of utilizing MAP messages.

MAP building:

1. Create a tool to convert from open-source input (such as OpenStreetMap) to MAP messages. While global maps are complex to generate, the need for globally registered maps is highlighted as vehicles invariably cross jurisdiction and regional boundaries. Creating a tool that leverages existing sources would be efficient and beneficial.
2. Create roadway data definitions that are specifically designed for longer-distance roadways and fit within the J2735 standard. The value of encoding geometric messages that are not limited to intersections would enable the MAP message to be used for many additional use-cases. This would require re-structuring and potentially regenerating the MAP message, and incorporating those extensions into the J2735 standard.
3. Create a tool that provides a template for an intersection with pre-populated default values. A user would provide the tool with inputs such as number of lanes, number of connecting roads and a center point, and the tool could pre-populate a best-guess layout. This would be valuable for many of the applications but would not necessarily address all of the application needs.
4. Building on recommendation #1, image processing techniques can extract features from satellite image and lay out an initial geometry.

MAP accuracy:

5. BSMs could be gathered from vehicles traveling in the area and could improve an existing layout or create an initial layout of intersections and roadways. Over time this would provide lane-level accuracy and connecting nodes.
6. Establishing a national or global registry of assigned IDs would prevent conflict between unique IDs across the various jurisdictions.

Both:

7. As automated vehicles become more prevalent, their advanced sensors and the technology that enables them will generate vast amounts of data that could contribute to both map building and verification or maintenance of MAP message accuracy. While this is a more long-term effort, initial work in this effort early-on would greatly assist both AV and CV functionality. This high-resolution data could provide ground truth and would assist with the registration of mapping satellite information to the MAP message. As an example, an AV could verify that the MAP information that was provided is accurate to the world-map that is generated by the sensors. Discrepancies with one system may not indicate which was accurate, but multiple failures to register the same features between the infrastructure data and the vehicle-generated data would indicate a need for improvement. Another example could be comparing in real-time the GPS output of the BSM to the navigational output that the AV is using in order to operate. This could provide constant verification of the data provided by the BSM or highlight areas (including context such as weather, location, time of day, etc.) of necessary improvements.

5. CONCLUSION

MAP messages as defined in the J2735 standard and utilized by a variety of use cases represent the physical roadway geometry, specifically for intersections. The usage of the MAP message enables certain DSRC use-cases, though there are existing gaps. Recommendations to close those gaps have been provided. Modifications or further effort to extend the usage of the MAP message have been recommended and could be performed in future projects.