# Multi-Modal Intelligent Traffic Signal System (MMITSS) Phase III:

# Task 3.2 Specification for MAP Engine Library

**Version 1.1**

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**University of Arizona (Lead)**

**University of California PATH Program**

# RECORD OF CHANGES

A – Added, M- Modified, D - Deleted

| Version | Date | Description |
|---|---|---|
| 1.0 | 10/10/2018 | Initial |
| 1.1 | 11/14/2018 | Incorporated comments from MMITSS team |
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# 1 Introduction

In the development of MMITSS development plan, a review of the current MMITSS prototypes has resulted in identification of several common libraries/components that can be abstracted from the current code base and then updated/improved in the modified code base and used by both the AZ and CA prototypes. Figure 1 illustrates these common components that will support both the MMITSS-AZ and the MMITSS-CA prototypes, as well as other Connected Vehicle (CV) applications that could be developed in the same framework.

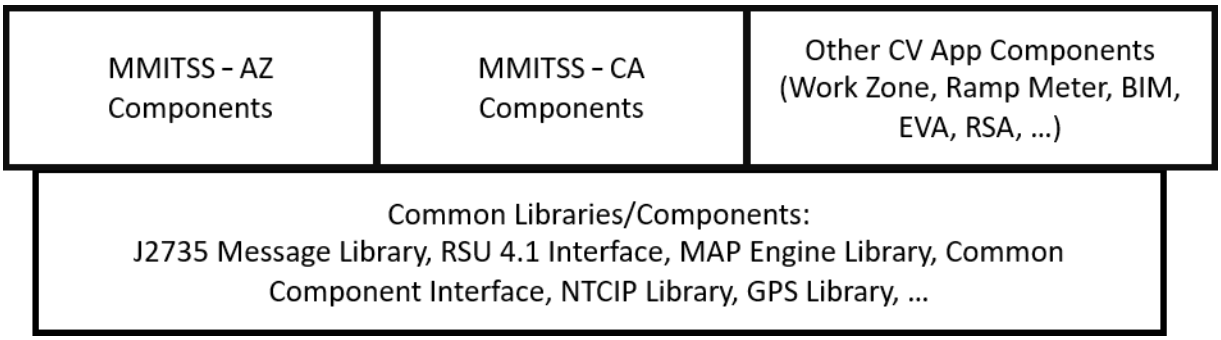


Figure 1: Common MMITSS Libraries/Components

## 1.1 Overview of MAP Engine Library

The common MAP Engine Library should be able to compile and link by other MMITSS software modules on both the stand-alone Linux-like MRP (MMITSS Roadside Processor) computer and vendor specific On-Board Unit (OBU) to support critical MAP related functions such as determining if a vehicle is within the coverage of the map as defined in a MAP message, determining lane of travel, estimating the distance from the vehicle to the stop bar, etc.

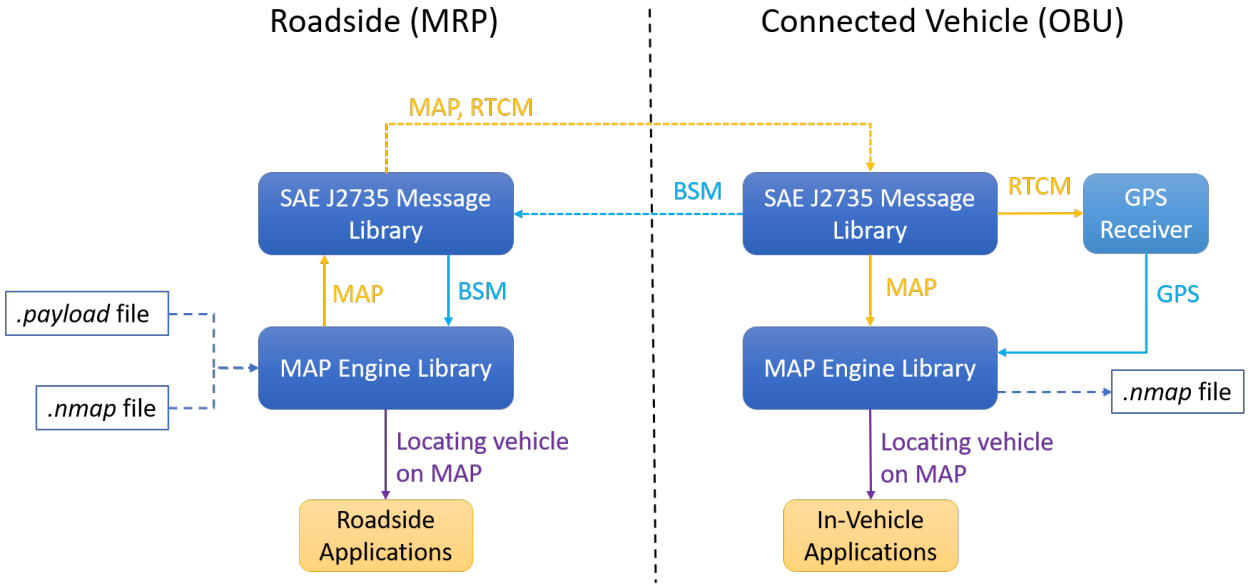


Figure 2: Context Diagram of MAP Engine Library

Figure 2 is a basic Context Diagram of the MAP Engine Library (MEL). Inputs to MEL are different on MRP computer versus on an OBU. An MRP should always maintain the latest intersection MAP, in the form of either a *.nmap* file that contains the necessary information for encoding SAE J2735-201603 MAP message for transmission or a *.payload* file that contains the encoded SAE J2735-201603 MAP payload. The encoded MAP payload could be created either based on the *.nmap* file using the MEL or by other tools such as USDOT's MAP tool[1]. An OBU receives over-the-air MAP messages from RSUs (Road-Side Units) that are within its DSRC communication range. The OBU could utilize RTCM broadcasts for position corrections and broadcasts BSM. The MRP receives BSMs from OBUs that are within the communication range of its associated RSU. On the MRP, vehicle location inputs to MEL are BSMs or the MMITSS internal GPS data object decoded from BSM; on an OBU, vehicle location inputs are the MMITSS internal GPS data object that contains the current GPS measurement (latitude, longitude, altitude, speed, heading, etc.) and BSMs from nearby connected vehicles. When provided with a BSM, the MEL calls the J2735 Message Library to decode the BSM into a MMITSS internal GPS data object (e.g., *bsm_t* defined in *MMITSScommon.h*). Please refer to Specification for J2735 Message Library document for more information regarding the common J2735 Message Library.

Outputs from MEL are the same for MRP and OBU, i.e., the results of locating a vehicle on MAP:

- Determine if a vehicle is within the coverage of a MAP (e.g., geofencing);
- Determine vehicle's lane of travel; and
- Estimate the distance from the vehicle to the stop bar in the current lane.

## 1.2 Basic Functions

Figure 3 illustrates the basic functions and activities of MEL highlighting Inputs on MRP and OBU.

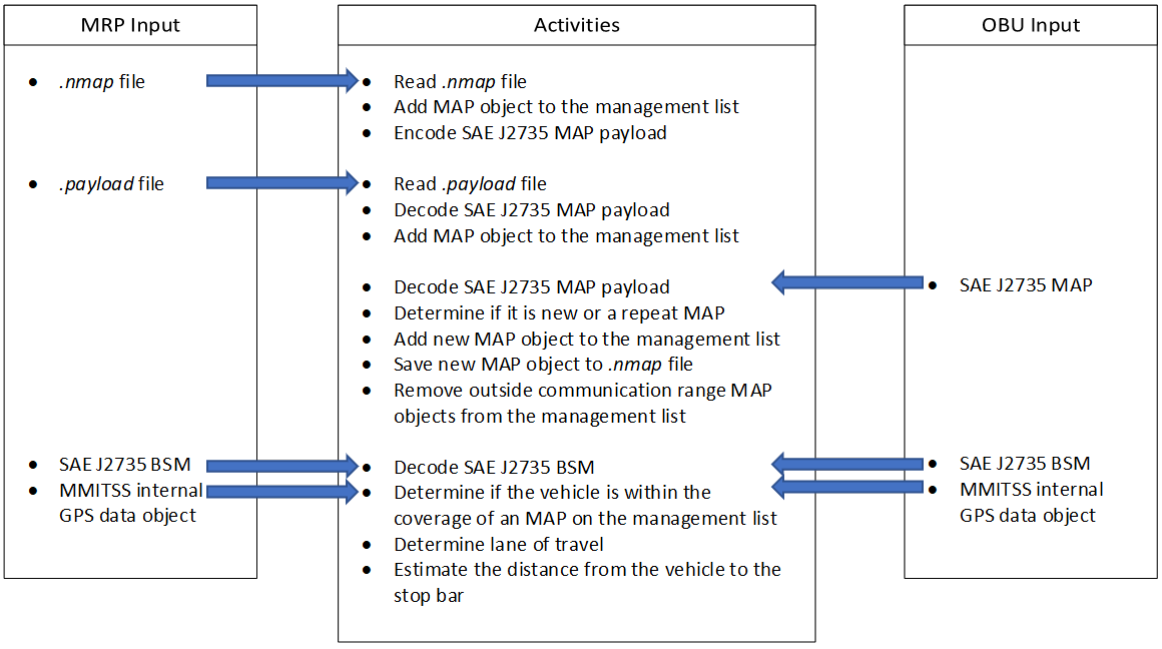


Figure 3: Basic Functions and Activities of MAP Engine Library

[1] USDOT MAP tool, version 2.23. https://webapp.connectedvcs.com/isd/.

The MEL class manages an array of MAP objects (e.g., the management list). The size of the array is usually one for MRP and is dynamic on an OBU, depending on the number of RSUs within the DSRC communication range. When provided with vehicle location input, either in the form of SAE J2735-201603 BSM or MMITSS internal GPS data object, the MEL performs the functions of locating the vehicle on MAP as described in Section 1.1 and illustrated in Figure 3.

On MRP, the MEL class can be initialized by reading a *.nmap* file or a *.payload* file. We recommend the use of *.payload* file for initiating the MEL class. The *.nmap* format supports backward compatibility with existing MMITSS deployments. When using other MAP tools to create the MAP payload rather than the MEL, the encoded MAP payload needs to include MMITSS required MAP data elements (see Appendix A for more information). Users can utilize the MEL to read the *.nmap* file and to get the encoded MAP payload.

On an OBU, the MEL class shall be initialized without the knowledge of any intersection MAP. When an OBU receives an over-the-air MAP messages, the MEL will add new MAP objects to its management list. The function of saving new MAP object to *.nmap* file is for debugging purpose only and is not required for operation as the OBU is always receiving the up-to-date MAP from RSUs. Determination of outside-communication-range MAP objects is based on the timestamp when the last MAP message was received. For example, not-receiving MAP from an intersection for more than 5 seconds[2] is an indication that the intersection is outside OBU's communication range.

## 1.3 Document Organization

- Section 1.4 describes the structure of *.payload* file;
- Section 1.5 presents the specification of *.nmap* file;
- Section 1.6 depicts the intended operating system for MEL;
- Section 2 defines the requirements on MEL;
- Section 3 describes the verification procedures and results;
- Appendix A to Appendix G provide supporting materials to Section 1 to 3; and
- Appendix H discusses few difficult scenarios when creating intersection MAP.

## 1.4 Format of *.payload* File

The *.payload* file shall have the following format:

*payload intersection-name encode-map-payload-in-hex-string*

Each MAP payload is input as a single line. The String *payload* serves as the keyword to indicate this line is an input for an encoded MAP payload. *intersection-name* is a String type and should not contain any white spaces. The encoded MAP payload follows the *intersection-name* and is represented as hex String.

The *.payload* file may contain MAP payload of multiple intersections. Each intersection MAP payload should have the same format as described above, i.e.,

*payload intersection-name-1 encode-map-payload-in-hex-string*

[2] The age of a MAP can be configured.

*payload intersection-name-2 encode-map-payload-in-hex-string*

*…*

An example intersection *.payload* file is provided in Appendix B.

## 1.5 Specification of *.nmap* File

Intersection *.nmap* files are a set of critical inputs provided by MMITSS implementers/users. In MMITSS Phase I and II, specification of *.nmap* file was based on the DARPA Grand Challenge *.rndf* file format and was also adopted in Battelle's version of the MAP message (SAE J2735-200911 standard)[3].

When upgrading to SAE J2735-201603 standard, the format of *.nmap* file was modified to reflect the changes in SAE J2735 MAP message. The modifications include:

- Added *Regional ID*;
- Added *Speed Limit*; and
- Modified the coding of *Intersection Attributes* (8-bits String) and *Lane Attributes* (16-bits String) to capture SAE J2735-201603 MAP *LaneAttributes* and *AllowedManeuvers*. This makes these attributes more readable by a human.

See Appendix C for more information regarding the *.nmap* file structure that was used in MMITSS Phase II (SAE J2735-200911) and the updated version for SAE J2735-201603 standard.

In the development of this specification, the MMITSS team realized there is a need for further simplifying the format of *.nmap* file and to remove complexities which could lead to user input errors. The identified modifications include:

- Remove unnecessary data fields such as *RSU ID;*
- Replace complex data fields such as *Intersection Attributes* (8-bits String) and *Lane Attributes* (16-bits String) with more specific data fields such as *With Elevation*, *Lane Use*, *Lane Rules*, etc.;
- Remove manual ordering of *Lanes* (e.g., *Number of Lanes* and *Lane ID*) and *nodes* (e.g., *Number of Nodes* and *Node Sequence*), which can lead to input errors, particularly when adding or removing lanes and/or nodes;
- Use String input variables as much as possible rather than using Integer code, e.g., *leftTurn* rather than *2* for left-turn maneuver at the stop bar; and
- Remove the unnecessary *End-of-Lane* and *End-of-Approach* tags.

The current version of *.nmap* file structure is provided in Appendix D, together with a comparison with MMITSS required MAP data elements. Note that the current version is an updated version of that is included in MMITSS Development Plan dated September 15, 2018.

## 1.6 Operating System

The same MEL class should be able to be built and used on both the MRP computer and OBU. The MRP is a stand-alone Linux-like computer and the vendor specific OBU a vendor developed

[3] Battelle Memorial Institute, Signal Phase and Timing and Related Message Binary Format (BLOB) Details, Rev. c, 2012

SDK (Software Development Kit) that is required to compile the MEL. Different OBU vendors have different versions of SDK. Since both AZ and CA utilize Savari OBUs, the development of MEL focuses on Ubuntu (MRP) and Savari OBU. The MEL implementation might be able to work with OBUs from other vendors, however, the development of MEL to work with other vendors' OBU is out of scope of this task. Table 1 lists the requirement on operating system.

Table 1: Requirement on Operating System

| Device | Operating System | Version | Note |
|---|---|---|---|
| **MRP Computer** | Ubuntu | 16.04 or later | As of September 2018, the latest Ubuntu is version 18.04. |
| **Savari OBU** | Embedded Linux | 5.10 or later | |

# 2 Requirements

This section contains the requirements for MAP Engine Library (MEL). Requirements listed in this section use the following terminology:

- SHALL: Indicate that the definition is an absolute requirement of the specification.
- SHOULD: Indicates the definition is non-mandatory but recommended.
- MAY: Indicates that an item is truly optional.

Table 2: List of Requirements for MAP Engine Library

| Req. ID | Category | Description | Apply To | Verification Method |
|---|---|---|---|---|
| **MEL-Req-001** | Operating System | The MEL SHALL be able to be built on Ubuntu 16.04 or later. | MRP | Test |
| **MEL-Req-002** | Operating System | The MEL SHALL be able to be built on a Savari OBU with firmware 5.10 or later. | OBU | Test |
| **MEL-Req-003** | Initialization | The MEL SHALL be initialized by reading a *.payload* file that contains the MAP payload.<br>Note: Section 1.4 contains the format of *.payload* file. The encoded MAP payload should contain MMITSS required MAP data elements as described in Appendix A. | MRP | Test |
| **MEL-Req-004** | Initialization | The MEL SHALL be initialized by reading a *.nmap* file that contains intersection geographic information.<br>Note: Appendix D contains format of *.nmap* file. | MRP | Test |
| **MEL-Req-005** | Initialization | The MEL SHALL be able to initialize without using either a *.payload* or *.nmap* file. | OBU | Test |
| **MEL-Req-006** | Initialization | The MEL MAY be initialized by reading a *.payload* or *.nmap* file.<br>See Note in MEL-Req-003 and MEL-Req-004. | OBU | Test |
| **MEL-Req-007** | Functional | When provided with a received over-the-air MAP payload, the MEL SHALL determine if it is a new MAP or a repeat MAP that is already contained in its management list. | OBU | Test |

| | | | | |
|---|---|---|---|---|
| **MEL-Req-008** | Functional | The MEL SHALL add new MAP object to its management list. | OBU | Test |
| **MEL-Req-009** | Functional | The MEL MAY provide the option of saving new MAP object into *.nmap* file under specified directory.<br>Note: to be used only in debug mode. | OBU | Test |
| **MEL-Req-010** | Functional | The MEL SHOULD determine if a MAP object contained in its management list is outside OBU's DSRC communication range and remove outside-communication-range MAP objects from the management list. | OBU | Test |
| **MEL-Req-011** | Interface | The MEL SHALL accept vehicle location input in the form of either a BSM or a MMITSS internal GPS data object which include, at a minimum, latitude, longitude, altitude, speed, and heading.<br>Note: The MMITSS internal GPS data object (e.g. *bsm_t*) is defined in *MMITSScommon.h*. | MRP and OBU | Test |
| **MEL-Req-012** | Functional | When provided with vehicle location input, the MEL SHALL determine if the vehicle is within the coverage of a MAP on its management list.<br>Note: On OBU, the vehicle could be within the coverage of multiple MAPs. | MRP and OBU | Test |
| **MEL-Req-013** | Functional | For a MAP that the vehicle is within its coverage, the MEL SHALL determine vehicle's lane of travel. In case of multiple MAPs, the MEL SHALL determine the MAP that the vehicle is on an inbound lane. | MRP and OBU | Test |
| **MEL-Req-014** | Functional | For an inbound lane, the MEL SHALL determine the distance from the vehicle to the stop bar. | MRP and OBU | Test |
| **MEL-Req-015** | Functional | For an outbound lane, the MEL SHALL determine the distance from the exit bar to the vehicle. | MRP and OBU | Test |
| **MEL-Req-016** | Interface | When provided with vehicle location input, the MEL SHALL return the result of locating the vehicle on MAP. The result should include, at a minimum, regional ID, intersection ID, lane ID, approach type (inbound or outbound), and distance to/from stop-bar/exit-bar. | MRP and OBU | Test |
| **MEL-Req-017** | Interface | When provided with intersection name or ID, the MEL SHALL return the encoded MAP payload of the acquired intersection. | MRP | Test |
| **MEL-Req-018** | Interface | When provided with regional ID, intersection ID, and (inbound) lane ID, the MEL SHELL return the signal group ID that controls the lane movement at the stop bar. | MRP and OBU | Test |

| | | | | |
|---|---|---|---|---|
| **MEL-Req-019** | Interface | When provided with regional ID, intersection ID, and (inbound) lane ID, the MEL SHELL return the allowed maneuvers at the stop bar. | MRP and OBU | Test |
| **MEL-Req-020** | Interface | When provided with regional ID, intersection ID, and lane ID, the MEL SHELL return the speed limit for the acquired lane. | MRP and OBU | Test |

# 3 Verification

This section describes the procedures and outcomes of verification tests of requirements listed in Table 2. Note that the verification and validation of MAP accuracy are out of the scope of this task.

## 3.1 Test Environment

The verification tests were conducted in a lab testing environment and in the CA Palo Alto test bed. Requirements that do not require transmitting and receiving of over-the-air DSRC messages were tested in the lab environment.

### 3.1.1 Lab Testing Environment

The Lab testing environment consists of

- An MRP computer installed with Ubuntu 18.04 LTS and Savari SDK version 5.10; and
- A Savari MW-1000 OBU.

### 3.1.2 Test Bed Testing Environment

The CA Palo Alto test bed consists of

- Eleven (11) MRP computers installed with Ubuntu 18.04 LTS;
- Eleven (11) v4.1 Savari SW-1000 RSUs;
- One Savari MW-1000 OBU;
- A *msgTransceiver* application running on RSU and OBU for transmitting and receiving over-the-air DSRC messages; and
- A SAE J2735-201603 Message Library for encoding and decoding DSRC messages.

Note that under Task 3.1 – Update to the SAE J2735 2016 Standard and Task 3.4 – Develop an API Specification for an RSU Deployed Message Transceiver, the MMITSS team is developing a common SAE 2735 Message Library and an API specification for a *msgTransceiver* application that runs on the MRP computer. The use of the intermediate SAE J2735 Message Library and *msgTransceiver* application is appropriate as the MEL functionality is independent of how the over-the-air DSRC messages are encoded and decoded and how the messages are transmitted and received over-the-air.

## 3.2 Verification of Requirements on Operating System

Two (2) requirements fall into this category: *MEL-Req-001* and *MEL-Req-002*. The verification tests were conducted in the lab testing environment with the following procedure:

Step 1. Compile the MEL source code on the MRP computer with Ubuntu 18.04 C++ compiler and verify the MEL library file is successfully created.
Step 2. Compile the MEL source code on the MRP computer with Savari SDK toolchains and verify the MEL library file is successfully created.
Step 3. Copy the MEL library file to Savari OBU and verify the OBU File System recognize the library file.

Outcome of the verification tests is listed in Table 3. The created MEL library file for MRP and OBU are used for the rest of verification tests described in this section.

Table 3: Verification Test of Requirements on Operating System

| Req. ID | Category | Apply To | Verification Method | Verification Environment | Verification Outcome |
|---|---|---|---|---|---|
| MEL-Req-001 | Operating System | MRP | Test | Lab Testing | Passed |
| MEL-Req-002 | Operating System | OBU | Test | Lab Testing | Passed |

## 3.3 Verification of Requirements on Initialization of MAP Library Class

Six (6) requirements fall into this category: *MEL-Req-003* to *MEL-Req-006*, *MEL-Req-009* and *MEL-Req-017*. The verification tests were conducted in the lab testing environment. Intersection *.nmap* files of CA Palo Alto test bed were used as inputs to the verification tests. If interested, use link http://caconnectedvehicletestbed.org/index.php/datasample.php to download the PDF version of intersection *.nmap* files from CA Test Bed website.

Using the intersection of Page Mill Road at EL Camino Real as an example, *ecr-page-mill.nmap* file is included in Appendix E. *ecr-page-mill.payload* file is created from *ecr-page-mill.nmap* and is included in Appendix B. The verification procedure is as follows:

Step 1. On MRP, initiate the MEL class by reading *ecr-page-mill.payload* file. The MEL will call the SAE J2735 Message Library to decode the MAP payload and add the MAP object to its management list.
Step 2. On MRP, save the MAP object loaded to the management list into *ecr-page-mill-out.nmap* file and compare it with the original *ecr-page-mill.nmap* file ➔verification of *MEL-Req-003*.
Step 3. On MRP, initiate the MEL class by reading *ecr-page-mill.nmap* file. The MEL will encode the MAP and add the MAP object to its management list.
Step 4. Repeat Step 2 above ➔ verification of *MEL-Req-004*.
Step 5. On MRP, acquire the MAP payload of *ecr-page-mill*, log the returned MAP payload to *ecr-page-mill-out.payload* file, and compare it with *ecr-page-mill.payload* file ➔ verification of *MEL-Req-017*.
Step 6. On OBU, repeat Step 1 to Step 4 above ➔ verification of *MEL-Req-006* and *MEL-Req-009*.
Step 7. On OBU, initiate the MEL class without any input argument. The MEL should be initiated with an empty management list.
Step 8. On OBU, print the size of the management list and verify the size is zero ➔ verification of *MEL-Req-005*.

Outcomes of the verification tests using *ecr-page-mill.nmap* and *ecr-page-mill.payload* as inputs:

- Output *ecr-page-mill-out.payload* file created at Step 5 is identical to *ecr-page-mill.payload* file as expected;
- Output *ecr-page-mill-out.nmap* file created at Step 4 is identical to *ecr-page-mill.nmap* file as expected;
- Output *ecr-page-mill-out.nmap* file created at Step 2 has twenty-one (21) way-point longitude different from that of *ecr-page-mill.nmap* file on the 7th digit after the decimal (i.e., 1/10th micro degree precision). The total number of way-points is 151;
- Outputs created at Step 6 on OBU are identical to the that created on MRP; and
- Size of management list output at Step 8 is zero (0) as expected.

Output *ecr-page-mill-out.nmap* file created at Step 2 is included in Appendix F, with differences from *ecr-page-mill.nmap* file marked in dark color. The difference on the 7th digit after the decimal is introduced by coordinate conversion:

- When encoding MAP payload from *ecr-page-mill.nmap* file, way-point latitude and longitude are converted to local X-Y coordinates w.r.t the intersection reference point; and
- When saving MAP object created based on MAP payload, the local X-Y coordinates are converted to global latitude and longitude.

Since the difference of 1/10th micro degree in longitude only produces a distance error that is less than 1 cm, Output *ecr-page-mill-out.nmap* file created at Step 2 is considered the same as *ecr-page-mill.nmap* file.

The above verification procedure was repeated from every intersection at the CA Palo Alto test bed, and the verification test passed for every intersection. Table 4 summarizes the verification test results.

Table 4: Verification Test of Requirements on Initialization of MAP Engine Library Class

| Req. ID | Category | Apply To | Verification Method | Verification Environment | Verification Outcome |
|---|---|---|---|---|---|
| **MEL-Req-003** | Initialization | MRP | Test | Lab Testing | Passed |
| **MEL-Req-004** | Initialization | MRP | Test | Lab Testing | Passed |
| **MEL-Req-005** | Initialization | OBU | Test | Lab Testing | Passed |
| **MEL-Req-006** | Initialization | OBU | Test | Lab Testing | Passed |
| **MEL-Req-009** | Interface | OBU | Test | Lab Testing | Passed |
| **MEL-Req-017** | Interface | MRP | Test | Lab Testing | Passed |

## 3.4 Verification of Requirements on Locating a Vehicle on MAP

Nine (9) requirements fall into this category: *MEL-Req-011* to *MEL-Req-016* and *MEL-Req-018* to *MEL-Req-020*. The verification tests were conducted in the lab testing environment. GPS trace data (timestamp, latitude, longitude, altitude, speed, and heading) along the CA Palo Alto test bed were logged into data file with the Savari OBU. The recorded GPS trace file was used as input for the verification tests.

The verification procedure is as follows:

Step 1. On MRP, initiate the MEL class by reading *.payload* file of all the eleven (11) intersections. The MEL will add the 11 MAP objects to its management list.

Step 2. On MRP, use a test program to read the GPS trace file line-by-line (each line corresponds to one GPS measurement), call MEL's locating a vehicle on MAP functions using the GPS measurement as input, and log MEL returned results into an output file.
Step 3. Plot the output results with MATLAB.
Step 4. Repeat Step 1 to Step 3 on OBU.

Detailed verification results are presented in Appendix G. *MEL-Req-011* needs to further vitrificated using SAE J2735 BSM as input. Since BSM include all the GPS measurement (latitude, longitude, altitude, speed, and heading), using BSM as input for locating a vehicle on MAP functions does not affect the verification results of other requirements in this category.

Table 5: Verification Test of Requirements on Locating a Vehicle on MAP

| Req. ID | Category | Apply To | Verification Method | Verification Environment | Verification Outcome |
|---|---|---|---|---|---|
| MEL-Req-011 | Interface | MRP and OBU | Test | Lab Testing | Passed using GPS measurement as input |
| MEL-Req-012 | Functional | MRP and OBU | Test | Lab Testing | Passed |
| MEL-Req-013 | Functional | MRP and OBU | Test | Lab Testing | Passed |
| MEL-Req-014 | Functional | MRP and OBU | Test | Lab Testing | Passed |
| MEL-Req-015 | Functional | MRP and OBU | Test | Lab Testing | Passed |
| MEL-Req-016 | Interface | MRP and OBU | Test | Lab Testing | Passed |
| MEL-Req-018 | Interface | MRP and OBU | Test | Lab Testing | Passed |
| MEL-Req-019 | Interface | MRP and OBU | Test | Lab Testing | Passed |
| MEL-Req-020 | Interface | MRP and OBU | Test | Lab Testing | Passed |

## 3.5 Verification of Requirements on Managing the Management List

The remaining three requirements fall into this category: *MEL-Req-007*, *MEL-Req-008*, and *MEL-Req-010*. Verification of these 3 requirements requires DSRC communication between the OBU and RSUs and is currently on-going.

The verification procedure is as follows:

Step 1. On OBU, initiate the MEL class without any input argument. The MEL class should be initiated with an empty management list.
Step 2. Drive along the CA Palo Alto test bed and log the size of the management list and intersections from which the OBU is receiving MAP into a data file.
Step 3. Plot the output results with MATLAB.

Table 6: Verification Test of Requirements on Managing the Management List

| Req. ID | Category | Apply To | Verification Method | Verification Environment | Verification Outcome |
|---|---|---|---|---|---|
| MEL-Req-007 | Functional | OBU | Test | Lab Testing | On-going |
| MEL-Req-008 | Functional | OBU | Test | Lab Testing | On-going |
| MEL-Req-010 | Functional | OBU | Test | Lab Testing | On-going |

# Appendix A MMITSS Required MAP Data Elements

Figure A-1 illustrates MMITSS required MAP data elements highlighting the purpose to include.

| MSG_MapData (MAP) | | SAE J2735-201603 | MMITSS Implementation | Purpose to Include |
|---|---|---|---|---|
| msgIssueRevision | MsgCount (DE) | Required | Required | |
| layerType | LayerType (DE) | Optional | Required | Specify this is intersectionData |
| intersections | IntersectionGeometryList (DF) | Optional | Required | |
| IntersectionGeometry (DF) | | | | |
| id | IntersectionReferenceID (DF) | Required | Required | |
| region | RoadRegulatorID (DE) | Optional | Required | For compatibility across regions |
| id | IntersectionID (DE) | Required | Required | |
| revision | MsgCount (DE) | Required | Required | |
| refPoint | Position3D (DF) | Required | Required | |
| lat | Latitude (DE) | Required | Required | |
| long | Longitude (DE) | Required | Required | |
| laneWidth | LaneWidth (DE) | Optional | Required | For geo-fencing |
| speedLimits | SpeedLimitList (DF) | Optional | Required | Specify regulatory speed limit |
| laneSet | LaneList (DF) | Required | Required | |
| GenericLane (DF) | | | | |
| laneID | LaneID (DE) | Required | Required | |
| ingressApproach | ApproachID (DE) | Optional | Required | For grouping vehicles on the same approach |
| egressApproach | ApproachID (DE) | Optional | Required | |
| laneAttributes | LaneAttributes (DF) | Required | Required | |
| maneuvers | AllowedManeuvers (DE) | Optional | Required | For generating SRM |
| nodeList | NodeListXY (DF) | Required | Required | |
| delta | NodeOffsetPointXY (DF) | Required | Required | |
| attributes | NodeAttributeSetXY (DF) | Optional | Optional | |
| connectsTo | ConnectsToList (DF) | Optional | Required | For associating with SPaT data |
| Connection (DF) | | | | |
| connectingLane | ConnectingLane (DF) | Required | Required | |
| lane | LaneID (DE) | Required | Required | |
| maneuver | AllowedManeuvers (DE) | Optional | Required | For generating SRM |
| remoteIntersection | IntersectionReferenceID (DF) | Optional | Required | For connecting to the next intersection |
| signalGroup | SignalGroupID (DE) | Optional | Required | For associating with SPaT data |

Figure A-1: MMITSS Required MAP Data Elements

# Appendix B Example *.payload* File

Figure B-1 illustrates the *ecr-page-mill.payload* file for Page Mill Road at EL Camino Real, Palo Alto, CA.

```
payload ecr-page-mill
  0012847C28093099000003F000A5F99BA5913E366E0832014A028C3878B0045000000A40041C6373983B916998761FB
  9D12EC0D9B495F3E0464AD53136148AC000224748001 0B00850000008000041CAB323C3B6A68B876D1BEE12DC9D34896
  4F62824ADDF122048B4000216018A0000008000239F9E150771CD638AB42E08121C8000E58082800000280012E9BF79
  60478876D8D498EB3F82025B7BA718A4144001D21E8000E300A4400000400010EF6D58C25AB9A1416483A6D98B25953
  926300C4400000400010ED1566B25A019F51647626BECB255F3840580E6800000520010F228FED1F2BCF264E6C4F052
  5DEAAEB8A4148001923B0000C581068000004000010F122ED31F3B4EB44E2F8F7F25E96AB50247A00018B024D0000008
  00021DF95BBC3E671DC49C6C1E5A4BDD1575048FC000316051A000000800022F1E4AB1F35CED44E188FC0048AA00009
  6059A000000A0002AE9138A047887D2D3A2932C34CB8521E200029164000110C0C42000002008047 2F810F0B4F1CB87A
  8261780436000703508000008000021D190EBE4B94961C2622EA679359B4874221F001000003F11C0E42000002000087
  50346A92EE6585C9842A92C4D5ED25F0888400400000FC4703D0800000800021D6493D64BBF960526116A5993563497
  822230010000003F12C10540000008000D716E0FD0243C344422FC8B13A5A243D8487E21BC24470243080020B0455000
  000800035B85CBDC090F0CEEE38A1A440A3E43F3C87C21B643DB824160002 0B0495000000800035B36CD88090F0CF6A
  3BA1A2A0A0C4412C8A321B503EB0241A00020B04D5000000400021AF30F7A33DF8F2868852741 12232DA0123C800065
  828A8000002800 10D5A283D19F30884344012DC8AE121AC2916100034 8FA00018C0AB100000100008B3D8A8F4121E19
  F88954341C14948B74A568345794D887B08D72302CC400000400022D1D49750487868032 2A0CFFC4DA19BA864A34889
  6EC87890CAE582EE800000120008CA6D098223DF4770CCC9729048A9000116 0C3A000001 0000632FEC5B088EE51C432
  D8598484135F1843D06B550486C0001160CBA000001000063340499089 45D1C832A25988841CDF0E43DFAB890487400
  01160D3A000001 0000633B44D788901528A32C9D8B084135EFA43DF6BB20487C0001160DBA000000800043419524C62
  9FC600CF13517216296BD0241500014B071D000000500025A3AAAFE08F10C73F81E19222E784487E8C8148320002A47
  C400147076080000080003 1AEDB222444169AB21A6761E910A7A72087ADD54A1105800800001F78E0F4100000100006
  357ADFC4889A536643286C31222C14B210F2FAAD4220D001000003EF1C1F820000020000C6A34B791114FA6D0863257
  FC4468694821E2157C0441E002000007DE4400000FC00A97E66E9644F8D9B820C805280C908258002 0C000237346ED4
  76A45760B0755BC52424000C923400062421A60008340010F2A116612228F58908057451147B8292040008491100041
  2115B00041A0008723F04509DDB09068ACA5708DD2A74524280004923200022423C60008300008C918EFF1D636DCA2C
  4FDD1149010002248900010 0
```

Figure B-1: Example *.payload* File (Page Mill Road at EL Camino Real, Palo Alto, CA)

USDOT's Message Validator tool[4] can be utilized to verify if MMITSS required MAP data elements are included in the encoded MAP payload.

[4] USDOT Connected Vehicle Message Validator. https://webapp2.connectedvcs.com/validator/

# Appendix C Format of *.nmap* File (Previous Versions)

Figure C-1 illustrates the format of *.nmap* file that was used in MMITSS Phase II with SAE J2735-200911 standard[5].

```
MAP_Name          Intersection_Name.nmap
RSU_ID            Intersection_Name
MAP_Version       xxx
IntersectionID    xxxx
Intersection_attributes xxxxxxxx  /*Attributes of the intersection, 8 bits */
Reference_point xx.xxxxxxx  xxx.xxxxxxx xxxx   /*lat, long, evelation(decimeter)*/
No_Approach       xx  /*number of approaches*/
Approach          1
Approach_type     x  /*1: approach, 2: engress, 3: barrier, 4: crosswalk*/
No_lane           x
Lane              1.1 x /*x - the signal phase that controls the lane movement*/
Lane_ID           1
Lane_type         x     /* Veh Lane, Computed Lane, Ped Lane, Special Lane, Barrier*/
Lane_attributes xxxxxxxxxxxxxxxx  /*Attributes of the lane, 16 bits*/
Lane_width        xxx   /*in centimeters */
No_nodes          x     /*number of lane nodes*/
1.1.1      xx.xxxxxxx    xxx.xxxxxxx  /*latitude longitude*/
1.1.2      xx.xxxxxxx    xxx.xxxxxxx
……
No_Conn_lane      x     /*connection lanes*/
x.xx
x.xx
end_lane
Lane              1.2 x /*x - the signal phase that controls the lane movement*/
……
end_lane
end_approach
Approach          2
……
end_approach
end_map
```

Figure C-1: Specification of *.nmap* File used in MMITSS Phase II (SAE J2735-200911)

[5] MMITSS-CA Detailed System and Software Design. Available at http://www.cts.virginia.edu/wp-content/uploads/2014/04/32-MMITSS-Phase-2-Detailed-Design-CA-final.pdf.

Figure C-2 illustrates the updated format of *.nmap* file that works with SAE J2735-201603 MAP.

```
MAP_Name        Intersection_Name.nmap
RSU_ID          Intersection_Name
MAP_Version     xxx
RegionalID      regionalID
IntersectionID  intersectionID
Intersection_attributes xxxxxxxx   /*attributes of the intersection, 8 bits*/
Reference_point xx.xxxxxxx  xxx.xxxxxxx xxxx   /*lat, long, evelation(in meter)*/
No Approach     xx     /*number of approaches (1 to 8 for traffic lanes, 9 to 12 for crosswalk*/
Approach        approachID  /*1 to num_approaches*/
Approach_type   x      /*1: approach, 2: engress, 3: barrier, 4: crosswalk*/
Speed_limit     x      /* in mph */
No_lane         x      /*number of traffic lanes or crosswalk on the approach*/
Lane            approachID.laneID x /*the signal phase that controls the lane movement*/
Lane_ID         laneID /*1 to num_lanes*/
Lane_type       x      /* Veh Lane, Computed Lane, Ped Lane, Special Lane, Barrier*/
Lane_attributes xxxxxxxxxxxxxxxx  /*Attributes of the lane, 16 bits*/
Lane_width      xxx    /*in centimeters */
No_nodes        x      /*number of nodes or waypoints on lane*/
approachID.laneID.nodeSeqence xx.xxxxxxx xxx.xxxxxxx  /*latitude longitude*/
......                 /*repeat for nodeSequency: 1 to num_nodes*/
No_Conn_lane    x      /*connection lanes*/
regionalID.intersectionID.approachID.laneID x  /*x is the connecting manuever*/
......                 /*repeat for 1 to num_conn_lanes/
end_lane
Lane            approachID.laneID x /*repeat for laneID 1 to num_lanes*/
......
end_lane
end_approach
Approach        approachID   /*repeat for approachID 1 to num_approaches*/
......
end_approach
end_map
```

Figure C-2: Specification of .nmap File for SAE J2735-201603 MAP (Intermediate Version)

# Appendix D Format of *.nmap* File (Final Version)

```
MAP_Name          IntersectionName       /* STRING                */
MAP_Version       verNum                 /* INTEGER, 0 - 127      */
RegionalID        regionalID             /* INTEGER, 0 - 65535    */
IntersectionID    intersectionID         /* INTEGER, 0 - 65535    */
WithElevation     withElevation          /* STRING, choice of "yes", "no". If "yes", include elevation in ref_point */
Reference_point   latitude longitude elevation
                                         /* latitude & longitude in degree, elevation in meter. */
ApproachID        approachID             /* INTEGER, 1 - 15. Start at west-inbound approach and move clockwise to
                                            north-outbound approach */
  Approach_type   approachType           /* STRING, choice of "inbound", "outbound", and "crosswalk" */
  Speed_limit     speedLimit             /* INTEGER, in mph. Set to 0 for crosswalks */
  Lane_seq        laneSeq                /* INTEGER, start from the curb lane (1) increasing towards the center of road */
    Lane_type     laneType               /* STRING, choice of "traffic" and "crosswalk" */
    Lane_phaseNo  lanePhase              /* INTEGER, 1 - 8, the signal phase that controls the lane movement.
                                            Set to 0 for outbound lanes */
    Lane_width    laneWidth              /* INTEGER, in centimeters */
    Lane_Use
      laneUseRestriction                 /* STRING. For traffic lane, choice of "flyOverLane", "hovOnly", busOnly", "TaxiOnly",
                                              "private", "hasIRbeaconCoverage".
                                            For crosswalk, choice of "flyOverLane", "bicyleUseAllowed", "hasPushButton",
                                              "pedRecallOn", "audioSupport", "unsignalizedSegmentsPresent"          */
      ......                             /* One restriction per row. Can skip LaneUse / EndLaneUse if no restrictions apply */
    End_LaneUse
    Lane_Rules
      laneRule                           /* STRING, apply to traffic lane only. Choice of "leftTurnOnRedAllowed",
                                            "rightTurnOnRedAllowed", "laneChangeAllowed", "noStopping", "yield",
                                            "goWithHalt", "caution"                                          */
      ......                             /* One rule per row. Can skip LaneRules / EndLaneRules if no rules apply */
    End_LaneRules
    Lane_Nodes                           /* Number of nodes should be between 2 and 63     */
      latitude longitude                 /* latitude longitude in degree, one node per row */
      ......                             /* Repeat for all nodes, start at the stop-line and move away from the intersection */
    End_Nodes
    Lane_ConnectsTo                      /* Number of Connecting lanes should be between 1 - 16 */
      regionalID.intersectionID.approachID.laneSeq connManeuver
                                         /* connManeuver: STRING, choice of "uTurn", "leftTurn", "rightTurn", and
                                           "straightAhead" */
      ......                             /* Repeat for all connecting lanes, one connecting lane per row. */
    End_LaneConnectsTo
  Lane_seq        laneSeq                /* Repeat for all lanes on the approach */
  ......
ApproachID        approachID             /* Repeat for all approaches at the intersection */
......
End_MAP
```

Figure D-1: Specification of .nmap File for SAE J2735-201603 MAP (Final Version)

Figure D-2 compares the final *.nmap* file structure with MMITSS required MAP data elements described in Figure A-1.

| Format of Intersection Geographic Description (.nmap) File | | Corresponding Data in SAE J2735-201603 MAP | |
|---|---|---|---|
| **Keyword** | **Value** | | |
| MAP_Name | Intersection Name (STRING) | | |
| MAP_Version | MAP version No (INTEGER) | msgIssueRevision | MsgCount (DE) |
| RegionalID | regionalID (INTEGER) | region | RoadRegulatorID (DE) |
| IntersectionID | intersectionID (INTEGER) | id | IntersectionID (DE) |
| WithElevation | STRING, choice of "yes" or "no".<br>When "yes", elevation is required in Reference_point. | | |
| Reference_point | latitude longitude elevation (optional) | refPoint | Position3D (DF) |
| ApproachID | approachID (INTEGER) | ingressApproach | ApproachID (DE) |
| Approach_type | STRING, choice of "inbound", "outbound", or "crosswalk". | egressApproach | ApproachID (DE) |
| Speed_limit | Speed limit in MPH (INTEGER) | speedLimits | SpeedLimitList (DF) |
| Lane_seq | Lane sequence number (of the current approach) (INTEGER) | laneID | LaneID (DE) |
| Lane_phaseNo | Signal phase number that controls the lane movement (INTEGER) | signalGroup | SignalGroupID (DE) |
| Lane_type | STRING, choice of "traffic" and "crosswalk" | laneAttributes | LaneAttributes (DF) |
| Lane_Use | STRING | | |
| | Choice of "flyOverLane", "hovOnly", busOnly", "TaxiOnly", etc. | | |
| Lane_Rules | STRING | maneuvers | AllowedManeuvers (DE) |
| | Chioce of "leftTurnOnRedAllowed", "rightTurnOnRedAllowed", etc. | | |
| Lane_width | Lane width in centimeter (INTEGER) | laneWidth | LaneWidth (DE) |
| Lane_Nodes | | nodeList | NodeListXY (DF) |
| | latitude longitude (repeat for all nodes on the current lane) | | |
| Lane_ConnectsTo | | connectsTo | ConnectsToList (DF) |
| | regionalID.intersectionID.approachID.laneSeq connManeuver<br>connManeuver - STRING, choice of "uTurn", "leftTurn", "rightTurn", and "straightAhead". (repeat for all connecting lanes) | | |
| Lane_seq | Repeat for all lanes of the current approach | laneSet | LaneList |
| ApproachID | Repeat for all approaches of the current intersection | | |
| End_MAP | Tag to identify the end of a MAP structure | | |

Figure D-2: Comparison of *.nmap* File with MMITSS Required MAP Data Elements

# Appendix E Example *.nmap* File

The example *ecr-page-mill.nmap* file is for the intersection of Page Mill Road at EL Camino Real, Palo Alto, CA. The PDF version of *ecr-page-mill.nmap* file can be downloaded from http://caconnectedvehicletestbed.org/index.php/datasample.php.

```
MAP_Name ecr-page-mill
MAP_Version 9
RegionalID 0
IntersectionID 1008
WithElevation yes
Reference_point 37.4230603  -122.1420323  10.0
ApproachID 1
  Approach_type inbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 4
    Lane_width 330
    Lane_Rules
      rightTurnOnRedAllowed
    End_LaneRules
    Lane_Nodes
      37.4232863  -122.1419874
      37.4235261  -122.1417812
      37.4236928  -122.1416041
      37.4242101  -122.1411775
      37.4245823  -122.1408333
      37.4249793  -122.1405057
    End_Nodes
    Lane_ConnectsTo
      0.1008.6.1 straightAhead
      0.1008.8.1 rightTurn
    End_LaneConnectsTo
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 4
    Lane_width 330
    Lane_Nodes
      37.4232706  -122.1419550
      37.4235054  -122.1417576
      37.4236867  -122.1415604
      37.4241669  -122.1411617
      37.4245649  -122.1407968
      37.4249601  -122.1404652
    End_Nodes
    Lane_ConnectsTo
      0.1008.6.2 straightAhead
    End_LaneConnectsTo
  Lane_seq 3
    Lane_type traffic
    Lane_phaseNo 7
    Lane_width 330
    Lane_Nodes
      37.4232524  -122.1419181
      37.4235010  -122.1417125
      37.4235819  -122.1416311
    End_Nodes
    Lane_ConnectsTo
      0.1008.4.3 leftTurn
    End_LaneConnectsTo
  Lane_seq 4
    Lane_type traffic
    Lane_phaseNo 7
    Lane_width 300
    Lane_Nodes
```

```
      37.4232353  -122.1418914
      37.4234792  -122.1416935
      37.4236666  -122.1415309
      37.4241484  -122.1411336
    End_Nodes
    Lane_ConnectsTo
      0.1008.2.1 uTurn
      0.1008.4.4 leftTurn
    End_LaneConnectsTo
ApproachID 2
  Approach_type outbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4231882  -122.1418093
      37.4236532  -122.1414229
      37.4242851  -122.1409007
      37.4249442  -122.1403573
    End_Nodes
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4232083  -122.1418432
      37.4236677  -122.1414672
      37.4242900  -122.1409511
      37.4249387  -122.1404108
    End_Nodes
ApproachID 3
  Approach_type inbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 6
    Lane_width 330
    Lane_Rules
      rightTurnOnRedAllowed
    End_LaneRules
    Lane_Nodes
      37.4230586  -122.1417698
      37.4228642  -122.1414029
      37.4224726  -122.1406599
      37.4222382  -122.1402273
    End_Nodes
    Lane_ConnectsTo
      0.1008.2.1 rightTurn
      0.1008.8.1 straightAhead
    End_LaneConnectsTo
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 6
    Lane_width 330
    Lane_Nodes
      37.4230332  -122.1417846
      37.4228337  -122.1414107
      37.4224530  -122.1406951
      37.4222088  -122.1402529
    End_Nodes
    Lane_ConnectsTo
      0.1008.8.2 straightAhead
    End_LaneConnectsTo
  Lane_seq 3
    Lane_type traffic
    Lane_phaseNo 6
    Lane_width 330
```

```
    Lane_Nodes
      37.4230111  -122.1418040
      37.4228137  -122.1414337
      37.4224256  -122.1407152
      37.4221824  -122.1402682
    End_Nodes
    Lane_ConnectsTo
      0.1008.8.3 straightAhead
    End_LaneConnectsTo
  Lane_seq 4
    Lane_type traffic
    Lane_phaseNo 1
    Lane_width 330
    Lane_Nodes
      37.4229834  -122.1418265
      37.4227854  -122.1414551
      37.4224106  -122.1407499
    End_Nodes
    Lane_ConnectsTo
      0.1008.6.1 leftTurn
    End_LaneConnectsTo
  Lane_seq 5
    Lane_type traffic
    Lane_phaseNo 1
    Lane_width 300
    Lane_Nodes
      37.4229574  -122.1418424
      37.4227560  -122.1414613
      37.4224603  -122.1409187
    End_Nodes
    Lane_ConnectsTo
      0.1008.4.4 uTurn
      0.1008.6.2 leftTurn
    End_LaneConnectsTo
ApproachID 4
  Approach_type outbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Rules
      caution
    End_LaneRules
    Lane_Nodes
      37.4227401  -122.1419464
      37.4227212  -122.1417950
      37.4226331  -122.1414912
    End_Nodes
    Lane_ConnectsTo
      0.1008.4.2 straightAhead
    End_LaneConnectsTo
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4228613  -122.1419053
      37.4226331  -122.1414912
      37.4223750  -122.1409969
      37.4220547  -122.1403721
    End_Nodes
    Lane_ConnectsTo
      0.1009.7.1 straightAhead
    End_LaneConnectsTo
  Lane_seq 3
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
```

```
    Lane_Nodes
      37.4228950  -122.1418874
      37.4226664  -122.1414565
      37.4224031  -122.1409787
      37.4220887  -122.1403575
    End_Nodes
    Lane_ConnectsTo
      0.1009.7.2 straightAhead
    End_LaneConnectsTo
  Lane_seq 4
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4229200  -122.1418712
      37.4226898  -122.1414376
      37.4224291  -122.1409592
      37.4221147  -122.1403407
    End_Nodes
    Lane_ConnectsTo
      0.1009.7.3 straightAhead
    End_LaneConnectsTo
ApproachID 5
  Approach_type inbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 8
    Lane_width 360
    Lane_Nodes
      37.4227368  -122.1419909
      37.4225695  -122.1422069
      37.4222654  -122.1424918
      37.4217232  -122.1429725
      37.4211824  -122.1434965
    End_Nodes
    Lane_ConnectsTo
      0.1008.4.1 rightTurn
    End_LaneConnectsTo
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 8
    Lane_width 360
    Lane_Nodes
      37.4228280  -122.1420876
      37.4225406  -122.1423344
      37.4222897  -122.1425350
      37.4217472  -122.1430033
      37.4211871  -122.1435327
    End_Nodes
    Lane_ConnectsTo
      0.1008.2.1 straightAhead
    End_LaneConnectsTo
  Lane_seq 3
    Lane_type traffic
    Lane_phaseNo 8
    Lane_width 360
    Lane_Nodes
      37.4228473  -122.1421233
      37.4225642  -122.1423631
      37.4223110  -122.1425755
      37.4217721  -122.1430297
      37.4212147  -122.1435602
    End_Nodes
    Lane_ConnectsTo
      0.1008.2.2 straightAhead
    End_LaneConnectsTo
  Lane_seq 4
    Lane_type traffic
```

```
    Lane_phaseNo 3
    Lane_width 330
    Lane_Nodes
      37.4228697  -122.1421539
      37.4225881  -122.1423926
      37.4223322  -122.1426089
      37.4218572  -122.1430099
    End_Nodes
    Lane_ConnectsTo
      0.1008.8.2 leftTurn
    End_LaneConnectsTo
  Lane_seq 5
    Lane_type traffic
    Lane_phaseNo 3
    Lane_width 330
    Lane_Nodes
      37.4228813  -122.1421822
      37.4226104  -122.1424195
      37.4223501  -122.1426364
      37.4220003  -122.1429326
    End_Nodes
    Lane_ConnectsTo
      0.1008.6.2 uTurn
      0.1008.8.3 leftTurn
    End_LaneConnectsTo
ApproachID 6
  Approach_type outbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 360
    Lane_Nodes
      37.4229274  -122.1422726
      37.4226659  -122.1425073
      37.4224155  -122.1427324
      37.4221088  -122.1429953
      37.4218600  -122.1432069
      37.4212769  -122.1436876
    End_Nodes
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 360
    Lane_Nodes
      37.4229094  -122.1422372
      37.4226402  -122.1424683
      37.4223830  -122.1426999
      37.4220865  -122.1429626
      37.4218496  -122.1431631
      37.4212577  -122.1436527
    End_Nodes
ApproachID 7
  Approach_type inbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 2
    Lane_width 330
    Lane_Rules
      rightTurnOnRedAllowed
    End_LaneRules
    Lane_Nodes
      37.4230740  -122.1423443
      37.4232800  -122.1427512
      37.4234451  -122.1430291
    End_Nodes
    Lane_ConnectsTo
      0.1008.6.1 rightTurn
```

```
  End_LaneConnectsTo
Lane_seq 2
  Lane_type traffic
  Lane_phaseNo 2
  Lane_width 330
  Lane_Nodes
    37.4230931  -122.1423219
    37.4232980  -122.1427308
    37.4234451  -122.1430291
    37.4238037  -122.1437189
    37.4240651  -122.1442032
  End_Nodes
  Lane_ConnectsTo
    0.1008.4.2 straightAhead
  End_LaneConnectsTo
Lane_seq 3
  Lane_type traffic
  Lane_phaseNo 2
  Lane_width 330
  Lane_Nodes
    37.4231154  -122.1423070
    37.4233205  -122.1426962
    37.4234677  -122.1430067
    37.4238259  -122.1436944
    37.4240919  -122.1441718
  End_Nodes
  Lane_ConnectsTo
    0.1008.4.3 straightAhead
  End_LaneConnectsTo
Lane_seq 4
  Lane_type traffic
  Lane_phaseNo 2
  Lane_width 330
  Lane_Nodes
    37.4231380  -122.1422808
    37.4233518  -122.1426855
    37.4234941  -122.1429870
    37.4238514  -122.1436769
    37.4241211  -122.1441544
  End_Nodes
  Lane_ConnectsTo
    0.1008.4.4 straightAhead
  End_LaneConnectsTo
Lane_seq 5
  Lane_type traffic
  Lane_phaseNo 5
  Lane_width 330
  Lane_Nodes
    37.4231658  -122.1422580
    37.4233676  -122.1426450
    37.4234850  -122.1428898
    37.4237959  -122.1434949
  End_Nodes
  Lane_ConnectsTo
    0.1008.2.1 leftTurn
  End_LaneConnectsTo
Lane_seq 6
  Lane_type traffic
  Lane_phaseNo 5
  Lane_width 300
  Lane_Nodes
    37.4231871  -122.1422372
    37.4233743  -122.1425952
    37.4235412  -122.1429269
    37.4237437  -122.1433284
  End_Nodes
  Lane_ConnectsTo
    0.1008.2.2 leftTurn
    0.1008.8.3 uTurn
```

```
    End_LaneConnectsTo
ApproachID 8
  Approach_type outbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4232694  -122.1421564
      37.4234924  -122.1425896
      37.4237747  -122.1431333
      37.4240003  -122.1435772
      37.4242458  -122.1440586
    End_Nodes
    Lane_ConnectsTo
      0.1007.3.1 straightAhead
    End_LaneConnectsTo
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4232435  -122.1421782
      37.4234672  -122.1426061
      37.4237484  -122.1431663
      37.4239650  -122.1435893
      37.4242120  -122.1440757
    End_Nodes
    Lane_ConnectsTo
      0.1007.3.2 straightAhead
    End_LaneConnectsTo
  Lane_seq 3
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4232205  -122.1422000
      37.4234443  -122.1426249
      37.4237209  -122.1431920
      37.4239350  -122.1436076
      37.4241880  -122.1440975
    End_Nodes
    Lane_ConnectsTo
      0.1007.3.3 straightAhead
    End_LaneConnectsTo
ApproachID 9
  Approach_type crosswalk
  Speed_limit 0
  Lane_seq 1
    Lane_type crosswalk
    Lane_phaseNo 6
    Lane_width 330
    Lane_Use
      hasPushButton
      audioSupport
    End_LaneUse
    Lane_Nodes
      37.4233303  -122.1420784
      37.4232132  -122.1418863
      37.4231540  -122.1417674
    End_Nodes
    Lane_ConnectsTo
      0.1008.10.1 rightTurn
      0.1008.12.1 leftTurn
    End_LaneConnectsTo
ApproachID 10
  Approach_type crosswalk
  Speed_limit 0
```

```
  Lane_seq 1
    Lane_type crosswalk
    Lane_phaseNo 8
    Lane_width 330
    Lane_Use
      hasPushButton
      audioSupport
      unsignalizedSegmentsPresent
    End_LaneUse
    Lane_Nodes
      37.4230926  -122.1417630
      37.4229523  -122.1418709
      37.4227992  -122.1419829
      37.4227037  -122.1419673
    End_Nodes
    Lane_ConnectsTo
      0.1008.9.1 leftTurn
      0.1008.11.1 rightTurn
    End_LaneConnectsTo
ApproachID 11
  Approach_type crosswalk
  Speed_limit 0
  Lane_seq 1
    Lane_type crosswalk
    Lane_phaseNo 2
    Lane_width 330
    Lane_Use
      hasPushButton
      audioSupport
      unsignalizedSegmentsPresent
    End_LaneUse
    Lane_Nodes
      37.4227037  -122.1419673
      37.4227992  -122.1419829
      37.4229071  -122.1421949
      37.4229674  -122.1423264
    End_Nodes
    Lane_ConnectsTo
      0.1008.10.1 leftTurn
      0.1008.12.1 rightTurn
    End_LaneConnectsTo
ApproachID 12
  Approach_type crosswalk
  Speed_limit 0
  Lane_seq 1
    Lane_type crosswalk
    Lane_phaseNo 4
    Lane_width 330
    Lane_Use
      hasPushButton
      audioSupport
    End_LaneUse
    Lane_Nodes
      37.4230371  -122.1423635
      37.4231962  -122.1422030
      37.4233303  -122.1420784
    End_Nodes
    Lane_ConnectsTo
      0.1008.9.1 rightTurn
      0.1008.11.1 leftTurn
    End_LaneConnectsTo
End_MAP
```

## Appendix F Example *.nmap* File Created from *.payload* File

The example *ecr-page-mill-out.nmap* file is created from *ecr-page-mill.payload* file (see Appendix B) by saving MAP object into *.nmap* file. The differences from *ecr-page-mill.nmap* (see Appendix E) are highlighted in dark color. All the differences occurred at the precision of way-point longitude ($1/10^{th}$ of micro degree), which is introduced during the coordinate conversion between global latitude and longitude coordinates and local X-Y coordinates w.r.t. the intersection reference point. See Section 3.3 for more information.

```
MAP_Name ecr-page-mill
MAP_Version 9
RegionalID 0
IntersectionID 1008
WithElevation yes
Reference_point 37.4230603  -122.1420323  10.0
ApproachID 1
  Approach_type inbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 4
    Lane_width 330
    Lane_Rules
      rightTurnOnRedAllowed
    End_LaneRules
    Lane_Nodes
      37.4232863  -122.1419874
      37.4235261  -122.1417812
      37.4236928  -122.1416041
      37.4242101  -122.1411775
      37.4245823  -122.1408333
      37.4249793  -122.1405056
    End_Nodes
    Lane_ConnectsTo
      0.1008.6.1 straightAhead
      0.1008.8.1 rightTurn
    End_LaneConnectsTo
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 4
    Lane_width 330
    Lane_Nodes
      37.4232706  -122.1419550
      37.4235054  -122.1417575
      37.4236867  -122.1415604
      37.4241669  -122.1411617
      37.4245649  -122.1407968
      37.4249601  -122.1404652
    End_Nodes
    Lane_ConnectsTo
      0.1008.6.2 straightAhead
    End_LaneConnectsTo
  Lane_seq 3
    Lane_type traffic
    Lane_phaseNo 7
    Lane_width 330
    Lane_Nodes
      37.4232524  -122.1419181
      37.4235010  -122.1417125
      37.4235819  -122.1416311
    End_Nodes
    Lane_ConnectsTo
      0.1008.4.3 leftTurn
    End_LaneConnectsTo
  Lane_seq 4
    Lane_type traffic
    Lane_phaseNo 7
    Lane_width 300
    Lane_Nodes
```

```
      37.4232353  -122.1418914
      37.4234792  -122.1416935
      37.4236666  -122.1415309
      37.4241484  -122.1411336
    End_Nodes
    Lane_ConnectsTo
      0.1008.2.1 uTurn
      0.1008.4.4 leftTurn
    End_LaneConnectsTo
ApproachID 2
  Approach_type outbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4231882  -122.1418093
      37.4236532  -122.1414229
      37.4242851  -122.1409007
      37.4249442  -122.1403573
    End_Nodes
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4232083  -122.1418432
      37.4236677  -122.1414672
      37.4242900  -122.1409511
      37.4249387  -122.1404107
    End_Nodes
ApproachID 3
  Approach_type inbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 6
    Lane_width 330
    Lane_Rules
      rightTurnOnRedAllowed
    End_LaneRules
    Lane_Nodes
      37.4230586  -122.1417697
      37.4228642  -122.1414029
      37.4224726  -122.1406599
      37.4222382  -122.1402273
    End_Nodes
    Lane_ConnectsTo
      0.1008.2.1 rightTurn
      0.1008.8.1 straightAhead
    End_LaneConnectsTo
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 6
    Lane_width 330
    Lane_Nodes
      37.4230332  -122.1417845
      37.4228337  -122.1414107
      37.4224530  -122.1406952
      37.4222088  -122.1402529
    End_Nodes
    Lane_ConnectsTo
      0.1008.8.2 straightAhead
    End_LaneConnectsTo
  Lane_seq 3
    Lane_type traffic
    Lane_phaseNo 6
    Lane_width 330
```

```
    Lane_Nodes
      37.4230111  -122.1418040
      37.4228137  -122.1414337
      37.4224256  -122.1407152
      37.4221824  -122.1402682
    End_Nodes
    Lane_ConnectsTo
      0.1008.8.3 straightAhead
    End_LaneConnectsTo
  Lane_seq 4
    Lane_type traffic
    Lane_phaseNo 1
    Lane_width 330
    Lane_Nodes
      37.4229834  -122.1418265
      37.4227854  -122.1414551
      37.4224106  -122.1407499
    End_Nodes
    Lane_ConnectsTo
      0.1008.6.1 leftTurn
    End_LaneConnectsTo
  Lane_seq 5
    Lane_type traffic
    Lane_phaseNo 1
    Lane_width 300
    Lane_Nodes
      37.4229574  -122.1418424
      37.4227560  -122.1414613
      37.4224603  -122.1409187
    End_Nodes
    Lane_ConnectsTo
      0.1008.4.4 uTurn
      0.1008.6.2 leftTurn
    End_LaneConnectsTo
ApproachID 4
  Approach_type outbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Rules
      caution
    End_LaneRules
    Lane_Nodes
      37.4227401  -122.1419464
      37.4227212  -122.1417951
      37.4226331  -122.1414912
    End_Nodes
    Lane_ConnectsTo
      0.1008.4.2 straightAhead
    End_LaneConnectsTo
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4228613  -122.1419053
      37.4226331  -122.1414912
      37.4223750  -122.1409969
      37.4220547  -122.1403721
    End_Nodes
    Lane_ConnectsTo
      0.1009.7.1 straightAhead
    End_LaneConnectsTo
  Lane_seq 3
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
```

```
    Lane_Nodes
      37.4228950  -122.1418874
      37.4226664  -122.1414565
      37.4224031  -122.1409787
      37.4220887  -122.1403575
    End_Nodes
    Lane_ConnectsTo
      0.1009.7.2 straightAhead
    End_LaneConnectsTo
  Lane_seq 4
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4229200  -122.1418712
      37.4226898  -122.1414376
      37.4224291  -122.1409592
      37.4221147  -122.1403407
    End_Nodes
    Lane_ConnectsTo
      0.1009.7.3 straightAhead
    End_LaneConnectsTo
ApproachID 5
  Approach_type inbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 8
    Lane_width 360
    Lane_Nodes
      37.4227368  -122.1419910
      37.4225695  -122.1422070
      37.4222654  -122.1424918
      37.4217232  -122.1429724
      37.4211824  -122.1434965
    End_Nodes
    Lane_ConnectsTo
      0.1008.4.1 rightTurn
    End_LaneConnectsTo
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 8
    Lane_width 360
    Lane_Nodes
      37.4228280  -122.1420875
      37.4225406  -122.1423344
      37.4222897  -122.1425350
      37.4217472  -122.1430033
      37.4211871  -122.1435327
    End_Nodes
    Lane_ConnectsTo
      0.1008.2.1 straightAhead
    End_LaneConnectsTo
  Lane_seq 3
    Lane_type traffic
    Lane_phaseNo 8
    Lane_width 360
    Lane_Nodes
      37.4228473  -122.1421232
      37.4225642  -122.1423631
      37.4223110  -122.1425755
      37.4217721  -122.1430297
      37.4212147  -122.1435602
    End_Nodes
    Lane_ConnectsTo
      0.1008.2.2 straightAhead
    End_LaneConnectsTo
  Lane_seq 4
    Lane_type traffic
```

```
    Lane_phaseNo 3
    Lane_width 330
    Lane_Nodes
      37.4228697  -122.1421539
      37.4225881  -122.1423926
      37.4223322  -122.1426089
      37.4218572  -122.1430098
    End_Nodes
    Lane_ConnectsTo
      0.1008.8.2 leftTurn
    End_LaneConnectsTo
  Lane_seq 5
    Lane_type traffic
    Lane_phaseNo 3
    Lane_width 330
    Lane_Nodes
      37.4228813  -122.1421822
      37.4226104  -122.1424195
      37.4223501  -122.1426364
      37.4220003  -122.1429326
    End_Nodes
    Lane_ConnectsTo
      0.1008.6.2 uTurn
      0.1008.8.3 leftTurn
    End_LaneConnectsTo
ApproachID 6
  Approach_type outbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 360
    Lane_Nodes
      37.4229274  -122.1422726
      37.4226659  -122.1425074
      37.4224155  -122.1427324
      37.4221088  -122.1429953
      37.4218600  -122.1432069
      37.4212769  -122.1436876
    End_Nodes
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 360
    Lane_Nodes
      37.4229094  -122.1422372
      37.4226402  -122.1424683
      37.4223830  -122.1426999
      37.4220865  -122.1429626
      37.4218496  -122.1431631
      37.4212577  -122.1436528
    End_Nodes
ApproachID 7
  Approach_type inbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 2
    Lane_width 330
    Lane_Rules
      rightTurnOnRedAllowed
    End_LaneRules
    Lane_Nodes
      37.4230740  -122.1423443
      37.4232800  -122.1427512
      37.4234451  -122.1430291
    End_Nodes
    Lane_ConnectsTo
      0.1008.6.1 rightTurn
```

```
  End_LaneConnectsTo
Lane_seq 2
  Lane_type traffic
  Lane_phaseNo 2
  Lane_width 330
  Lane_Nodes
    37.4230931  -122.1423219
    37.4232980  -122.1427308
    37.4234451  -122.1430291
    37.4238037  -122.1437189
    37.4240651  -122.1442032
  End_Nodes
  Lane_ConnectsTo
    0.1008.4.2 straightAhead
  End_LaneConnectsTo
Lane_seq 3
  Lane_type traffic
  Lane_phaseNo 2
  Lane_width 330
  Lane_Nodes
    37.4231154  -122.1423071
    37.4233205  -122.1426962
    37.4234677  -122.1430067
    37.4238259  -122.1436944
    37.4240919  -122.1441718
  End_Nodes
  Lane_ConnectsTo
    0.1008.4.3 straightAhead
  End_LaneConnectsTo
Lane_seq 4
  Lane_type traffic
  Lane_phaseNo 2
  Lane_width 330
  Lane_Nodes
    37.4231380  -122.1422808
    37.4233518  -122.1426855
    37.4234941  -122.1429870
    37.4238514  -122.1436769
    37.4241211  -122.1441544
  End_Nodes
  Lane_ConnectsTo
    0.1008.4.4 straightAhead
  End_LaneConnectsTo
Lane_seq 5
  Lane_type traffic
  Lane_phaseNo 5
  Lane_width 330
  Lane_Nodes
    37.4231658  -122.1422580
    37.4233676  -122.1426450
    37.4234850  -122.1428898
    37.4237959  -122.1434949
  End_Nodes
  Lane_ConnectsTo
    0.1008.2.1 leftTurn
  End_LaneConnectsTo
Lane_seq 6
  Lane_type traffic
  Lane_phaseNo 5
  Lane_width 300
  Lane_Nodes
    37.4231871  -122.1422372
    37.4233743  -122.1425952
    37.4235412  -122.1429269
    37.4237437  -122.1433283
  End_Nodes
  Lane_ConnectsTo
    0.1008.2.2 leftTurn
    0.1008.8.3 uTurn
```

```
    End_LaneConnectsTo
ApproachID 8
  Approach_type outbound
  Speed_limit 35
  Lane_seq 1
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4232694  -122.1421563
      37.4234924  -122.1425896
      37.4237747  -122.1431334
      37.4240003  -122.1435772
      37.4242458  -122.1440586
    End_Nodes
    Lane_ConnectsTo
      0.1007.3.1 straightAhead
    End_LaneConnectsTo
  Lane_seq 2
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4232435  -122.1421781
      37.4234672  -122.1426061
      37.4237484  -122.1431663
      37.4239650  -122.1435893
      37.4242120  -122.1440757
    End_Nodes
    Lane_ConnectsTo
      0.1007.3.2 straightAhead
    End_LaneConnectsTo
  Lane_seq 3
    Lane_type traffic
    Lane_phaseNo 0
    Lane_width 330
    Lane_Nodes
      37.4232205  -122.1422000
      37.4234443  -122.1426248
      37.4237209  -122.1431920
      37.4239350  -122.1436076
      37.4241880  -122.1440975
    End_Nodes
    Lane_ConnectsTo
      0.1007.3.3 straightAhead
    End_LaneConnectsTo
ApproachID 9
  Approach_type crosswalk
  Speed_limit 0
  Lane_seq 1
    Lane_type crosswalk
    Lane_phaseNo 6
    Lane_width 330
    Lane_Use
      hasPushButton
      audioSupport
    End_LaneUse
    Lane_Nodes
      37.4233303  -122.1420784
      37.4232132  -122.1418863
      37.4231540  -122.1417674
    End_Nodes
    Lane_ConnectsTo
      0.1008.10.1 rightTurn
      0.1008.12.1 leftTurn
    End_LaneConnectsTo
ApproachID 10
  Approach_type crosswalk
  Speed_limit 0
```

```
  Lane_seq 1
    Lane_type crosswalk
    Lane_phaseNo 8
    Lane_width 330
    Lane_Use
      hasPushButton
      audioSupport
      unsignalizedSegmentsPresent
    End_LaneUse
    Lane_Nodes
      37.4230926  -122.1417630
      37.4229523  -122.1418709
      37.4227992  -122.1419829
      37.4227037  -122.1419673
    End_Nodes
    Lane_ConnectsTo
      0.1008.9.1 leftTurn
      0.1008.11.1 rightTurn
    End_LaneConnectsTo
ApproachID 11
  Approach_type crosswalk
  Speed_limit 0
  Lane_seq 1
    Lane_type crosswalk
    Lane_phaseNo 2
    Lane_width 330
    Lane_Use
      hasPushButton
      audioSupport
      unsignalizedSegmentsPresent
    End_LaneUse
    Lane_Nodes
      37.4227037  -122.1419673
      37.4227992  -122.1419829
      37.4229071  -122.1421949
      37.4229674  -122.1423264
    End_Nodes
    Lane_ConnectsTo
      0.1008.10.1 leftTurn
      0.1008.12.1 rightTurn
    End_LaneConnectsTo
ApproachID 12
  Approach_type crosswalk
  Speed_limit 0
  Lane_seq 1
    Lane_type crosswalk
    Lane_phaseNo 4
    Lane_width 330
    Lane_Use
      hasPushButton
      audioSupport
    End_LaneUse
    Lane_Nodes
      37.4230371  -122.1423635
      37.4231962  -122.1422030
      37.4233303  -122.1420784
    End_Nodes
    Lane_ConnectsTo
      0.1008.9.1 rightTurn
      0.1008.11.1 leftTurn
    End_LaneConnectsTo
End_MAP
```

# Appendix G Verification of Locating a Vehicle MAP Functions

This appendix presents the results on verification of requirements on locating a vehicle on MAP using prerecorded GPS trace data along the Palo Alto test bed with a Savari OBU. GPS trace data contain timestamp, latitude, longitude, altitude, speed, and heading.

Figure G-1 plots the recorded northbound GPS trace data (blue line) and location of test bed intersections (green pins). Intersection ID of test bed intersection is listed in Table G-1. The posted speed limit on El Camino Real is 35 mph, and phase 6 controls the northbound through movement.

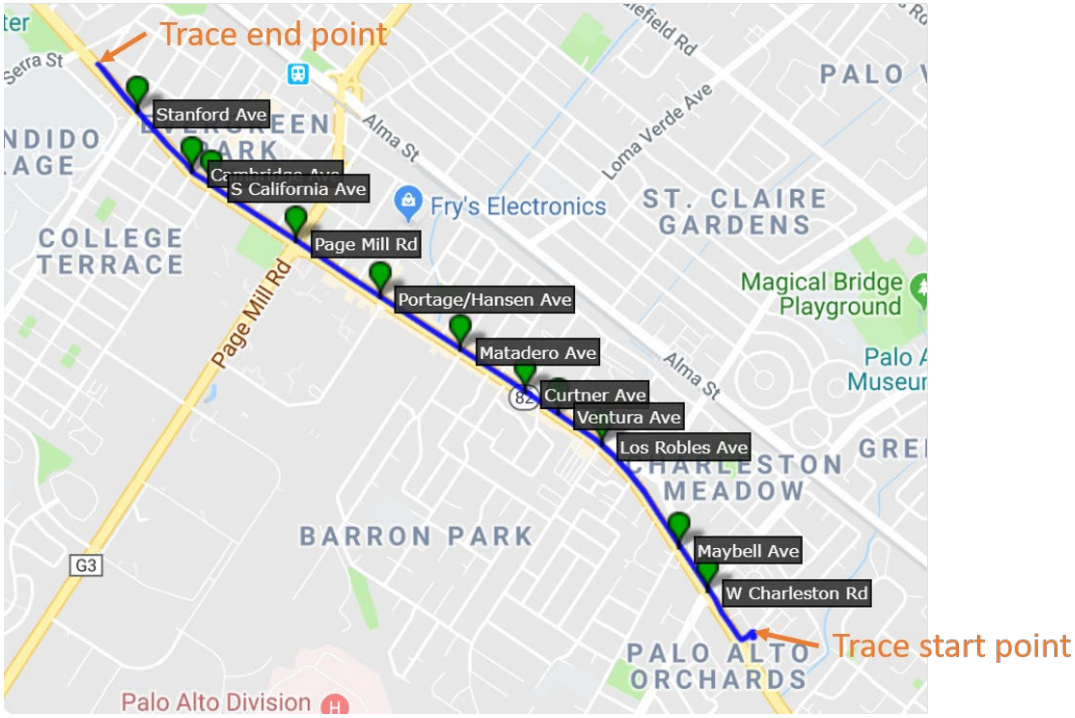


Figure G-1: A Northbound GPS Trace Data Recorded at the Palo Alto Test Bed

Table G-1: Intersection ID of Palo Alto Test Bed

| Cross-Street | Intersection ID |
|---|---|
| **Stanford Ave** | 1005 |
| **Cambridge Ave** | 1006 |
| **California Ave** | 1007 |
| **Page Mill Road** | 1008 |
| **Portage/Hansen Ave** | 1009 |
| **Matadero Ave** | 1010 |
| **Curtner Ave** | 1011 |
| **Ventura Ave** | 1012 |
| **Los Robles Ave** | 1013 |
| **Maybell Ave** | 1014 |
| **W Charleston Ave** | 1015 |

For the verification of requirements on locating a vehicle on MAP, the MAP Engine Library (MEL) is initiated by reading *.payload* file of all the eleven intersections and the MEL keeps all eleven MAP objects on its management list. Under OBU/RSU communication via DSRC, the size of the management list is dynamic, depending on the number of RSUs that are within the communication range with the OBU. Verification of requirements on MEL managing the management list (i.e., determining if a SAE J2735 MAP is a new or a repeat MAP on the management list, adding new MAP object to the management list, and removing outside-communication-range MAP objects from the management list) is presented in Section 3.5. The goal of tests presented in this appendix is to verify that, given vehicle's GPS measurement, whether the MEL is able to

- Determine if the vehicle is within the coverage of any MAP objects on the management list;
- Determine the approaching intersection;
- Determine vehicle's lane of travel;
- Estimating distance to the stop-bar for inbound lane and distance from the exit-bar for outbound lane;
- Determining allowed maneuvers at the stop-bar (for inbound lane);
- Determining the signal phase that controls vehicle's movement; and
- Determining speed limit.

Figure G-2 plots the raw speed and heading measurements as function of travel time. The total trip is about 7 minutes. Note the jump in heading measurement when the vehicle is near stopped.

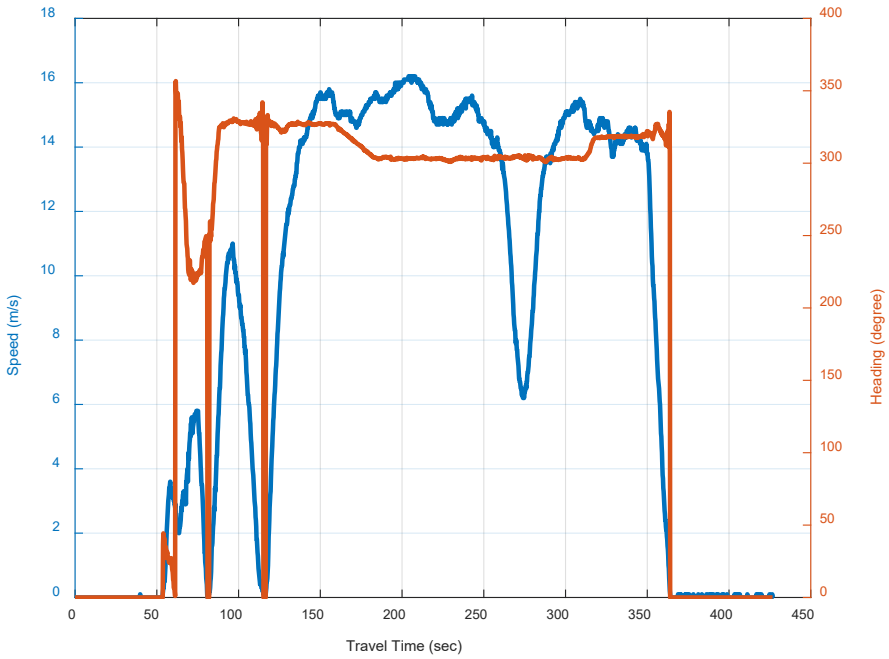


Figure G-2: Vehicle Speed and Heading vs. Travel Time

Figure G-3 plots MEL returned vehicle on-MAP status and approaching intersection as function of travel time. Values of vehicle on-MAP status could be “outside” – the vehicle is not within the coverage of any MAP objects; “inbound” – the vehicle is on an inbound lane; “outbound” – the vehicle in on an outbound lane; or “inside intersection box” – the vehicle is on the pathway that links the inbound lane to its connecting outbound lane. Before point A, “outside” status indicates the vehicle is outside the coverage of the test bed. The vehicle entered the coverage of Charleston Ave at point A (“inbound” status), crossed the stop-bar at point B (“inside box” status), and crossed the exit-bar at point C (on an outbound lane of Charleston Ave). Since the MAP includes ConnectTo information from the outbound lane to an inbound lane of Maybell Ave, the MEL is able to determine the correct approaching intersection as Maybell at point C (“inbound” to Maybell). At point F, since Stanford Ave is the last equipped intersection, it shows a transition from “inside box” to “outbound” and then “outside” when the vehicle left the coverage of Stanford Ave.

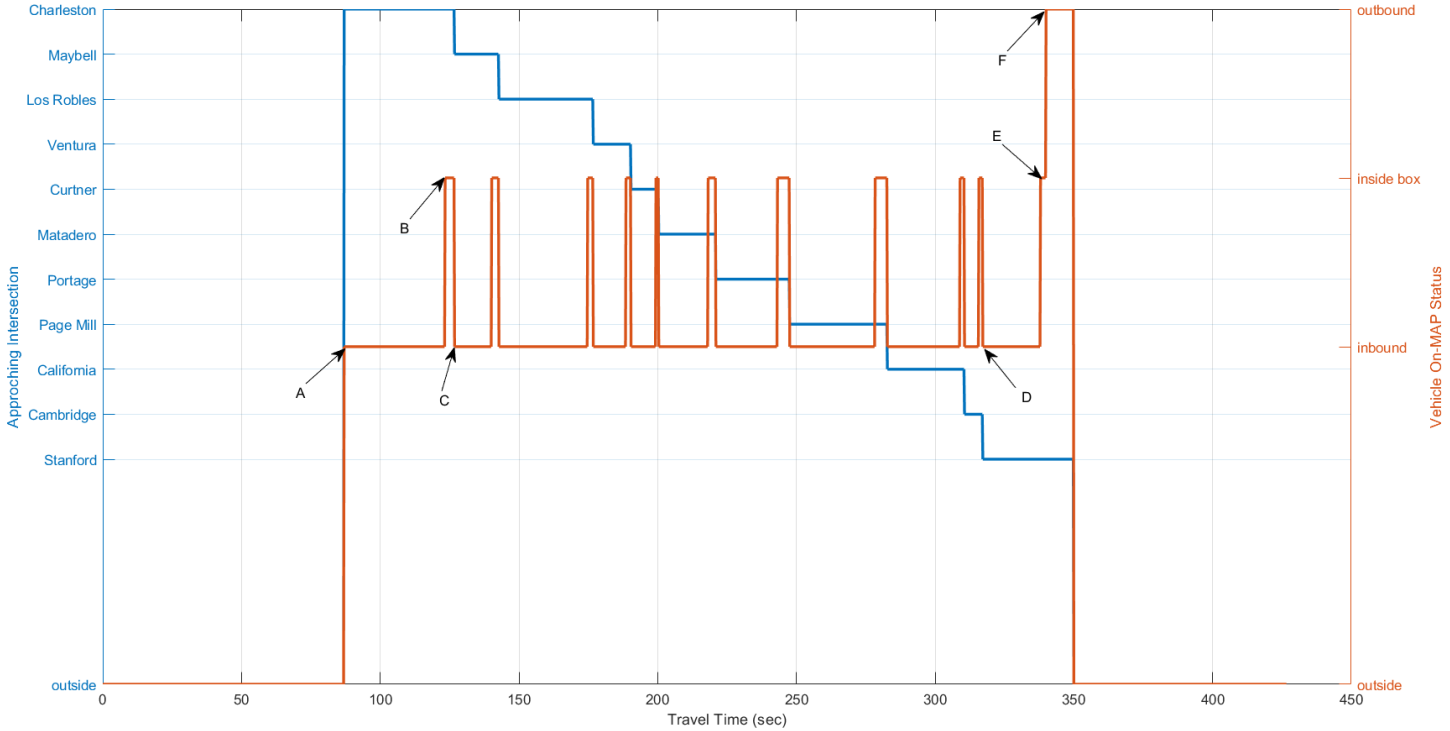


Figure G-3: Vehicle On-MAP Status and Approaching Intersection vs. Travel Time

Figure G-4 plots MEL estimated distance to the stop-bar (inbound lane) or distance from the exit-bar (outbound lane) as function of travel time. Point A to point F correspond to those points in Figure G-3. The vehicle entered the coverage of Charleston Ave at point A on an inbound lane. The distance to the stop-bar decreases to zero when it crossed the stop-bar at point B, and reaches the minimum (negative) value at point C when the vehicle crossed the exit-bar. It then switched to distance to the stop-bar of Maybell Ave. At point F, since Stanford Ave is the last equipped intersection, the distance is actually distance from the exit-bar. It keeps increasing until the vehicle left the coverage of Stanford Ave.

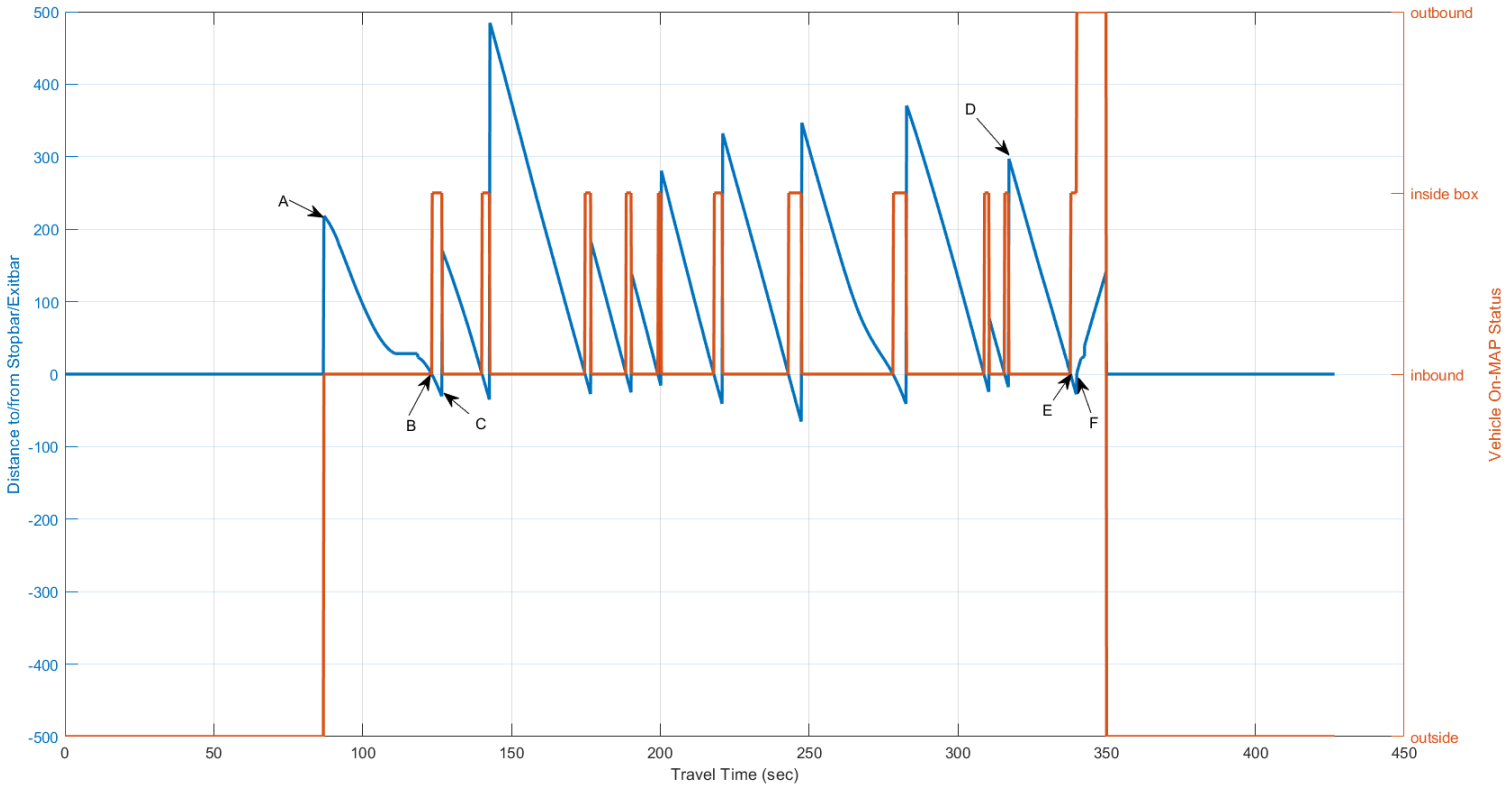


Figure G-4: Distance to/from Stopbar/Exitbar and Vehicle On-MAP Status vs. Travel Time

Figure G-5 plots lane ID and approaching intersection as function of travel time. Charleston Ave and Page Mill Road are bigger intersections and have larger Lane ID. The largest lane ID (value 18) occurred at “outbound” Stanford Ave as it is an outbound lane and the rest are inbound lanes. The order of lane ID starts from west-inbound and increases clockwise to north-outbound.

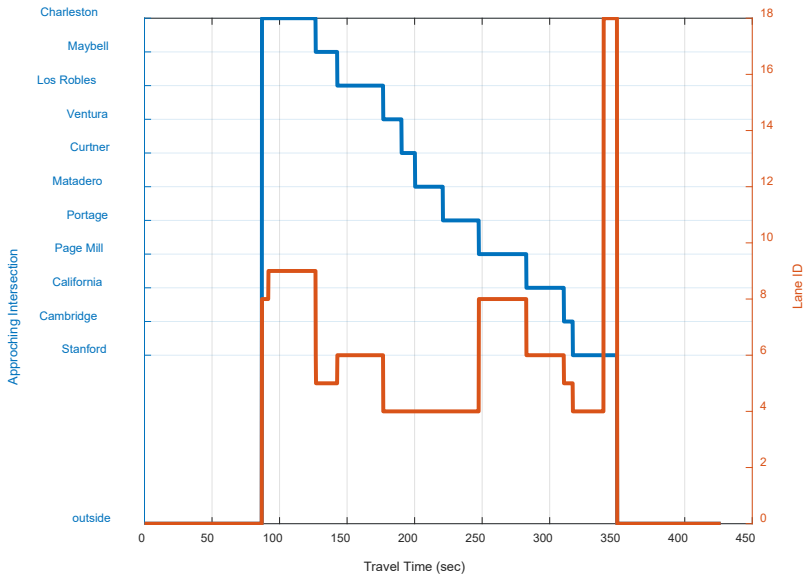


Figure G-5: Lane ID and Approaching Intersection vs. Travel Time

Figure G-6 plots MEL returned signal group ID, allowed maneuvers, and speed limit as function of travel time. The vehicle entered the coverage of Charleston Ave on the curb lane (from a parking lot) with right-turn and through movement allowed. It changed to the center lane (with through movement allowed) and maintained the same lane to the end of the trip. The logged speed limit (35 mph) and control phase (#6) are correctly matched with the MAP data.

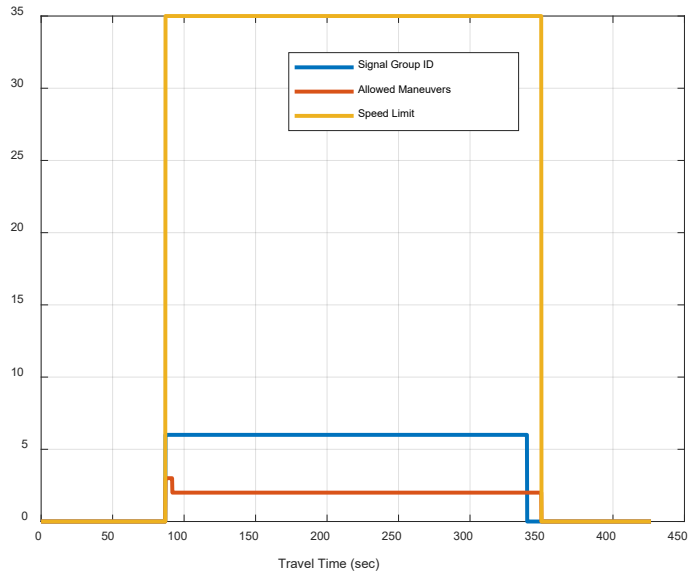


Figure G-6: Signal Group ID, Allowed Maneuvers, and Speed Limit vs. Travel Time

# Appendix H Discussion on Difficult MAP Scenarios

SAE J2735 MAP consists of inbound lanes that end at a stop-bar and outbound lanes that start at an exit-bar of an intersections. There are several scenarios are difficult to model. There scenarios include merging or splitting of inbound lanes, and mid-block lanes that do not connect with either a stop-bar or an exit-bar. Although the scenarios below may not critical for MMITSS, the MAP difficulties need to be addressed in general, particularly for safety applications such as intersection maneuver assist.

Figure H-1 plots the northbound inbound curb lane at Charleston Ave @ El Camino Real, Palo Alto, CA. The right-turn only lane B→D diverges from the curb lane A→B→C at point B.

- When modeling A→B→C as one lane, the allowed maneuver on segment A→B is different from that on segment B→C: right-turn and straight vs. straight-only. The difficulty is how to assign different allowed maneuver on different segments of one lane.
- When modeling A→B and B→C as two lanes, lane A→B does not fit into either inbound or outbound lane.
- The current temporary fix is to model A→B→C as one lane and the allowed maneuver on segment B→C is set as right-turn and straight.


Figure H-1 Splitting of an Inbound Lane

Figure H-2 plots the southbound inbound curb lane at Medical Foundation Dr @ El Camino Real, Palo Alto, CA. The roadway is actually merging of two lanes. As it is not clear how to model the merging case, we simply modeled it as one inbound lane.

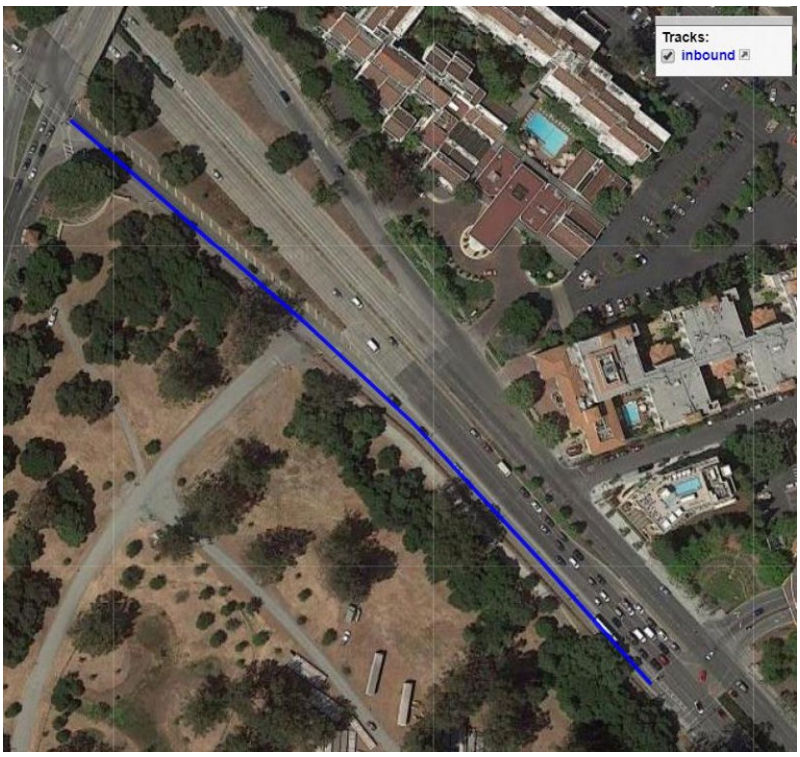


Figure H-2 Merging of two Inbound Lanes

Figure H-3 plot an outbound lane from California Ave (blue) connecting with an inbound lane to Page Mill Road (cyan). The mid-block left-turn lane is not included in MAP as it does not fit into either inbound or outbound lane.


Figure H-3 Mid-Block Traffic Lane