**CAMP LLC**

***Vehicle-to-Infrastructure (V2I-5) Consortium***

# *Connected Intersection MAP Data Assessment*

*Supporting Basic Red Light Violation Warning*

*Version 0.90*

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# List of Acronyms

| Acronym | Definition |
|---|---|
| CAMP | Crash Avoidance Metrics Partners LLC |
| CI | Connected Intersection |
| CV PFS | Connected Vehicle Pooled Fund Study |
| C-V2X | Cellular Vehicle-to-Everything |
| DGPS | Differential Global Positioning System |
| GPS | Global Positioning System |
| GNSS | Global Navigation Satellite System |
| HDOP | Horizontal Dilution of Precision |
| I2V | Infrastructure to Vehicle |
| IOO | Infrastructure Owner / Operator |
| ITE | Institute of Transportation Engineers |
| JSON | JavaScript Object Notation |
| MAP | SAE J2735 Map Message |
| NAD83 | North American Datum 1983 |
| NMEA | National Marine Electronics Association |
| OBU | On-board Unit |
| OEM | Original Equipment Manufacturer |
| PCAP | Packet Capture |
| PPS | Precise Positioning System |
| RLVW | Red Light Violation Warning |
| RSU | Roadside Unit |
| RTCM | Radio Technical Commission for Maritime Services |
| SAE | SAE International |
| SPaT | Signal Phase and Timing |
| SPS | Standard Positioning System |
| V2I | Vehicle-to-Infrastructure |
| WAAS | Wide Area Augmentation System |
| WGS84 | World Geodetic System 1984 |

# Connected Intersection MAP Utility Assessment
## Supporting Basic Red Light Violation Warning

## Background

The Society of Automotive Engineers (SAE) J2735 MAP message standard specifies the content and format of the geometric intersection description broadcast by a Connected Intersection (CI) using Infrastructure to Vehicle (I2V) communications to support in-vehicle safety and mobility applications such as Basic Red Light Violation Warning (RLVW). Basic RLVW operates within the Yellow Phase time interval of a through movement. The Institute of Transportation Engineers (ITE) CI Guidelines and Connected Vehicle Pooled Fund Study (CV PFS) MAP Guidance document specifies desired common practices for creating MAP messages describing connected intersections and position correction data to equipped vehicles.

The purpose of this assessment procedure by the Crash Avoidance Metrics Partners LLC (CAMP) Vehicle-to-Infrastructure 5 (V2I-5) Consortium is to verify that the MAP message and position correction data broadcast by a CI can be successfully utilized by an equipped vehicle to position itself on the correct approach lane to operate in-vehicle applications such as Basic RLVW utilizing the correct Signal Phase and Timing (SPaT) data for the actual lane of travel.

## Basis for Assessment

Verification of the connected intersection geometry contained in a MAP message is based on how well the connected vehicle matches itself to the correct lane using the positional information provided. It is assumed that the CI is broadcasting Radio Technical Commission for Maritime Services (RTCM) v3.x position corrections, as specified in the CI Guidance document, and that the vehicle is instrumented to use this information to improve its positional accuracy. The MAP verification procedures use vehicle path data collected by driving through the intersection in a prescribed manner.

This document describes two MAP message assessment / verification procedures. First, an optional MAP segment accuracy assessment procedure is provided for use by Infrastructure Owner / Operators (IOOs) interested in understanding the accuracy of their MAP messages including the means to assess / correct various errors that may be present. Second, an automotive Original Equipment Manufacturer (OEM) MAP verification procedure is provided to evaluate the utility of a MAP broadcast to enable vehicles to properly map match to the correct through approach lane segment(s) and determine the proper signal phase information to operate Basic RLVW. This includes test validity and MAP utility pass / fail criteria.

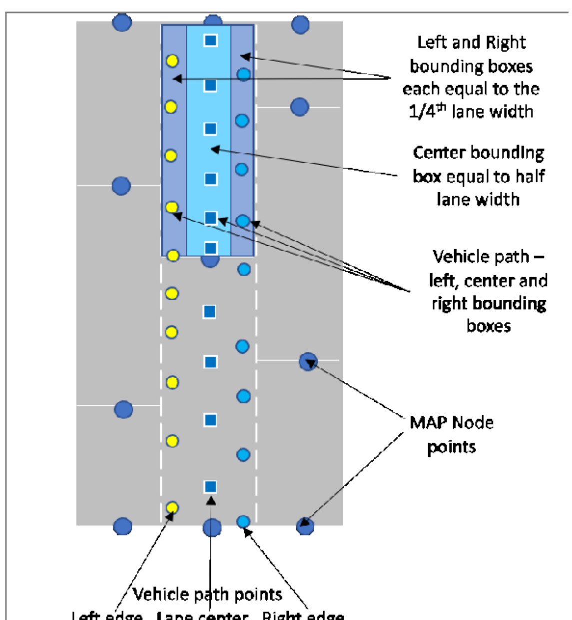
## MAP Segment Accuracy

This process is recommended for IOOs to check the accuracy of their MAP messages prior to utility assessment testing. It involves overlaying the intersection geometry defined in the MAP messages on Google satellite view for initial visual verification, and then overlaying vehicle path data collected by driving through the intersection onto the lane geometry provided in the MAP message for analysis.

The logic used to make this assessment involves establishing three levels of virtual bounding boxes between each set of sequential node points contained in the MAP message for each ingress lane at a CI to indicate the vehicle position is close to the left edge, to the right edge or within the center of the lane. If the node points that describe the lane geometry are not appropriately placed (e.g., shifted either to the left or right by 1/4$^{th}$ the lane width from the required lane center), the vehicle lane determination may indicate an incorrect lane match. As illustrated in Figure 1, the analysis tool creates three virtual bounding boxes. The center box is equal to ½ the lane width between two node points that describe a lane segment. The left and right boxes are equal to ¼ of the lane width for the same lane segment.

Vehicle position data collected by driving each ingress lane, centering the vehicle in lane, close to the left lane edge, and close to the right lane edge is then compared to the lateral limits of each virtual bounding box on the approach.

- MAP bias due to a shift in node placement to the left or right from lane center will result in either a left or right edge assessment failure causing incorrect lane identification
- Excessive node point spacing for a lane segment's curvature will result in a center assessment failure
- Successfully verifying crossing approaches at an intersection indicates proper placement of the MAP reference point




Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 1: MAP Assessment Procedure using Virtual Bounding Boxes

## Equipment and Personnel

The following items and personnel are needed to execute the drive procedure described above and collect the data elements described in the next section:

- A light duty passenger vehicle which can be easily maneuvered within the approach lane to maintain position on center or at the right / left edges of the lane without crossing the lane boundaries.
- An On Board Unit (OBU) capable of receiving CI MAP, position correction and SPaT broadcast data in Packet Capture (PCAP) format as well as logging vehicle position data at 10 Hz for post processing. The OBU should be equipped with automotive grade or higher accuracy Global Navigation Satellite System (GNSS) capable of applying RTCM corrections v3.3 as prescribed in the CI implementation guide received from the infrastructure.
- A driver to follow the lane as indicated and a test engineer to initiate and terminate data collection for each test run.

## Data Elements

To perform the MAP Segment Accuracy assessment, the following vehicle position data elements are required at 10Hz as the vehicle is driven on different ingress lanes through the intersection:

1. Timestamp in UTC for each record
2. Vehicle Speed (meters per second)
3. Vehicle Latitude in degrees (accuracy to 7 decimal places)
4. Vehicle Longitude in degrees (accuracy to 7 decimal places)
5. Vehicle Altitude in meters (for future use)
6. Vehicle Heading in degrees
7. Number of satellites being tracked
8. Horizontal Dilution of Precision (HDOP)
9. GNSS Fix Quality to indicate type of position correction utilized:
   0 = invalid
   1 = Global Positioning System (GPS) fix (Standard Positioning Service (SPS))
   2 = Differential GPS (DGPS) fix
   3 = PPS (Precise Positioning Service (PPS)) fix
   4 = Fixed Real Time Kinematic
   5 = Float Real Time Kinematic
   6 = Estimated (dead reckoning) (2.3 feature)
   7 = Manual input mode
   8 = Simulation mode

## Data Collection Method(s)

Vehicle path data can be collected using one of the following two methods:

*Method 1:* OBU based data logging system:

Any OBU based system capable of applying RTCM 3.3 position corrections and collecting the data elements specified at 10Hz can be used for data collection. Such a system should:

- Allow the user to start / stop / pause data collection

- Generate unique file names based on date and time
- Log data in .csv format for post processing

A vehicle data log generated using an OBU based system is shown in Figure 2.

| TimeStamp Formatted | Speed (m/s) | Latitude | Longitude | Elevation (m) | Heading (deg) | Matched Lane ID | Dist To Stop Bar (m) | Intersection ID | Signal Phase | TimeToNext Phase (sec) | ThreatState | Num Satellites | HDOP | FixQuality |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2022/03/09-15:55:25.177 | 15.6 | 42.5664645 | -82.950936 | 152.07 | 178.35 | 1 | 126.4 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55.8 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:25.277 | 15.6 | 42.5664503 | -82.950936 | 152.06 | 178.37 | 1 | 124.9 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55.7 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:25.377 | 15.6 | 42.5664362 | -82.950935 | 152.06 | 178.17 | 1 | 123.3 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55.6 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:25.477 | 15.7 | 42.5664222 | -82.950935 | 152.07 | 178.34 | 1 | 121.7 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55.5 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:25.577 | 15.7 | 42.566408 | -82.950934 | 152.07 | 178.47 | 1 | 120.2 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55.4 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:25.677 | 15.7 | 42.5663938 | -82.950933 | 152.08 | 178.35 | 1 | 118.6 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55.3 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:25.777 | 15.7 | 42.5663797 | -82.950933 | 152.1 | 178.45 | 1 | 117 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55.2 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:25.877 | 15.7 | 42.5663656 | -82.950932 | 152.12 | 178.41 | 1 | 115.5 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55.1 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:25.977 | 15.7 | 42.5663515 | -82.950932 | 152.12 | 178.25 | 1 | 113.9 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:26.077 | 15.7 | 42.5663374 | -82.950931 | 152.12 | 178.32 | 1 | 112.3 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 54.9 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:26.177 | 15.7 | 42.5663233 | -82.95093 | 152.13 | 178.41 | 1 | 110.7 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 54.8 | 0 | 9 | 0.97 | 2 |

Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 2: Example Vehicle Path Data Logged Using an OBU

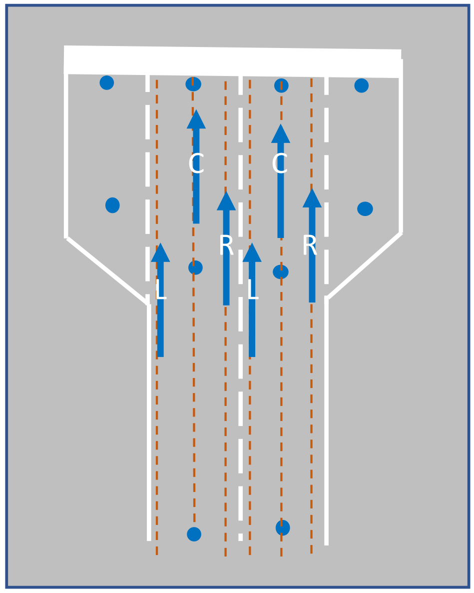
*Method 2:* Log National Marine Electronics Association (NMEA) sentences at 10 Hz:

- User needs to start / stop / pause data collection as needed for ingress lanes
- Separately provide the following:
  a. Intersection ID and description
  b. List of lane IDs on which the vehicle was driven for path data collection
  c. For each lane driven, intended vehicle drive type as:
     I. Left edge
     II. Right edge
     III. Lane center
  d. Intersection MAP message either in JavaScript Object Notation (JSON) (as defined in the CI field validation report [1]) or in a PCAP file. A MAP message in PCAP format will require translation to JSON to overlay the intersection geometry on Google satellite view for analysis.

### Test Procedure

For each ingress lane:

- Bring the vehicle to the posted speed limit at a distance greater than the extent of the MAP data for the lane of travel being evaluated (requires knowledge of the specific MAP configuration) and initiate data logging
- As illustrated in Figure 3, maintain vehicle position either on center or close to the left /right lane boundary without allowing the nearest tire to touch the lane marking, until the vehicle reaches the stop bar.
- Terminate data logging at the stop bar for each individual test run.




Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 3: Vehicle Drive Path for MAP Assessment Data Logging

## Data Analysis

Assessment of MAP segment accuracy is comprised of two evaluation steps using the data collected from driving through the intersection in the manner described.

### *Visual Verification*

The initial visual verification is performed by overlaying the broadcast MAP message onto the Google satellite view. All node points for the ingress lanes are used to formulate virtual bounding boxes. The analysis software is a web application in JavaScript that uses Google's geometry and drawing library API to overlay the intersection geometry from the MAP message, to draw virtual bounding boxes and to plot vehicle position information as shown in screen capture in Figure 4. The left panel provides the intersection map detail as defined in the MAP message. The assessment of how well the MAP matches the image is performed by visual inspection of ingress lane boundary and stop bar alignment on all approaches.

### *Path Data Analysis*

Path data analysis is performed by drawing three additional virtual bounding boxes for each ingress lane segment. The left and right bounding box each of 1/4$^{th}$ lane width is represented by blue color and the middle box of half the lane width is represented by magenta color. Vehicle position information is represented by colored dots as follows:

- Purple dots indicate the vehicle is outside the mapped ingress lanes area
- Yellow dots indicate the vehicle is on the left (1/4 lane width) bounding box
- Blue dots with white boarder indicate the vehicle is in the middle (half lane width) bounding box
- Cyan dots indicate the vehicle is on the right (1/4 lane width) bounding box

Each vehicle position dot contains following information which can be viewed by clicking on it as illustrated in Figure 4.

- Data#: logged data point #
- Speed: vehicle speed in m/s and mph
- Lane: determined lane number by the RLVW application, the independent algorithm and indication of left, middle or right bounding box from the virtual bounding box
- SB: distance to stop bar from the current location by the RLVW application
- Veh Pos: current vehicle position in latitude and longitude
- Heading: current vehicle heading angle

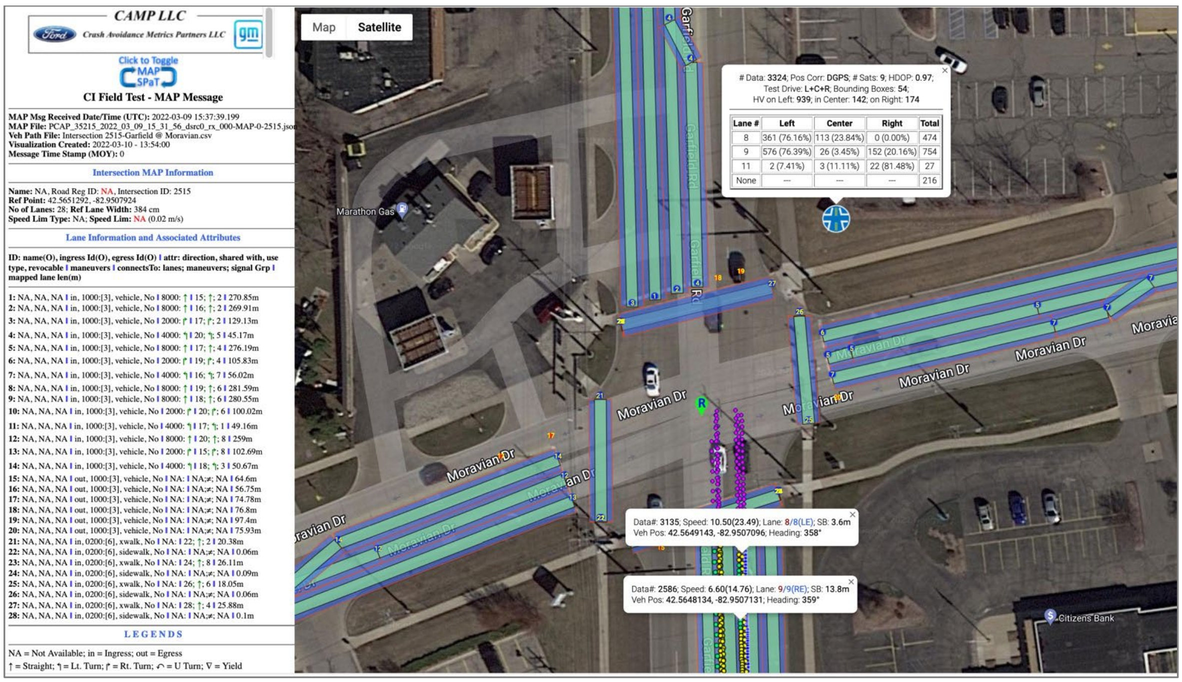



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Figure 4: Screenshot of MAP Assessment Visualization and Data Analysis

Appendix A – GNSS Position Trace Assessment provides illustration(s) of several types of MAP segment errors that may be identified using this method as well as a decision tree to assist in the interpretation of driving data.

The analysis software identifies the lane and counts number of times the vehicle position is located within each bounding box for each ingress lane. The percentage of the total number of vehicle position counts, matched lane counts, and matched bounding box counts are determined. Figure 5 shows the test assessment analysis provided by clicking on the  icon in the visualization.

Intersection ID: **2515; Garfield & Moravian**;
Veh Pos Corr Applied: **DGPS**; No of Sats: **9**; HDOP: **0.97**;
Drive Type: **L+C+R**; Bounding Boxes: **54**;
Veh in Left Box: **939**; Center Box: **142**; Right Box: **174**

| Lane # | Left | Center | Right | Total |
|---|---|---|---|---|
| 8 | 361 (76.16%) | 113 (23.84%) | 0 (0.00%) | 474 |
| 9 | 576 (76.39%) | 26 (3.45%) | 152 (20.16%) | 754 |
| 11 | 2 (7.41%) | 3 (11.11%) | 22 (81.48%) | 27 |
| None | --- | --- | --- | 216 |

Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 5: Path Data Analysis

Where:

- Veh Pos Corr Applied: Position correction applied as reported by "Fix Quality" by the GPS/GNSS receiver
- No of Sats: Number of satellites in view as reported by the GPS/GNSS receiver
- HDOP: Horizontal Dilution of Precision as reported by the GPS/GNSS receiver
- Drive Type: Indicates drive type where, L = Left Edge, C = Lane Center, R = Right Edge
- Bounding Boxes: Number of ingress lane segments containing bounding boxes
- Veh Pos:
    - Left Box: Indicates number of times the vehicle position indicated in the left bounding boxes (number of times the vehicle close to the left edge of ingress lanes)
    - Center Box: Indicates number of times the vehicle position indicated in the center or middle bounding boxes (number of times the vehicle close to the lane center of ingress lanes)
    - Right Box: Indicates number of times the vehicle position indicated in the right bounding boxes (number of times the vehicle close to the right edge of ingress lanes)

In this example, the vehicle was driven northbound in lanes 8 and 9. The vehicle was driven on left edge and lane center on lane 8, while on left edge, lane center and right edge on lane 9. The vehicle also matched lane 11. Lane 11 is the start of left turn lane pocket that overlays on lane 9 (not visible in the figure). The vehicle did not match any lane for 216 vehicle position points. These position points are for when the vehicle was driven outside the intersection map coming out of a parking lot.

### *Survey of Strategic Node Points*

The analysis of intersection map geometry described above does not quantitatively assess stop bar location. It would be beneficial to also conduct a GNSS survey of several points at each intersection stop location to determine if there is any bias/shift of node points in the broadcast MAP message not identified by vehicle path data analysis or visual inspection. This should be done by selecting points on the lane boundary (lane marker) at each stop bar, the computing lane center from the lane width, and comparing this data to the first node point node point in each ingress lane in the MAP message.

### *RSU Broadcast Range*

For the RLVW application, the Roadside Unit (RSU) broadcast range must be at least the length of geometry defined in the MAP message for each ingress lane. This can be confirmed by examining the data present at the last node point for each ingress lane to confirm reception of SPaT, MAP and RTCM data.

### *MAP Issue Identification*

The analyses below illustrates application of the MAP Segment Accuracy assessment process and tools to identify specific issues at deployed intersections. MAP messages for both intersections shown were generated from Lidar survey data. Vehicle position data was collected by driving all ingress lanes in each of the four available directions using a CAMP/Denso OBU with Wide Area Augmentation System (WAAS) position corrections applied.

#### Example 1 – Incorrect Reference Point

MAP data analysis for the intersection of Garfield Road and Moravian Drive in Macomb County, Michigan is shown in Figure 6. Vehicle path data collected northbound in lane 9 and southbound in lane 2 align with the MAP provided and places the vehicle in the correct lane. However, vehicle path data collected westbound in lane 5, highlighted by the white ellipse, does not align with the MAP and the vehicle is incorrectly matched to lane 6.

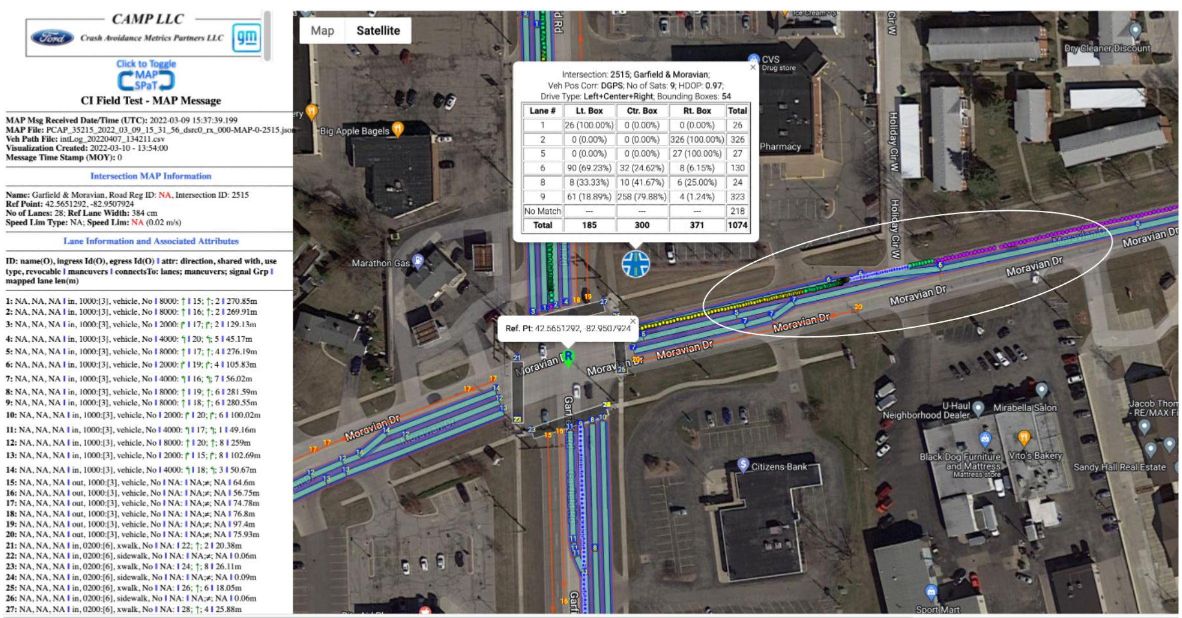


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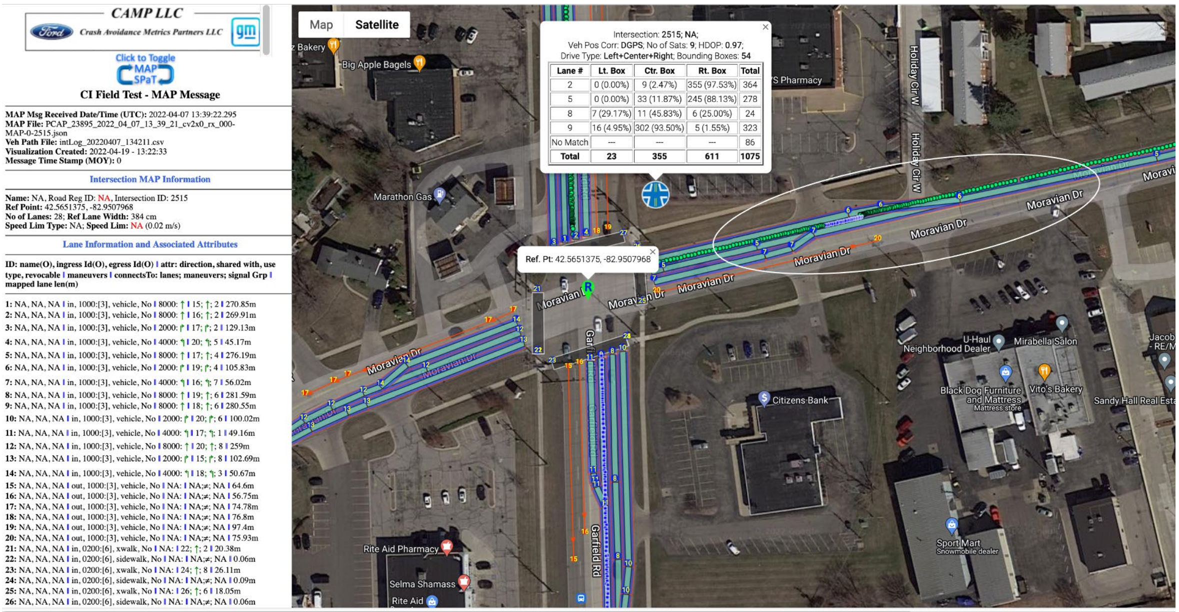
Figure 6: Intersection MAP with Reference Point in NAD83 Datum

Further investigation revealed that the reference point for the MAP message was based on the North America Datum 1983 (NAD83) [2] utilized in the laser survey. However, the SAE J2735 specification requires map representation provided to the vehicle to utilize the World Geodetic System 1984 (WGS84) datum [2]. The WGS84 datum has moved 100 meters [3] from the prior utilized prime meridian while the NAD83 datum has not moved. Since the node points that describe lane geometry are defined as XY offsets from the reference, use of the incorrect datum for the reference point causes the lanes defined in the MAP to appear as shifted slightly south causing the incorrect lane determination observed on the westbound approach.

Figure *7* shows the same intersection after converting the MAP reference point from NAD83 to WGS84 datum. The reference point conversion adjusted lane placements accordingly and the same vehicle path data collected in lane 5 on the westbound approach now correctly aligns with the MAP data.

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Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 7: Intersection MAP with Reference Point in WGS84 Datum

### Example 2 – Incorrect Lane Width

MAP data analysis for the intersection of Garfield Road and Metropolitan Parkway in Macomb County, Michigan is shown in Figure 8. In this example, vehicle path data analysis shows a high percentage of correctly determined lanes, apart from lanes 8 and 10. Vehicle path data recorded in lanes 8 and 10 is the result of the test vehicle crossing these lanes to position itself in lane 9 prior to driving through the intersection. The data collection software is currently being updated to enable the test operator to easily start / stop data collection to eliminate such artifacts.

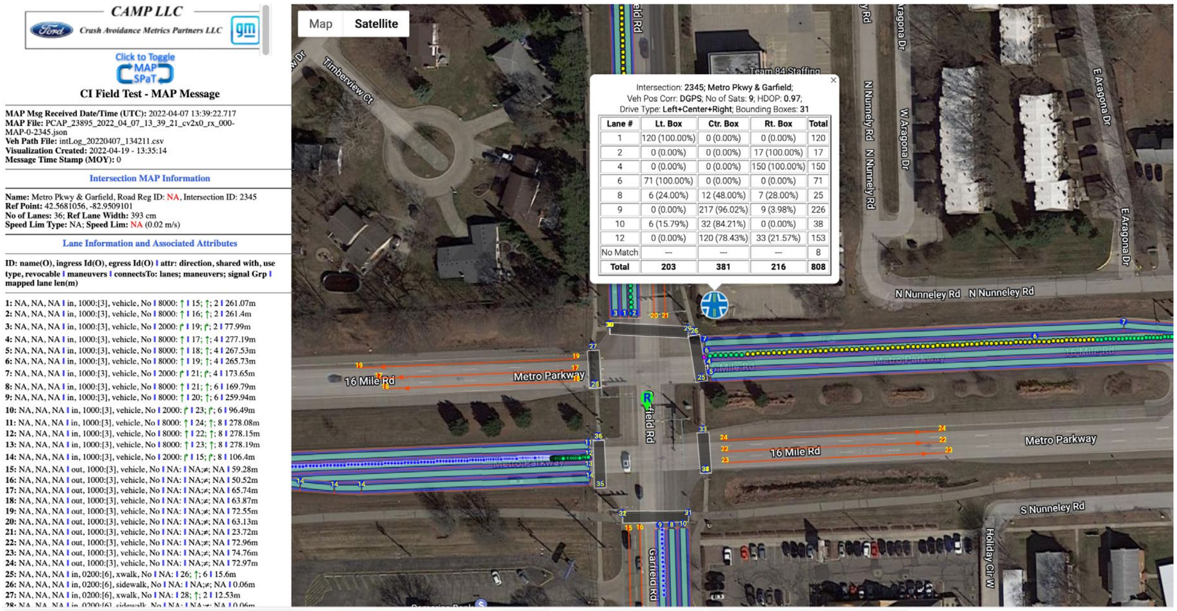


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Figure 8: Intersection MAP with Wider Over lapping Lane Width

Examination of the map data provided shows the lane width indicated in MAP message as 393 cm for all approaches, which is wider than normal width of 360 cm. This appears to be true for Metropolitan Parkway (east/west direction) and for Garfield Road in the northbound direction but not for Garfield Road in the southbound direction. Based on measurements made using Google Earth satellite view, the lane width for Metropolitan Parkway is approximately 390 cm, while the lane width for Garfield Road southbound approach is only 360 cm. Applying an incorrect lane width in the analysis tool results in a bounding box that is too wide and overlaps the bounding boxes for adjacent lanes. Figure 9 shows an expanded view of the bounding boxes for the southbound approach with lane 1 changed to white to help visualize the lateral overlap with lanes 2 and 3 shown in cyan. This overlap may cause incorrect lane determination when the vehicle is driven close to the lane edges.


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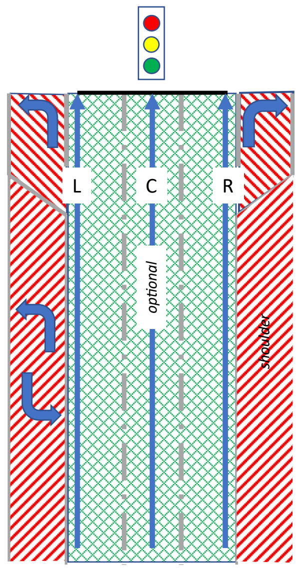
Figure 9: Bounding Box Overlap on Southbound Approach

## MAP Utility Verification

This process is utilized to verify that a vehicle can properly match itself to the through approach lanes of a CI using broadcast MAP and RTCM data. Figure 10 illustrates a multi-lane approach to a single signal phase where the green cross hatching indicates the valid map matching region for Basic RLVW, and the red diagonal stripped areas are invalid. For multiple lanes utilizing the same signal phase, this assessment involves driving the left and right lane edges for the outer lanes of the through approach and monitoring the vehicle's lane selection performance. Previous work developing similar test procedures for CI assessment to support RLVW can be found on CAMP's website [5].




Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 10: Through Lane Map Matching Assessment

### Equipment and Personnel

The following items and personnel are needed to execute the drive procedure described above and collect the data elements described in the next section:

- A light duty passenger vehicle which can be easily maneuvered within the approach lane to maintain position on center or at the right / left edges of the lane without crossing the lane boundaries.
- An OBU capable of receiving CI MAP, position correction and SPaT broadcast data in PCAP format as well as logging vehicle position data at 10 Hz for post processing. The OBU should be equipped with an automotive grade GNSS capable of applying RTCM v3.3 corrections as prescribed by the CI implementation guide received from the infrastructure. CAMP has developed this capability using a Denso dual-mode Dedicated Short-range Communication (DSRC) and Cellular Vehicle-to-Everything (C-V2X) Hercules OBU with an external ublox EVK-M91 Global Navigation Satellite System (GNSS) receiver and custom data logging software (CAMP/Denso OBU).
- A driver to follow the lane as indicated and a test engineer to initiate and terminate data collection for each test run.

### Data Elements

To perform the MAP Segment Accuracy Assessment, the following vehicle position data elements are required at 10Hz as the vehicle is driven on different ingress lanes through the intersection:

1. Timestamp in UTC for each record
2. Vehicle Speed (meters per second)
3. Vehicle Latitude in degrees (accuracy to 7 decimal places)
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9. GNSS Fix Quality to indicate type of position correction utilized:
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   3 = PPS (Precise Positioning Service (PPS)) fix
   4 = Fixed Real Time Kinematic
   5 = Float Real Time Kinematic
   6 = Estimated (dead reckoning) (2.3 feature)
   7 = Manual input mode
   8 = Simulation mode

The CAMP/DENSO OBU based data logging tool is also equipped with CAMP's version of a RLVW application to log the following additional test parameters which provide additional data needed for MAP Utility Verification:

10. Intersection ID from the MAP message
11. Host vehicle's matched lane number (id) as defined in the MAP message
12. Distance to stop bar in meters as computed in the application from the current vehicle position
13. RLVW application performance
14. Current signal phase of the host vehicle lane
15. Time remaining in the current phase in milliseconds
16. RLVW application warning status

### Data Collection Method

The CAMP/DENSO OBU based data logging system:

- Allows user to start / stop / pause data collection
- Generates unique file name based on date and time
- Logs data in .csv format for processing

A vehicle data log generated using the CAMP/DENSO OBU is shown in Figure 11.

| TimeStamp Formatted | Speed (m/s) | Latitude | Longitude | Elevation (m) | Heading (deg) | Matched Lane ID | Dist To Stop Bar (m) | Intersection ID | Signal Phase | TimeToNext Phase (sec) | ThreatState | Num Satellites | HDOP | FixQuality |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2022/03/09-15:55:25.177 | 15.6 | 42.5664645 | -82.950936 | 152.07 | 178.35 | 1 | 126.4 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55.8 | 0 | 9 | 0.97 | 2 |
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| 2022/03/09-15:55:25.777 | 15.7 | 42.5663797 | -82.950933 | 152.1 | 178.45 | 1 | 117 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55.2 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:25.877 | 15.7 | 42.5663656 | -82.950932 | 152.12 | 178.41 | 1 | 115.5 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55.1 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:25.977 | 15.7 | 42.5663515 | -82.950932 | 152.12 | 178.25 | 1 | 113.9 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 55 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:26.077 | 15.7 | 42.5663374 | -82.950931 | 152.12 | 178.32 | 1 | 112.3 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 54.9 | 0 | 9 | 0.97 | 2 |
| 2022/03/09-15:55:26.177 | 15.7 | 42.5663233 | -82.95093 | 152.13 | 178.41 | 1 | 110.7 | 2515 | MPS_PERMISSIVE_MOVEMENT_ALLOWED | 54.8 | 0 | 9 | 0.97 | 2 |

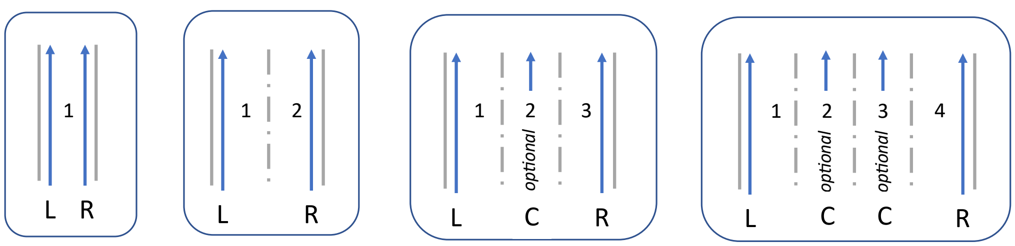
Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 11: Example Vehicle Path Data Logged Using the CAMP/Denso OBU

## Test Procedure

For each test run:

- Bring the vehicle to the posted speed limit at a distance greater than the extent of the MAP data for the lane of travel being evaluated (requires knowledge of the specific MAP configuration) and initiate data logging
- As illustrated in Figure 12, maintain vehicle position close to the left / right lane boundaries of the combined set of through lanes (associated with the same signal group) without allowing the nearest tire to touch the lane marking, until the vehicle reaches the stop bar. Collecting data along individual lane centers is considered optional.
- Terminate data logging at the stop bar for each individual test run.




Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 12: Example Vehicle Drive Path for MAP Utility Assessment Data Logging

## Data Analysis

### *Test Validity*

Valid runs must indicate minimum GNSS quality [4] for the entire run:

- HDOP <= 1.0 (smaller is better)
- # Satellites >= 9 (more is better)

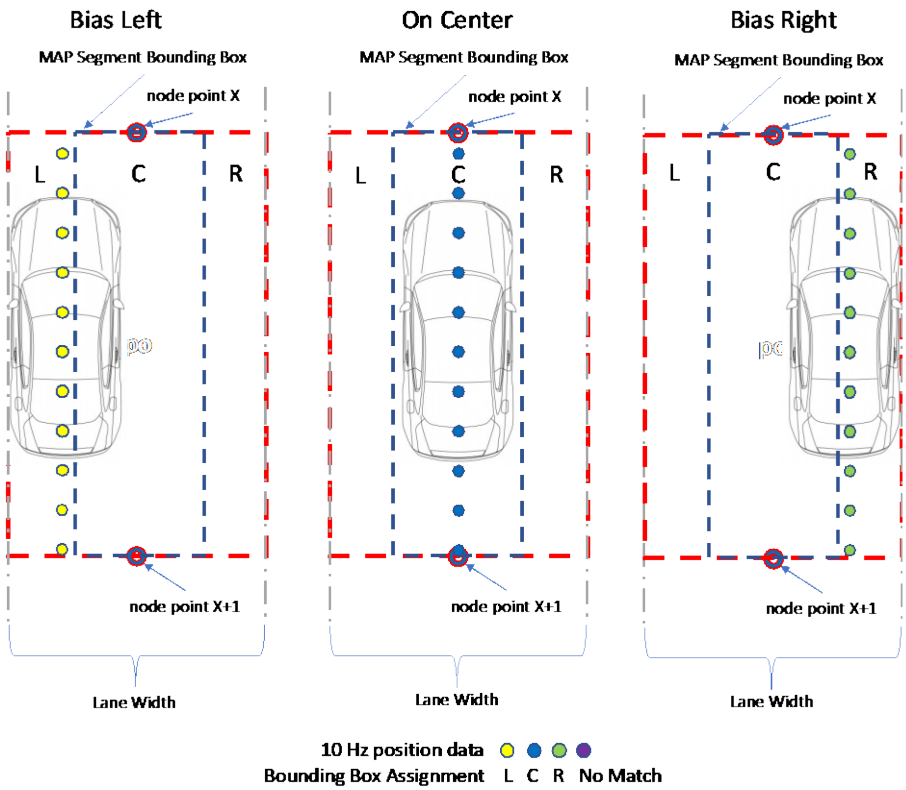
### *Pass/Fail Criteria*

For each CI approach evaluated, map matching to the group of through lane segments must be maintained for the entire run for both L and R drive paths for at least 7 out of 8 runs each with starting distance at least 10 sec from the stop bar for the 85$^{th}$ percentile speed determined as the posted speed plus 7 mph.

## References

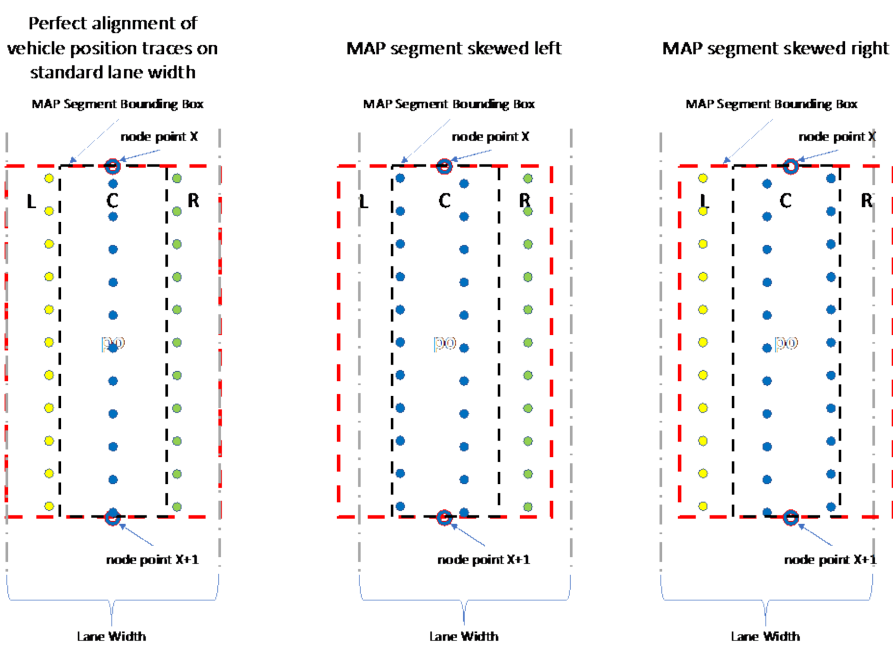

1. CTI 4502 v01.00 Connected Transportation Interoperability (CTI), Connected Intersections Validation Report, Findings from the Connected Intersections (CI) Project Validation Phase, February 2022, https://www.ite.org/pub/?id=59A8D354-F7B1-6A18-6FCC-1CECE6ACDE5B
2. What is the difference between WGS84 and NAD83? https://www.uvm.edu/giv/resources/WGS84_NAD83.pdf
3. Difference Between WGS84 and NAD83 (With Table) https://askanydifference.com/difference-between-wgs84-and-nad83-with-table/
4. Experimental Studies on the Relationship Between HDOP and Position Error in the GPS System, Metrology and Measurement Systems, Index 330930, ISSN 0860-8229, https://metrology.wat.edu.pl/earlyaccess/29/1/MMS-01244-2021-02-Early-Access.pdf
5. Cooperative Intersection Collision Avoidance System Limited to Stop Signs and Traffic Signal Violations (CICAS-V) Task 11 Final Report: Objective Tests, September 30, 2008, FHWA-JPO-10-068, https://pronto-core-cdn.prontomarketing.com/2/wp-content/uploads/sites/2896/2020/09/Appendix-H2-CICAS-V-Task-11-Objectives-Tests.pdf

## Appendix A – GNSS Position Trace Assessment for MAP Accuracy



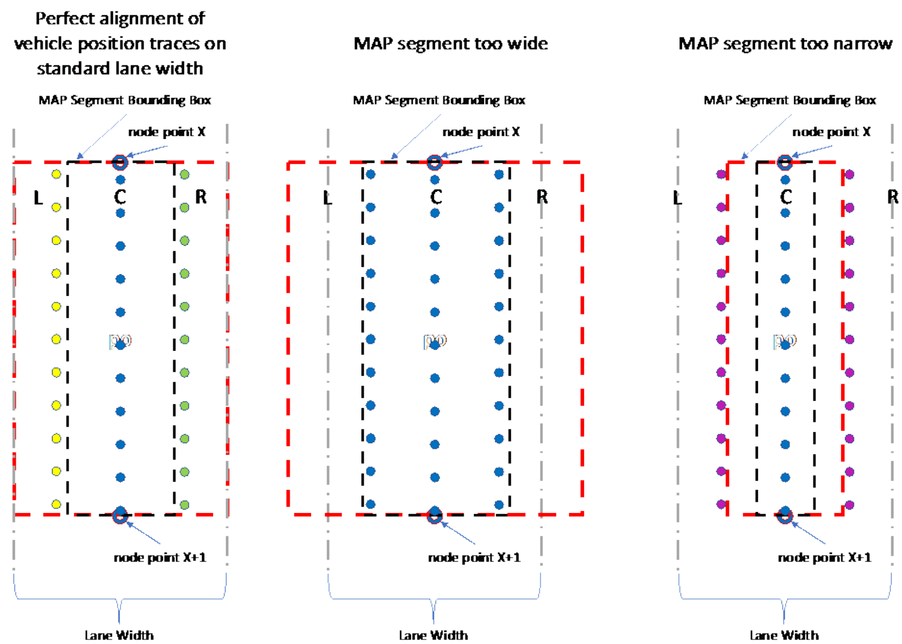

Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 13: Driving Positions for Data Collection



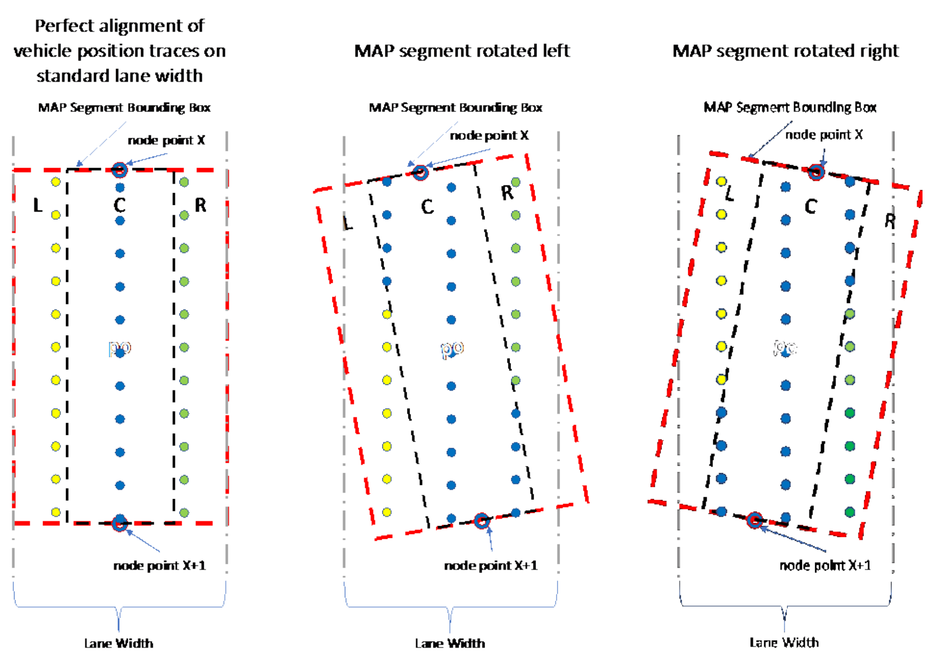

Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 14: Drive Data Interpretation - MAP Segment Skewed




Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

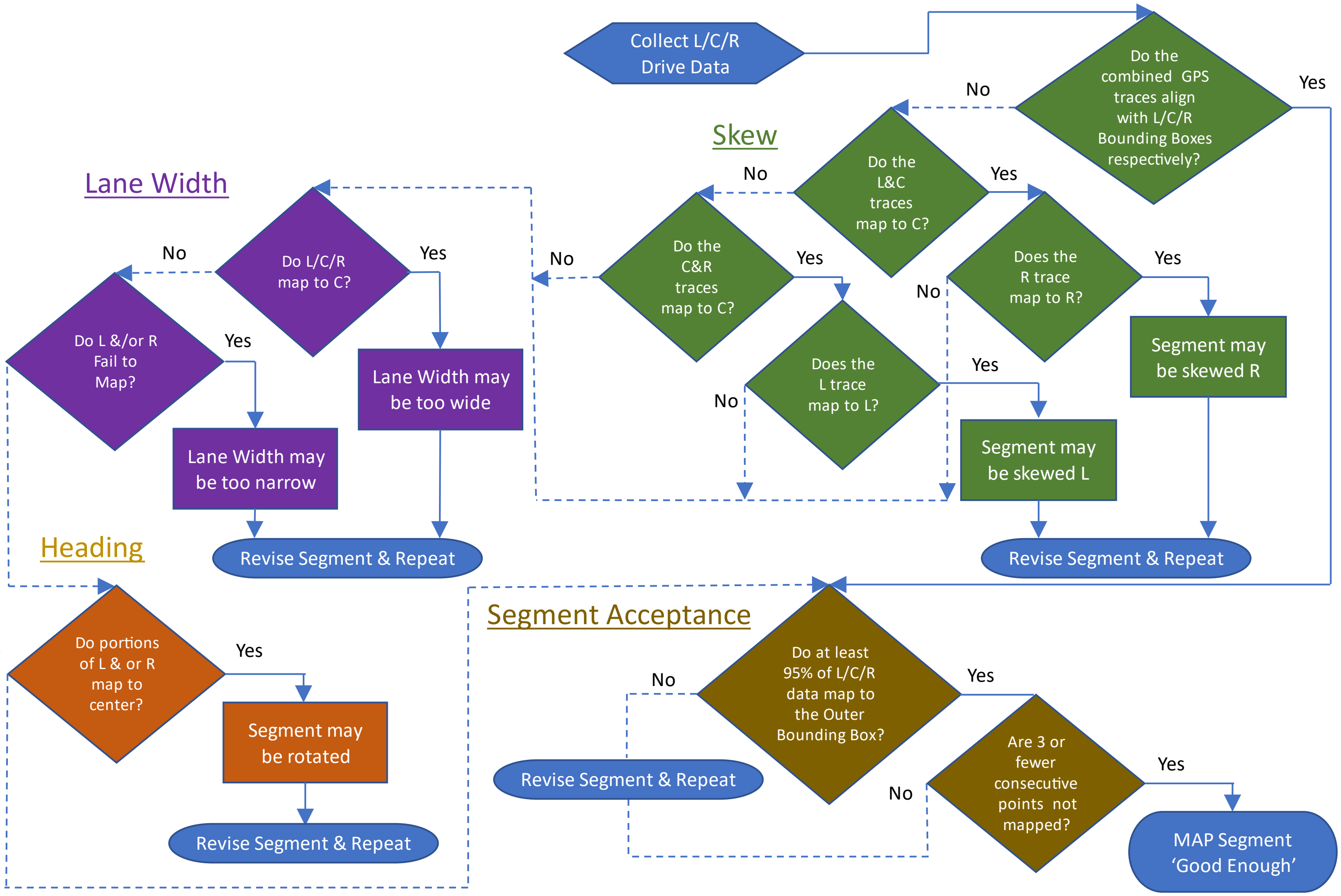
Figure 15: Drive Data Interpretation - Incorrect MAP Segment Width




Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 16: Drive Data Interpretation - Incorrect MAP Segment Heading

**Connected Intersection MAP Utility Assessment**
**Supporting Basic Red Light Violation Warning**




Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 17: Drive Data Interpretation Decision Tree