CAMP LLC

Vehicle to Infrastructure (V2I) Consortium

Vehicle-to-Infrastructure Program

V2I Safety Applications

Task 14 Interim Report
Development of Software Toolchain to Map, Visualize and Build Message for Connected Work Zone Safety Application

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Executive Summary

This report describes the work completed during Task 14 of the Vehicle-to-Infrastructure Safety Applications (V2I-SA) Project. Task 14, titled "Development of Software Toolchain to Map, Visualize and Build Message for Connected Work Zone Safety Application," was conducted from May 2017 through October 2018.

In this task, a dynamic mapping technique was developed to enable work zone mapping near real-time for the Reduced Speed Zone/Lane Closure Warning (RSZW/LC) application and evaluated efficacy of the technique in live work zones. The key element of this task was the development of a "software toolchain" that provides Infrastructure Owners and Operators (IOOs) the ability to easily generate and validate accurate and efficient lane level digital maps in standard format that represent both stable as well as dynamically changing road environments at a lane level for over-the-air transmission. The toolchain provides a mechanism for developing work zone map in a consistent manner.

The RSZW/LC safety application requires infrastructure related information to inform the driver of a transient reduction in speed limit ahead due to roadway configuration change such as lane closure. The work zone related data elements in a wireless message from the infrastructure include:

- Geometry of the work zone represented by waypoints that describe the layout for each lane
- Lane closure location(s) – start and end of lane closure(s) in the work zone
- Workers present zones(s) – area(s) where the workers are present in the work zone
- Posted speed limit(s)

The software toolchain contains applications to:

- Collect vehicle path data by traversing the work zone with an instrumented vehicle equipped with suitable positioning and recording capabilities
- Configure work zone parameters such as number of lanes, average lane width, posted speed limits and work zone schedule for building map and wireless message for over-the-air transmission
- Build work zone map geometry using collected vehicle path data that describes waypoints (node points) for each lane in the work zone including lane closures and workers present zones. The map is represented in Extended eXtensible Markup Language (XML) Encoding Rules (EXER) format for building wireless messages.
- Visualize the generated map waypoints (node points) on google map satellite view for visual verification

- Build Road Safety Message (RSM) as per the defined specification in the standard for over-the-air transmission

During the development of applications in the toolchain, applications were tested in live work zones on freeways and on arterial roads in Southeast Michigan and on I-35 near Temple, Texas. The live work zone provided real-world roadway configurations in refining the mapping technique, helped improve the waypoint selection algorithm and helped in building message for transmission. In addition, the ASN.1 definition for RSM was further enhanced from conducting tests in live work zones. The in-vehicle RSZW/LC application developed in the V2I-SA Project that used CAMP defined Basic Information Message (BIM) was updated for RSM.

To validate the mapping technique, vehicle path data was collected using an instrumented vehicle in live work zones from which maps were built and verified through the visualization tool in the toolchain. End-to-end toolchain functionality was tested including the in-vehicle RSZW/LC application on a four-lane arterial road work zone in Southeastern Michigan in a suburb of Detroit. The in-vehicle application performed as intended and generated appropriate alerts.

The software toolchain developed by the V2I Consortium in CAMP will be made available as free software to IOOs.

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List of Acronyms

ASN.1	Abstract Syntax Notation One
BSM	Basic Safety Message
CAMP	Crash Avoidance Metrics Partners LLC
CAV	Connected Autonomous Vehicle
CSW	Curve Speed Warning
CVMB	Connected Vehicle Message Builder
eGUI	engineering Graphical User Interface
EXER	Extended XML Encoding Rules
FHWA	Federal Highway Administration
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GUI	Graphical User Interface
IOOs	Infrastructure Owners and Operators
NMEA	National Marine Electronics Association
RSZW	Reduce Speed Zone Warning
RSZW/LC	Reduce Speed Zone Warning with Lane Closure
SAE	Society of Automotive Engineers
UPER	Unaligned Packed Encoding Rules
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2I-SA	Vehicle-to-Infrastructure Safety Applications Project
XML	eXtensible Markup Language

1 Introduction

This document describes the development of a software toolchain to build map describing work zone geometry, visualize and verify the map and build the Road Safety Message (RSM) for Reduced Speed Zone Warning with Lane Closures (RSZW/LC) safety application based on the functionality and data needs of the application. The application is developed under the Vehicle-to-Infrastructure Safety Applications (V2I-SA) Project conducted by the Crash Avoidance Metrics Partners LLC (CAMP) V2I Consortium. The project is sponsored by the Federal Highway Administration (FHWA) through Cooperative Agreement DTFH611H0002, Work Order 0003.

V2I applications potentially address scenarios that require information from the infrastructure for which vehicle on-board sensors alone may not be sufficient to provide the driver or system with information needed to take appropriate action in a timely manner. Proper and accurate infrastructure maps are crucial for the desired functioning of many V2I applications. V2I applications can employ any suitable technology or method to transmit infrastructure related information.

The ability to easily generate, validate and transmit accurate and efficient lane level digital maps is a key enabler for a wide range of safety, mobility and Connected Autonomous Vehicle (CAV) applications (i.e., V2I enabled applications). National implementation of consistent mapping technology to easily produce efficient, standard format over-the-air digital maps representing both stable as well as dynamically changing road environments at a lane level is beneficial for both vehicle manufactures and Infrastructure Owners Operators (IOO) to support deployment of wireless communication based V2I applications.

For example, the RSZW/LC safety application transmits infrastructure related information to inform the driver of a transient reduction in speed limit ahead due to roadway configuration change such as lane closure. A Road-side Unit (RSU) broadcasts work zone data elements in a wireless message from the infrastructure that include:

- Geometry of the work zone represented by waypoints that describe the layout for each lane
- Lane closure location(s) – Start and end of lane closure(s) in the work zone
- Workers present location(s) – area(s) where the workers are present in the work zone
- Posted speed limit(s) in the work zone

The in-vehicle application receives work zone related information from the infrastructure and combines it with on-board Global Navigation Satellite System (GNSS) data for vehicle position determination and vehicle dynamics data to alert the driver when:

- Lane closure(s) require the driver to change lanes
- Vehicle speed is higher than the work zone speed limit

One of the key functions of the in-vehicle application is to accurately determine the vehicle's lane-level position using the work zone geometry transmitted from the infrastructure. The selection of waypoints to represent work zone lane geometry has direct implications on the performance of the vehicle map matching algorithm in determining vehicle's position at a lane-level.

Experience has shown that effectiveness of this application is dependent upon timely information, which may require frequent infrastructure information updates as the work zone configuration and the presence of workers change. Figure 1 provides several examples of RSZW/LC scenarios which illustrate the variability in work zone configurations the system should address.

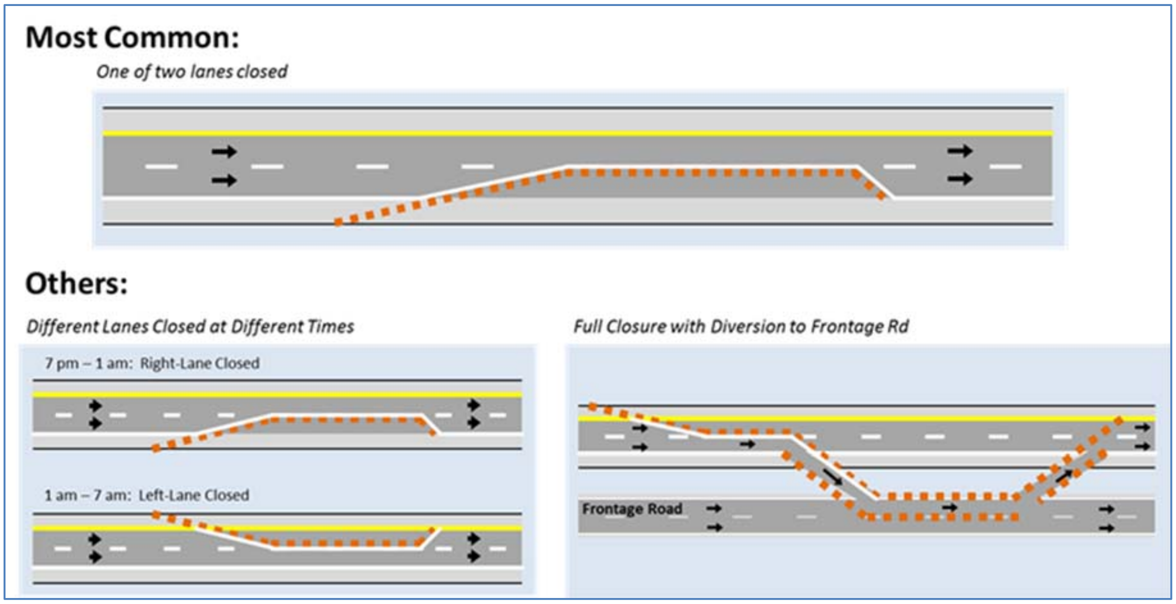


Figure 1: Examples of Work Zone Configuration

The toolchain consists of a set of application software developed to collect vehicle path data using an instrumented vehicle driven through the work zone for mapping, building the work zone map, visualizing the generated map and building the message for over-the-air transmission based on defined Abstract Syntax Notation One (ASN.1) schema for RSM and the SAE J2735 data dictionary as defined in the standard.

The Connected Work Zone software toolchain main menu shown in Figure 2 contains the following tools and steps associated in building a map, visualizing it and building the RSM for connected work zone for over-the-air transmission.

- Vehicle Path Data Acquisition: Collect vehicle path data of an instrumented vehicle equipped with high resolution GNSS receiver
- Work Zone Configuration: Configure work zone parameters such as number of lanes, average lane width, posted speed limits and work zone schedule

- Work Zone Map Builder: Build work zone map geometry using collected vehicle path data that describes waypoints (node points) for each lane in the work zone including lane closures and workers present zone. The map is represented in Extended eXtensible Markup Language (XML) Encoding Rules (EXER).
- Work Zone Map Visualizer: Visualize the generated map waypoints (node points) on google map satellite view for verification
- Connected Vehicle Message Builder (CVMP): Build the UPER encoded message as per the RSM defined specification for over the air transmission

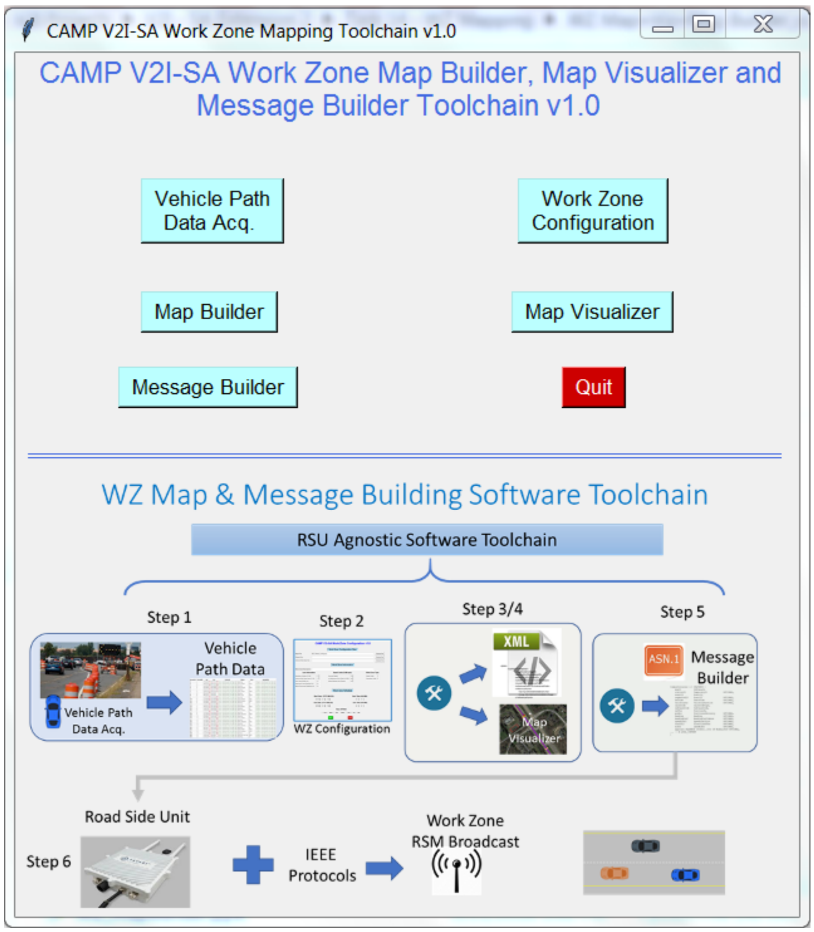


Figure 2: Software Toolchain - Main Menu

The remainder of the report is organized as follows:

- Section 2 describes work zone mapping, mapping requirements and traditional methods used
- Section 3 describes developed mapping technique and software tool for collecting and building map to represent lane geometry. A visualizer tool to see the built map overlaid on Google Map is also described in this section.

- Section 4 describes the visualizer tool to view the constructed map and associated node level attributes overlaid on Google Map.
- Section 5 describes map message builder tool. This tool builds RSU independent RSM for the constructed work zone map for over the air transmission.
- Section 6 describes end-to-end toolchain testing and data analysis for a work zone
- Section 7 contains summary for Task 14

2 Mapping a Work Zone

A work zone map defines the layout and configuration of the lanes approaching the work zone and available lanes for traveling in the work zone.

Work zone map consists of three major elements:

Reference Point: Defines beginning of the work zone. The vehicle application uses the location of the reference point for generating appropriate alerts for the driver.

Approach Lane(s): Defines lane(s) that lead to the work zone

Work Zone Lane(s): Defines lane(s) within the work zone

Figure 3 illustrates a map that shows three approach lanes leading to the work zone and lanes in a work zone. The event begins at the marked reference point. As shown, lane geometry in the work zone has two lane closures. Lane closures and path through the work zone is defined by lane geometry. Lane numbers are designated from left to right in the direction of travel, with left lane being the lane number 1.

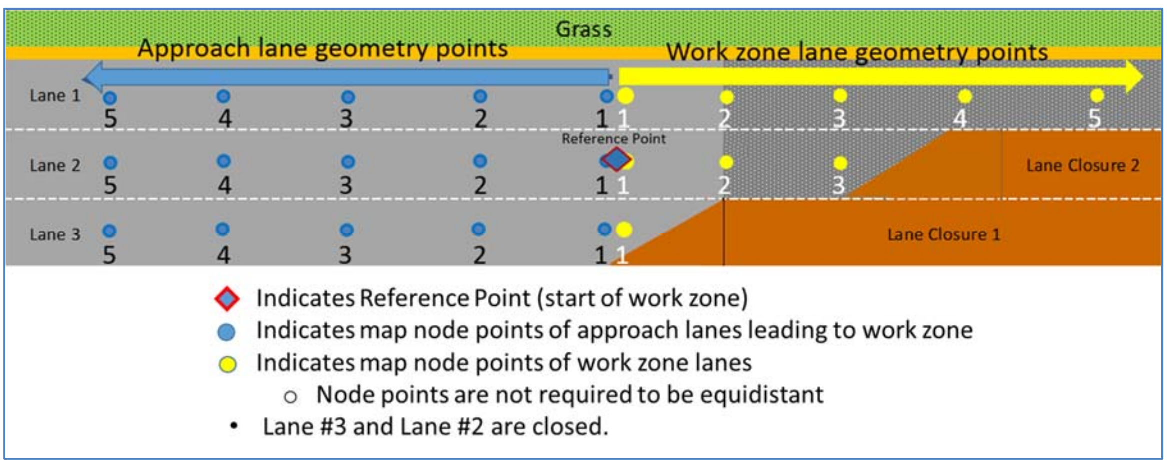


Figure 3: Illustrative Work Zone Map - 3 Lanes with 2 Lane Closures

The following guidelines are established to generate a work zone map. The guidelines are based on ASN.1 schema defined for RSM as proposed in SAE J2945/4 document, SAE J2735 data dictionary and requirements for on-board application.

The Reference Point to designate the start of the work zone is placed in the middle of the overall road cross section. The reference point is represented by latitude, longitude in degrees and altitude in meters.

Lane geometry waypoints (node points) are always in sequence starting from the "Reference Point" and moving away as shown in Figure 2. For the approach lane(s), waypoints (node points) are sequenced opposite to the direction of travel and the work zone lane(s) sequencing follows in the direction of the travel.

For each lane, geometry waypoints (node points) are represented in an X and Y offset from the prior node point. For simplicity, the waypoints (node points) are defined by their latitude, longitude in degrees and altitude in meters at the center line path of the lane. Each node point is then converted into XY offset in centimeters from the previous node point to reduce message payload size

The distance between the “Reference Point” and the 1st geometry waypoint (node point) for both the approach lane and the work zone lane should be equal to or less than the lane width to maintain map matching continuity from approach to work zone by the in-vehicle application.

It is recommended that all approach lanes contain map waypoints (node points) that cover a distance equivalent to a minimum of 20 seconds of vehicle travel at the posted speed limit. This is required by the in-vehicle application to determine vehicle position at lane level and to generate inform / warning messages for the driver to take appropriate action. For example, to support a vehicle approaching a work zone at a speed of 117kph (70mph), approach lanes should contain a minimum 626 meters (2054 ft) of map waypoints (node points).

Lane geometry for each lane in the work zone should be provided for the entire length of the work zone.

The start of a lane closure (lane taper) distance in work zone is defined as an offset in meters from the “Reference Point.”

Traditionally, for V2I applications, waypoints (node points) for lane geometry are constructed by conducting a survey of lanes with fixed distance points. The surveyed points are then converted to proper format as described in SAE J2735 message set data dictionary. Such practice of conducting a survey can be costly and time consuming. It may also be necessary to conduct such survey multiple times since the road configuration, such as lane closures, invariably change several times during the roadway construction.

Alternately, waypoints for lane geometry can be generated by selecting points using a mapping software tool such as Google Earth Pro that provides latitude, longitude and elevation to define waypoints for lane geometry and then converts the waypoints to the appropriate format. For long roadway construction segments, this method can be very slow and prone to errors and may produce highly inaccurate lane geometry that would be insufficient for meeting V2I application map matching requirements. In cases where new roadway is being constructed, Google Map may not be available to define lane geometry.

2.1 Lane Level Vehicle Map Matching

Figure 4 shows a map matching algorithm concept that uses waypoints for a lane geometry and vehicle position using GPS. A virtual bounding box equal to the lane width (shown using a blue dashed line) is created using two consecutive waypoints or node points of the lane geometry. When the vehicle position is within the virtual bounding box, it is determined to be within the lane. The placement of consecutive waypoints (node points) may result in portions of the virtual bounding box being located outside the physical lane, particularly for a curved lane segment. In such cases, the map matching algorithm may produce either a false-positive result, indicating the vehicle is in lane when it is not (shown by the green crosshatched area in the figure), or a false-negative result, indicating the vehicle is out of the lane when it is in the physical lane (red crosshatched area).

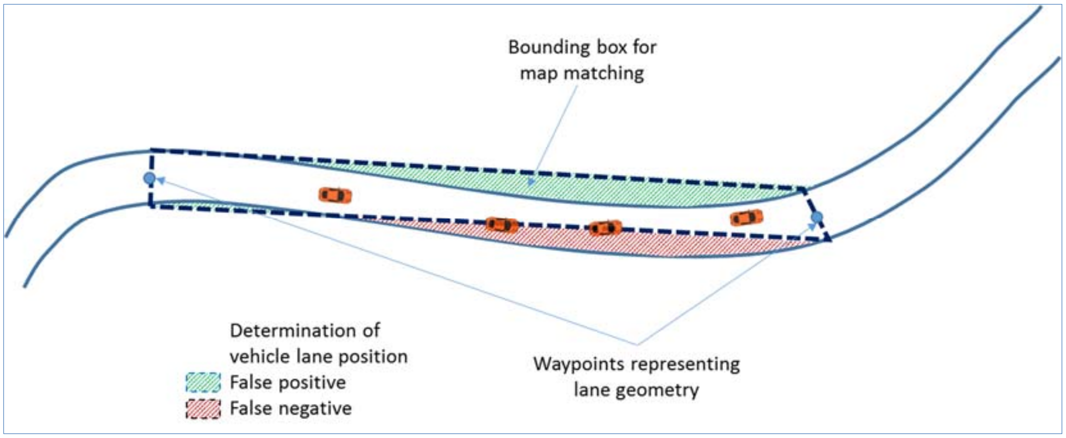


Figure 4: Vehicle Map Matching Using A Bounding Box

As illustrated in Figure 5, as the distance between the placement of the consecutive waypoints increases along a curved road segment, more and more portions of the virtual bounding box, as shown by dashed line, falls outside the physical lane, which increases potential for false positive and false negative errors in the map matching.

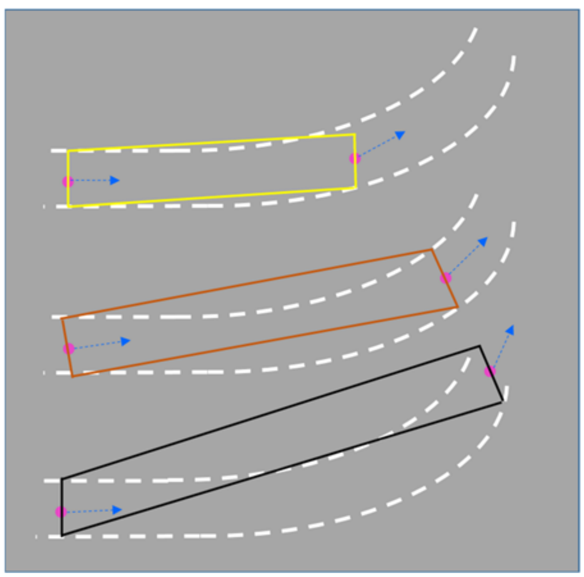


Figure 5: Placement of Lane Geometry Waypoints Based on Fixed Distance

As shown in Figure 6, lane geometry can be described by placing waypoints at a very close distance such that the virtual bounding box fully covers the physical lane segment. However, for a long work zone, it is very likely that the number of waypoints needed to represent the lane geometry could be greater than 63 waypoints (upper limit set in SAE J2735 specification) and would require splitting the lane geometry into multiple segments requiring multiple messages to represent the work zone resulting in loss of efficiency.

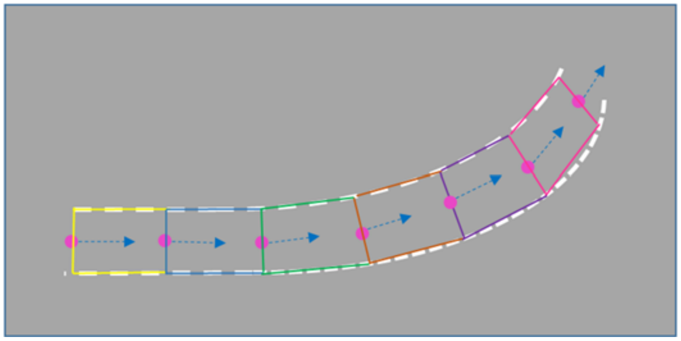


Figure 6: Lane Geometry Waypoints Based on Close Fixed Distance

To alleviate the issue described in previous section, the lane geometry waypoints need to be closer on curved lane segments while they can be further apart on straight segments such that the virtual bounding box for two consecutive waypoints maximizes the coverage of the lane area. As shown in Figure 7, the distance between waypoints can be varied as lane curvature changes to better accommodate straight and curved lane segments.

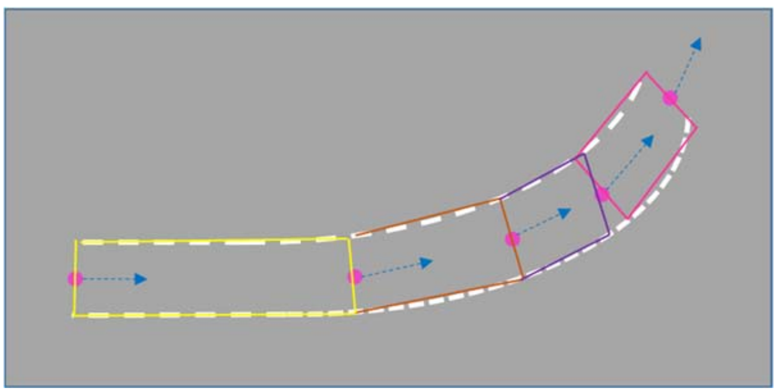


Figure 7: Lane Geometry Waypoints Based on Variable Distance

3 Mapping Technique

First step towards developing a work zone map is to acquire data points that describe centerline of a lane represented in latitude, longitude and elevation at sufficient resolution and accuracy. A vehicle instrumented with a GNSS receiver with submeter accuracy under open sky condition is used in the toolchain to acquire data vehicle path data

3.1 Vehicle Path Data

A U-blox EVK-M8N GNSS receiver was configured to interface with the data acquisition computer for serial communication and to acquire appropriate National Marine Electronics Association (NMEA) string from the receiver at 10Hz. Steps for the one-time setup to configure the U-blox GNSS receiver is described in a separate user guide document.

3.1.1 Vehicle Path Data Collection

It is required to collect vehicle path data by driving an instrumented vehicle with the GNSS receiver connected to PC running the vehicle path data acquisition module. It can be initiated from the main menu shown in Figure 2. Following data elements are collected at 10Hz and logged in comma separated value (csv) format for use by Map Builder tool in the toolchain.

- GNSS Date and Time stamp
- Number of satellite seen by the receiver
- Horizontal Delusion of Precision (HDOP) - A factor in determining the relative accuracy of a horizontal position. The smaller the DOP number, the better the geometry.
- Latitude and Longitude in degrees and Altitude in meters
- Vehicle speed (m/s)
- Vehicle heading in degrees
- User entered marker and value – list of work zone markers, its meaning and value is described later in this document

Table 1 provides list of markers for the work zone, its value and meaning.

Table 1: List of Markers for Work Zone, Associated Value and Meaning

Marker	Value	Meaning
Data log	TRUE | FALSE	Data logging true or false (start / stop)
LC	1|2|3|…|9	Start of lane closure followed by lane number
LO	1|2|3|…|9	End of lane closure (lane open) followed by lane number
RP		Reference point (start of work zone)
LC+RP	1|2|3|…|9	Start of lane closure at start of work zone (reference point)

Marker	Value	Meaning
WP	TRUE | FALSE	Workers present True or False (start / end of workers present zone)
WP+RP	TRUE | FALSE	Start of workers present zone at start of work zone (reference point)
App Ended		Application ended

Figure 8 shows an example of a csv file of collected vehicle path data.

GPS Time	# of Sats	HDOP	Latitude	Longitude	Altitude(m	Speed(m/s	Heading(D	Marker	Value
20:16:48:8	12	0.74	42.57763	-83.2397	262.4	7.131743	149.79	Data Log	TRUE
20:16:48:9	12	0.74	42.57763	-83.2397	262.4	7.131743	149.79		
20:16:49:0	12	0.74	42.57762	-83.2397	262.4	7.252638	149.45		
20:16:49:1	12	0.74	42.57762	-83.2397	262.4	7.379191	148.95		
20:16:49:2	12	0.74	42.57761	-83.2397	262.4	7.423948	148.35		
20:16:49:3	12	0.77	42.5776	-83.2397	262.4	7.586512	148.08		
20:16:49:4	12	0.77	42.5776	-83.2397	262.4	7.761423	148.28		
20:16:49:5	12	0.77	42.57759	-83.2397	262.4	7.845278	147.44		
20:16:49:6	12	0.77	42.57759	-83.2397	262.4	8.052599	147.71		
				…					
20:17:22:6	11	0.8	42.57302	-83.2354	253.7	21.41941	145.29	LC+RP	4
20:17:43:6	11	0.8	42.56985	-83.2324	247.4	19.39919	145.35		
20:17:43:7	11	0.8	42.56983	-83.2324	247.4	19.4388	145.44		
20:17:43:8	11	0.8	42.56982	-83.2323	247.4	19.42645	145.11		
				…					
20:17:45:1	11	0.8	42.56963	-83.2322	246.9	19.23405	145.56		
20:17:45:2	11	0.8	42.56962	-83.2322	246.8	19.18775	145.38		
20:17:45:2	11	0.8	42.56961	-83.2321	246.8	19.05142	145.33	LC	3
20:17:45:3	11	0.8	42.56961	-83.2321	246.8	19.05142	145.33		
20:17:45:4	11	0.8	42.56959	-83.2321	246.8	19.15071	145.43		
				…					
20:18:14:2	12	0.77	42.56633	-83.229	242.4	7.279389	145.45	WP	TRUE
20:22:12:6	12	0.74	42.54705	-83.2116	238.5	10.61608	161.7	App Ended	

Figure 8: Example of Collected Vehicle Path Data

3.1.2 Steps to Collect Vehicle Path Data

It is necessary to follow the steps described here when acquiring data for building a lane level map.

- Select an open lane throughout the work zone for driving to collect data
- While collecting vehicle path data:
    - Drive on the selected open lane and stay on the lane through the entire work zone being mapped. Do not change lane
    - Maintain the vehicle position in the centerline of the as much as possible
    - Maintain constant vehicle speed within the posted speed limit as much as possible.

  - Start data logging at least 600m before the start of the work zone. This portion of logged data provides approach lane leading to the work zone.
- Graphical representation of a work zone for vehicle path data collection is shown in Figure 9.

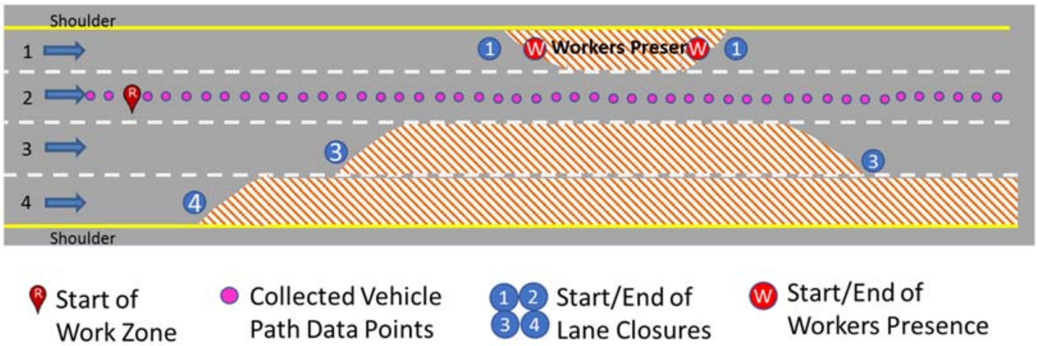


Figure 9: Graphical Representation of Vehicle Path Data Collection

- In addition to collecting vehicle path data, users can mark the following markers to associate location of occurrence in a work zone. The markers can be marked either by using the appropriate key on the key board or by selecting the appropriate button on the tool's Graphical User Interface (GUI) screen shown in Figure 10. A detailed description of the key / GUI button for marking occurrences is described in the user guide.
  - Reference Point to Indicate Start of Work Zone
  - Start / End of Lane Closure
  - Start / End of Workers Present Zone
  - Start / Stop Vehicle Path Data Logging
  - End Data Logging and Stop the Application

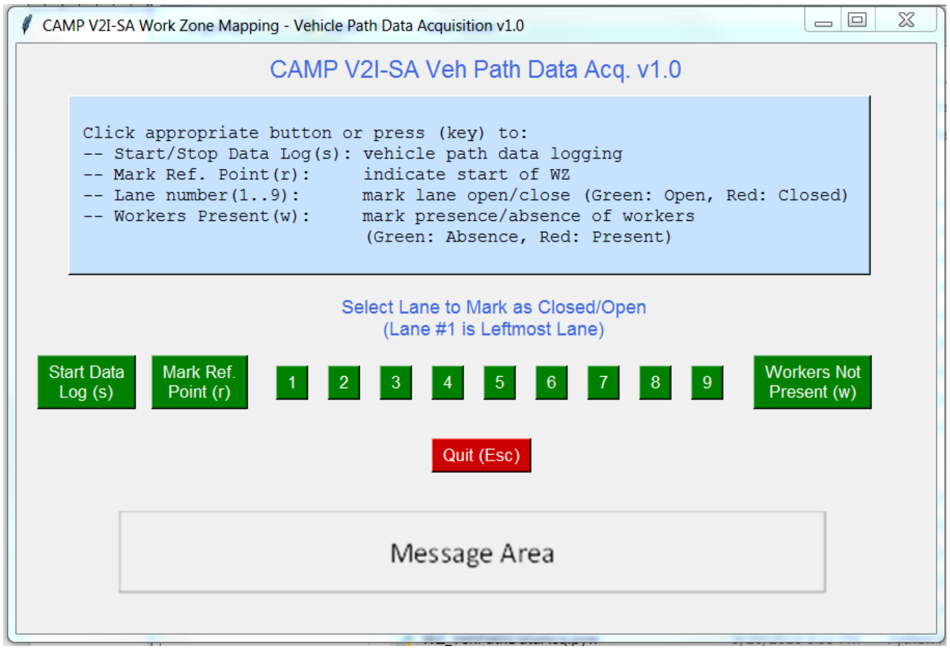


Figure 10: Graphical User Interface Screen

3.2 Work Zone Configuration

Configuring the work zone and providing required parameters is mandatory before proceeding to building map of the work zone. Work zone configuration can be initiated from the main menu shown Figure 2. Figure 11 shows the user interface screen to configure a work zone.

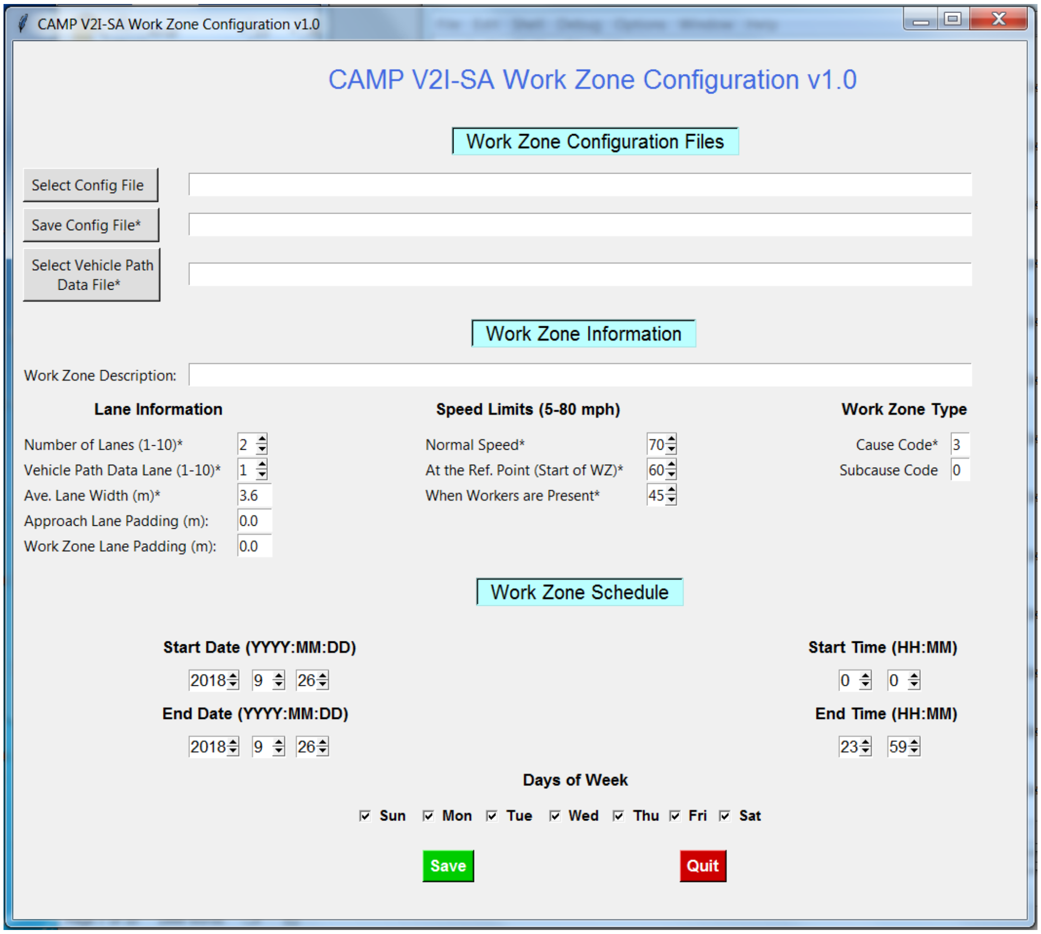


Figure 11: Work Zone Configuration Input Screen

User input is organized in three sections. Required input fields are marked with *.

1. **Work Zone Configuration Files:**
   a. Select Config File – Select an existing configuration file (.wzc file extension) or leave it blank. When an existing file is used, pertinent information from the file is used to fill in the input fields.
   b. Save Config File* – Save work zone configuration file
   c. Select Vehicle Path Data File* – User is required to enter collected vehicle path data file name (.csv file extension) generated in the "Collect Vehicle Path Data" step
2. **Work Zone Information:**
   a. Work Zone Description – Enter description of the work zone. This information is later used in visualizer tool for user information.
   b. Lane Information:
      - Number of Lanes (1-9)* – Enter number of lanes in the work zone

- Vehicle Path Data Lane (1-9)* – Enter the lane number on which the vehicle path data was collected in the "Collect Vehicle Path Data" step
- Ave. Lane Width (m)* – Enter average lane width in meters
- Approach Lane Padding (m) – This field allows variation in average lane width by the padding value
- Work Zone Lane Padding (m) – This field allows variation in average lane width by the padding value

c. Speed Limits:

- Normal speed* – Normal speed limit of the roadway before entering the work zone
- At the reference point* – Speed limit at the start of the work zone
- When Workers are Present* – Speed limit associated when the workers are present in the work zone

d. Work Zone Type:

- The cause and sub-cause codes are set to 3 and 0 respectively to indicate long term work zone. Refer to the user guide for list of Cause Codes.

3. **Work Zone Schedule:**
Work zone schedule provides date and time during which the transmitted message from an RSU for a work zone is applicable for the on-board application.

a. Start and end dates and start and end times for work zone is specified in this user input section. It should be noted that end date and time must be later than the start date and time.

b. In addition, the days of week can be checked for the work zone message transmitted by the infrastructure which is in effect for the on-board application.

3.3 Map Builder

The Map Builder tool builds the work zone map from collected vehicle path data and user provided work zone configuration. The tool generates two output files:

1. An output file containing data elements and arrays in JavaScript format for processing by the Map Visualizer tool to overlay data on google map.

2. Generated work zone map represented in EXER format based on the ASN.1 definition provided in Appendix A. This file is used by Message Builder tool to generate UPER encoded RSM for transmission.

3.3.1 Method for Selecting Lane Geometry Waypoints

In this section, the method for selecting dynamically spaced waypoints (node points) to represent lane geometry by adjusting for road segment curvature is described. These waypoints are derived from set of closely spaced data points generated by driving an instrumented vehicle on the roadway and collecting vehicle path data as shown by the purple dots in Figure 12. Each vehicle path data point contains latitude, longitude, altitude and heading information for the road segment under consideration (Note: data points should be collected as close to the center line of the lane as possible).

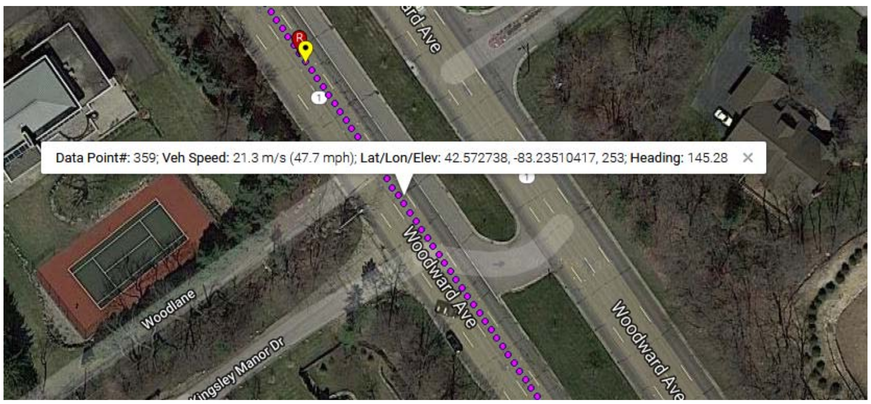


Image Source: Map data ©2018 Google Imagery ©2018. Used with permission.

Figure 12: Vehicle Path Data Points and Associated Location Information

3.3.2 Algorithm for Selecting Waypoints

The algorithm used for selecting appropriate waypoints to represent lane geometry uses vehicle heading information to determine if the projected path of the vehicle remains within the current lane or leads to an adjacent lane by virtually connecting consecutive data points (purple dots) with respect to deviation in the vehicle's heading angle. Algorithm steps for selecting waypoint is described.

<u>Steps:</u>

1. Select a vehicle path data point as the first waypoint (node point) and mark it as the current waypoint. The next waypoint for the lane geometry will be selected with respect to the current waypoint.
2. Select the next vehicle path data point.
    a. Compute linear distance between the current waypoint and the selected vehicle path data point and set it as base of a right triangle.
    b. Construct a right triangle as shown in Figure 13 in red using the current waypoint and the selected vehicle path data point as a hypotenuse of the triangle and the angle between the hypotenuse and the base as the difference in heading angle between the two points.

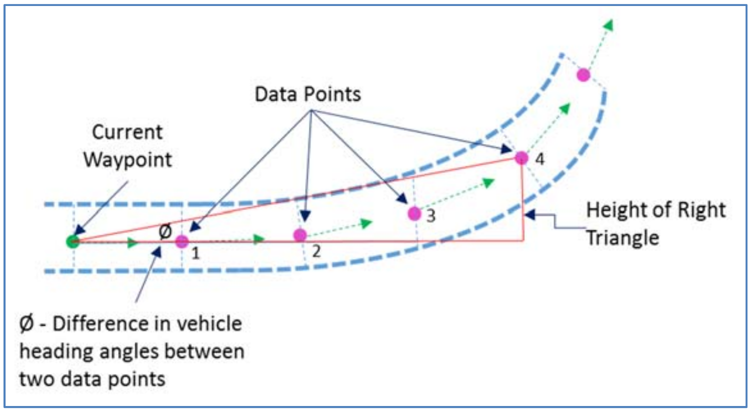


Figure 13: Construction of Right Triangle for Selecting a Waypoint

3. Compute the height of the triangle.
    a. If the computed height of the triangle is less than required height (e.g., half the lane width plus tolerance), go to step 2.
    b. If the computed height is equal or greater than the required height, mark the current vehicle path data point or previous vehicle path data point as potential new waypoint (node point).
    c. Check computed height of right triangle for next N_{eval} vehicle path data points.
        i. If for all N_{eval} vehicle path data points the height is greater than the required height, set the marked data point as the new waypoint (node point) otherwise go to step 2.
4. Go to step 2 until all vehicle path data points are processed.
5. Select the last data point as the final waypoint (node point).

A detailed flowchart for the steps described for selecting waypoints for lane geometry is shown in Figure 14.

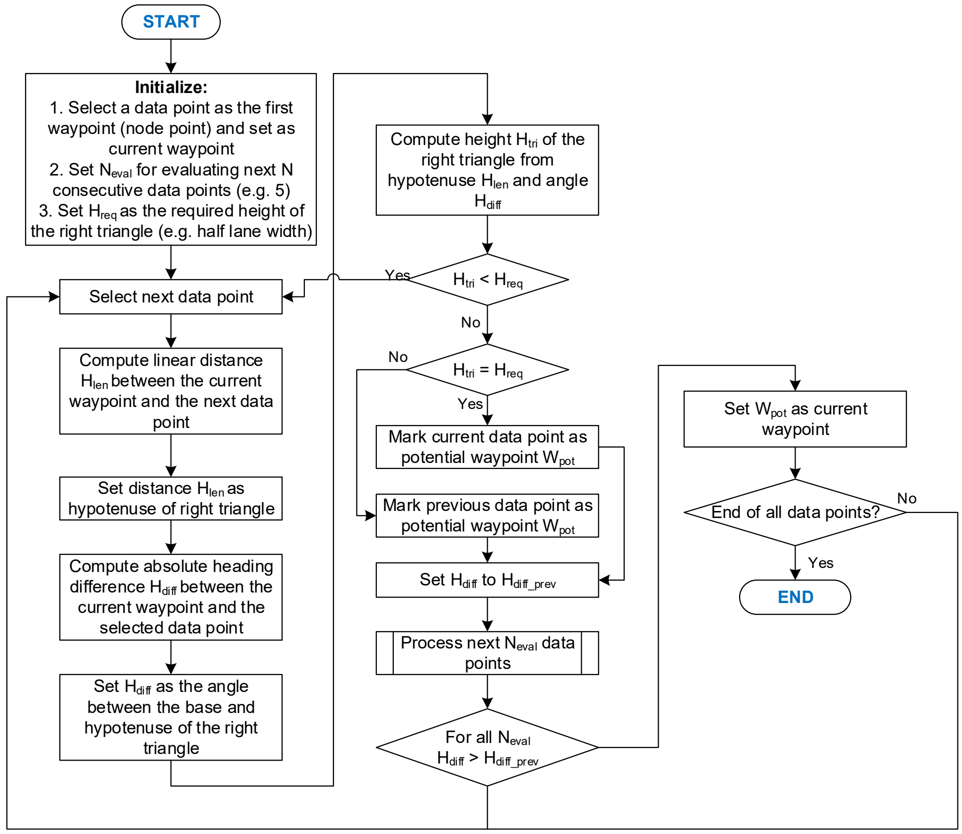


Figure 14: Detailed Flowchart for Selecting Waypoints for Lane Geometry

The algorithm first selects the waypoints for the lane for which vehicle path data points are collected. The waypoints for adjacent lanes are computed as an offset based on the lane position (left or right) and average lane width plus allowed variation in lane width, all in meters. An array of waypoints for all lanes in the work zone is generated for further processing.

Additional forced waypoints (node points) are inserted for the lane geometry. These forced waypoints have attributes that define the following specific changes in the work zone configuration.

1. Marked lane closure and open: When a lane is marked as closed or open, a waypoint is induced in the waypoint list that provides start or end of lane closure attribute to the waypoint. This waypoint provides needed information to the on-board application to inform/warn driver for a lane change including possible lane to change to.

2. Marked workers present zone: Location where workers present zone is marked. Induced waypoint indicates start or end of workers present zone and may indicate change in speed limit. This information is essential to warn the driver about the presence of workers and may require speed change.

3.3.3 Message Segmentation

For a long and complex work zone consisting of a roadway with lanes on curvature following two conditions may violate the requirements set for defining work zone map and constructed message for transmission.

1. It is likely that the number of waypoints (nodes points) to represent lane geometry may exceed the limit of 63 nodes per lane as set in SAE J2735 specification.
2. The message payload for transmission may exceed the maximum size of 1500 octet (1 octet = 8 bits). In addition to the work zone map message portion of the payload, the payload includes the required header and protocols defined in IEEE.

To meet these requirements, the generated map message may be required to split in multiples messages called segments to represent the entre work zone. The algorithm in map builder tool considers both requirements and builds waypoint lists to split the work zone map in two or more segments as appropriate. To represent a waypoint, approximately 11 octet is required. Also, approximately 400 octet are required for the message header and other required protocols in a payload for transmission leaving 1100 octet for the work zone map. A work zone map consisting 100 or less waypoints can be represented in a single message.

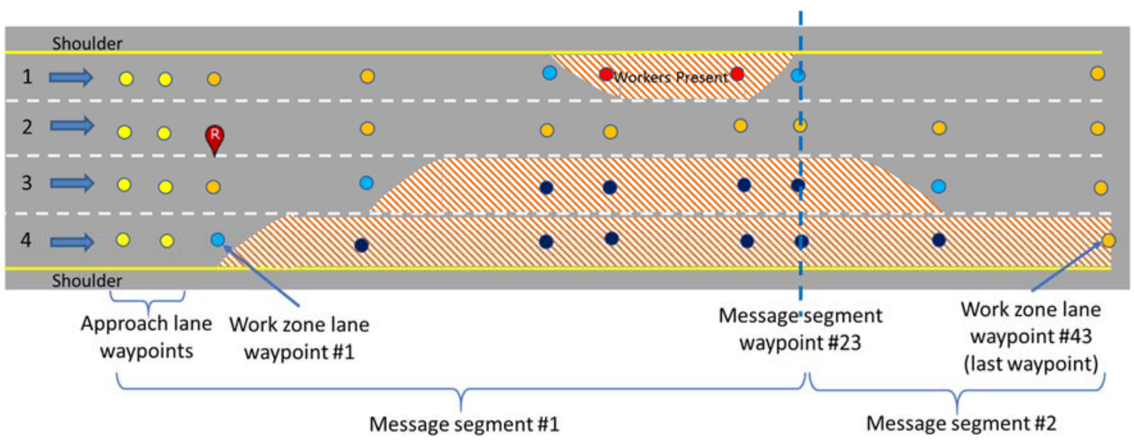


Figure 15: Real-World Example of Segmented Work Zone Map Message

As shown in real-world example of a four-lane work zone in Figure 15, the work zone map message for the entire work zone is divided in two segments. The first segment includes all waypoints for the approach lanes. The remainder of the first segment includes 23 waypoints for the work zone lanes (up to computed maximum waypoints per segment). The last waypoint in the current segment is repeated as the first waypoint in the next segment to maintain continuity at lane level map matching for the on-board application. In this example, the work zone map has total 45 waypoints (2 waypoints for approach lane and 43 waypoints for work zone lane) per lane. In all, the entire work zone with four lanes is represented by 180 waypoints. The first message segment contains total 25 waypoints including two waypoints 1 and 2 for the approach lanes and waypoints 1 through 23 for the work zone lanes. The second segment contains the remaining 20 waypoints. Every message segment also has a reference point to indicate the start of work zone segment.

4 Work Zone Map Visualization

The Map Visualizer tool provides visual verification of the work zone map built in the Map Builder step. The visualizer uses the computer's default web browser to overlay map's waypoints on Google Satellite view for display. When the tool is initiated, collected vehicle path data points are overlaid as shown in Figure 16. Each purple dot indicates the position of vehicle path as driven for data collection. Selecting any purple dot with the mouse click shows data point number, vehicle speed, latitude, longitude, altitude and heading information at that location of the vehicle. In addition, the location marked for the reference point that indicates the start of the work zone is shown by a red pin. Mouse click on the red pin shows marked latitude, longitude and altitude of the reference point.

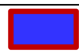
Image Source: Map data ©2018 Google Imagery ©2018. Used with permission.

Figure 16: Map Visualizer - Vehicle Path Data Points

Locations marked to indicate work zone lane status (closed/open) are displayed as shown in the inset in Figure 16. The start of a lane closure is shown by a yellow pin and the end of a lane closure is shown by a blue.

To view overlaid constructed work zone map waypoints (node points) for each lane, select the "Overlay WZ Map" button. Generated waypoints that represent lane geometry are denoted by different legends/icons is listed in Table 2.

Table 2: Legends/Icons used in Map Visualization

Legend / Icon	Description
	Collected Vehicle Path Data Point
	Approach Lane Geometry Waypoint (node point)
	Work Zone Lane Geometry Waypoint (node point)
	Closed Lane Geometry Waypoint (node point)
	Bounding Box for Map Matching for Approach Lane
	Bounding Box for Map Matching for Work Zone Lane
	Workers present Indicator
	Reference Point – Start of Work Zone
	Marked Start of Lane Closure
	Marked End of Lane Closure

In addition to overlaying map waypoints, a shaded rectangle bounding box spanning each segment formulated by two consecutive waypoints and specified lane width is drawn to show a bounding box generated from the waypoints to verify that the vehicle path data points are within the bounding box. As described earlier, the bounding box provides the basis for the map matching algorithm.

Boxes shaded in green indicate approach lane node segments and boxes shaded in blue indicate work zone lane node segments as shown in inset in Figure 11. Selecting any waypoint legend/icon with mouse click, and associated attributes, for example, lane and node number, lane status, and node position in latitude, longitude and altitude are shown.

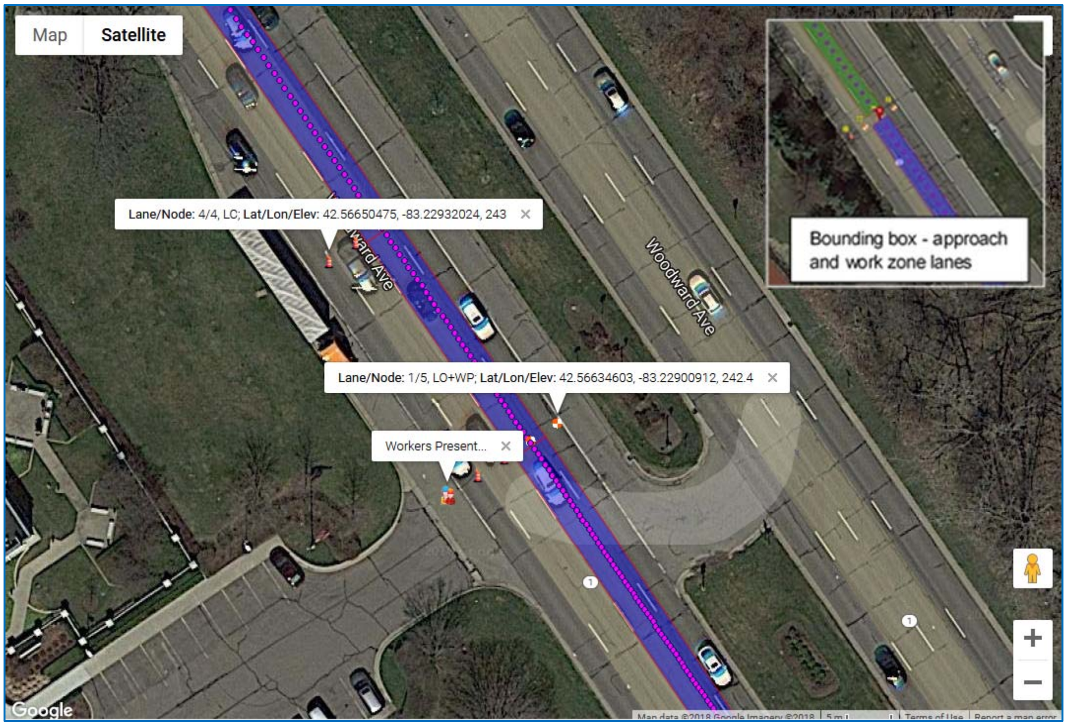


Image Source: Map data ©2018 Google Imagery ©2018. Used with permission.

Figure 17: Map Visualizer - Work Zone Map Node Points and Shaded Bounding Box

Visualization provides a detailed map of the work zone to help verify created work zone map.

5 Connected Vehicle Message Builder (CVMB)

The CVMB provides an automated software-based solution to convert an XML schema into UPER-encoded RSZW/LC and curve speed warning (CSW) messages compliant with the ASN.1 representation of RSM. The CVMB accepts EXER messages and generates UPER encoded messages based on user inputs. CVMB also accepts UPER encoded messages and convert them to XML. All messages are based on the ASN.1 schema for the RSM and the SAE J2735 (March 2016) data dictionary. The generated UPER encoded message is the communication medium agnostic for message transmission. Figure 18 shows CVMB tool as step 5 in the toolchain highlighted in green.

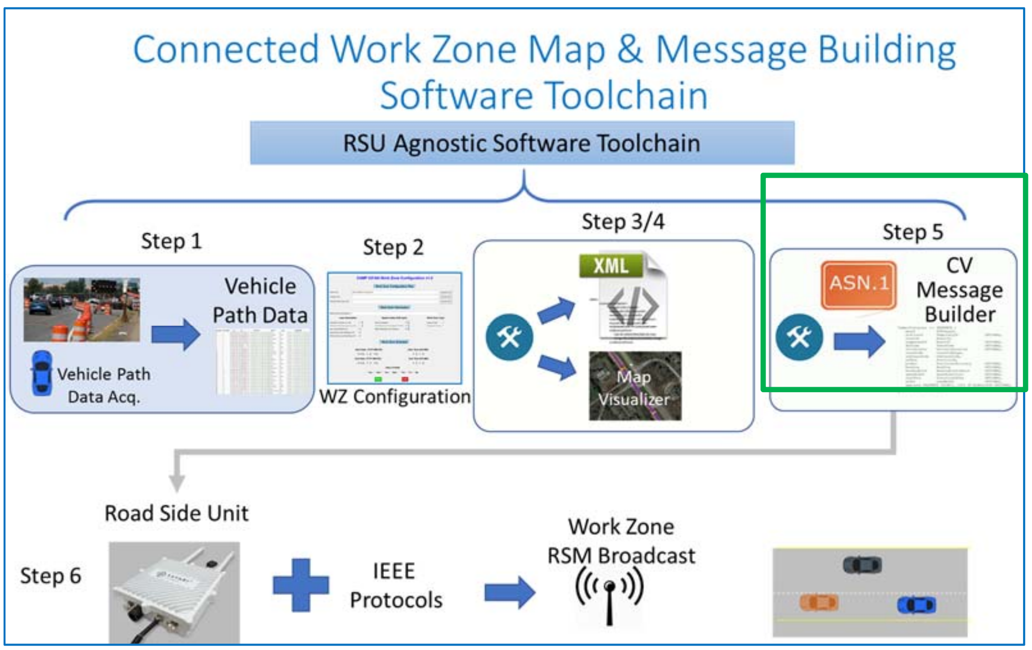


Figure 18: Connected Vehicle Message Builder Tool in the Toolchain

5.1 Management Information Base (MIB)

A message framework to enable extensibility to support potential use cases and to address both static and dynamic events, the message consists of a common container that corresponds to the common requirements, and optionally an application-specific container is included as needed to support certain application use cases. Not all instances of a use cases require the application container. For example, a reduced speed zone warning that supports a school zone does not require an application container. However, a reduced speed zone warning that supports work zones does require an application container. The common and application containers concept is illustrated in Figure 19.

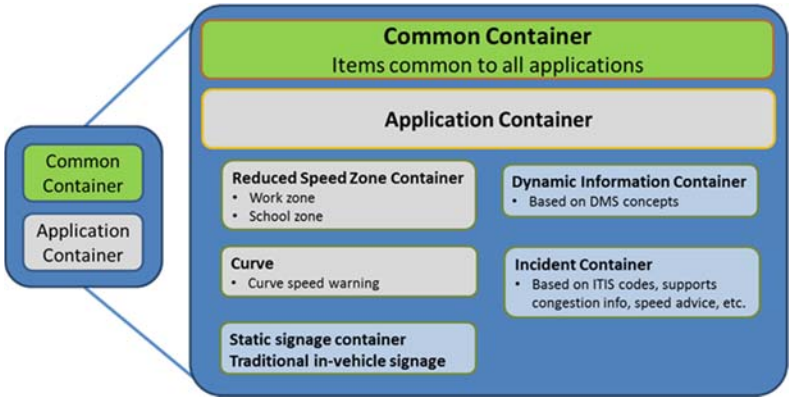


Figure 19: Common and Application Containers

5.2 CVMB User Interface

As shown in Figure 20, the CVMB tool provides a graphical user input screen for use to select conversion operation. The tool provides conversion from an XML file to UPER encoded binary file and from an UPER encoded binary file to XML file. This allows the user to compare and verify the conversion from XML UPER and back to XML. Steps to convert XML to UPER or UPER to XML are shown in the Figure.

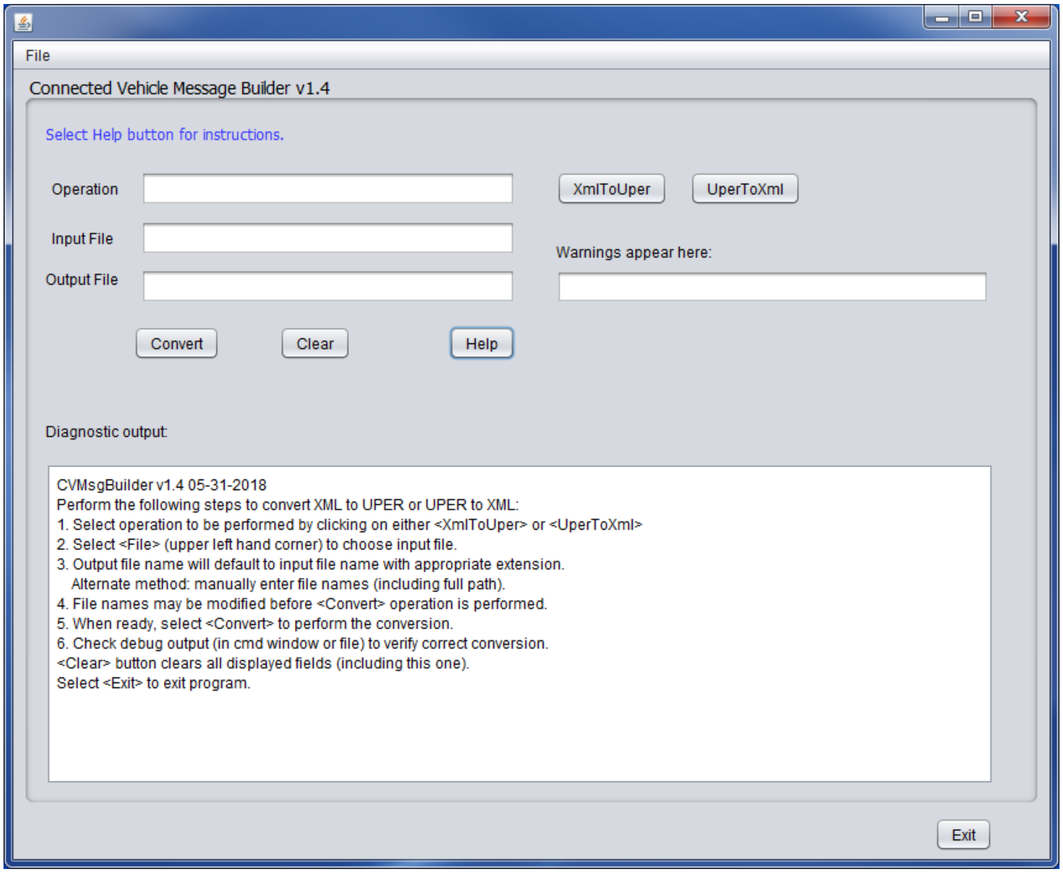


Figure 20: Connected Vehicle Message Builder (CVMB) User Interface

A detailed user guide v1.4 for the CVMB tool is provided in a separate document. The user guide provides:

- Using XML to Formulate a Message
  - How to Formulate EXER-encoded Message
  - XML Message Representation Detail
  - Example XML Representation of the RSM
- Use of optional fields
  - ASN.1 Definition of RSM
  - Encoding of Geometric Waypoint (node point) Latitude, Longitude and Elevation
- Software Installation and Operating Instructions for CVMB
  - System Requirements
  - CVMB software installation and to run it in command window, however, the tool is linked in the toolchain's main menu to run the message builder

- J2735 editing instructions for updating the standard J2735 ASN.1 file (J2735_201603DA.asn) to include support for the RSM

6 End-to-End Testing of the Toolchain

During the development of applications in the toolchain and to validate the mapping technique, vehicle path data using instrumented vehicle for live work zones were collected, maps were built and verified through the visualization tool in the toolchain. A work zone map and UPER encoded RSM was built using the toolchain and tested using the RSZW/LC application. The work zone configuration is as follows.

- Four-lane, ~ 3.5km Arterial Roadway
- 3 Lane Closures
- Workers present Zone (25 mph speed limit)
- 2 Speed Limit Changes
  - Normal: 45 mph
  - Work Zone: 35mph
  - Workers Present: 25mph
- 46 Waypoints per Lane to Represent Lane Geometry
- Built RSM consisting of two message segments. Appendix A shows built work zone map in EXER format.

The previous version of in-vehicle RSZW/LC application developed in the V2I-SA Project that used CAMP defined Basic Information Message (BIM) was updated to support RSM. To validate the end-to-end toolchain functionality, including the testing of the in-vehicle RSZW/LC application, tests were conducted on a four-lane arterial road work zone in Southeastern Michigan in a suburb of Detroit. The in-vehicle application performed as intended and generated appropriate alerts. Figure 21 shows engineering Graphical User Interface (eGUI) of the application in real-time data.

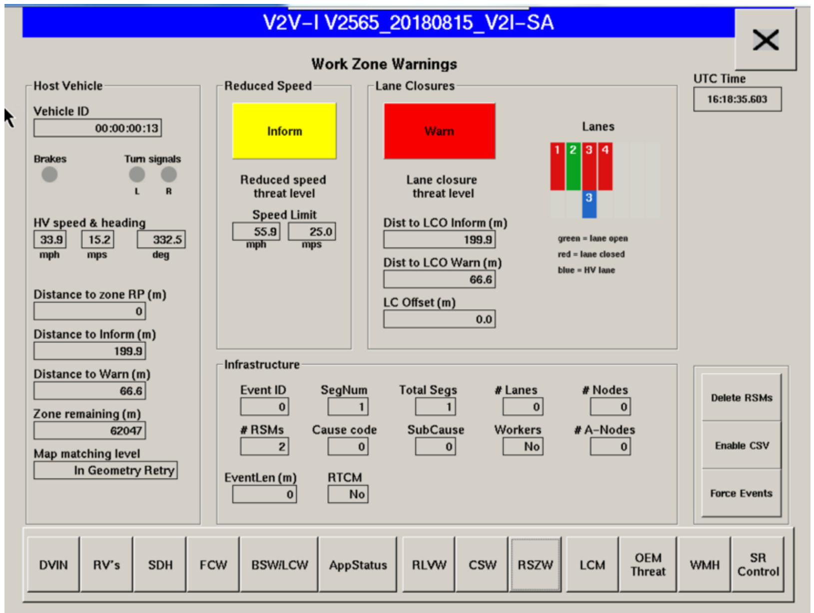


Figure 21: In-Vehicle RSZW/LC Real-Time eGUI Data Display

7 Summary

Traditionally, for V2I applications, waypoints (node points) for lane geometry are constructed by conducting a survey of the lane with nearly equidistant waypoints. Alternatively, lane geometry waypoints can also be constructed by using an application such as Google Earth or similar software tool that provides latitude, longitude, elevation to create path consisting waypoints. In either case, waypoints are then converted to the proper format as described in SAE J2735 message set dictionary. The practice of conducting a survey can be costly and time consuming and manually creating a path using Google Earth can be tedious and error prone. It may also be necessary to conduct such a survey multiple times and revise the lane geometry since the road configuration such as lane closures invariably change during the roadway construction.

One drawback in representing lane geometry using nearly equidistant waypoints, the placement of the waypoints is not optimized to support lane level map matching requirements to determine vehicle's lane position on curved roadway segments. It is essential that the distance between the consecutive waypoints be adjusted for curved versus straight roadway segments.

The work zone mapping technique for collecting a vehicle path data algorithm for selecting waypoints provides a more efficient, more accurate and consumes less time and cost in generating lane geometry required for communication based V2I applications.

A complete work zone mapping and RSM building software toolchain was developed to build work zone map and RSM in near real time. The toolchain consists of a set of software applications to collect vehicle path data, build work zone map from the collected vehicle path data, visualize the build map on Google satellite view for confirmation and build RSM for transmission from infrastructure for RSZW/LC application.

Appendix A Example EXER Representation of RSM for A Work Zone

EXER representation of a real-world work zone with following configuration is listed.

- Four-lane, ~ 3.5km Arterial Roadway
- 3 Lane Closures
- Workers present Zone (25 mph speed limit)
- 2 Speed Limit Changes
  - Normal: 45 mph
  - Work Zone: 35mph
  - Workers Present: 25mph
- 46 Waypoints per Lane to Represent Lane Geometry
- Built RSM Consisting of Two Message Segments

A.1 EXER File: Message Segment 1 of 2


```
<?xml version="1.0" encoding="UTF-8"?>
<!--
            CAMP xml file for RSZW/LC Mapping Project
            Message segment file 1 of 2...

            Version 1.5 - June, 2018
            for RSMv5.1 ASN
            File Name: ./WZ_MapMsg/RSZW_MAP_xml_File-20181023-221025-1_of_2.exer
            Created: 10/23/2018 - 22:10:07
-->
<MessageFrame>
 <messageId>33</messageId>
 <value>
  <RoadsideSafetyMessage>
   <version>1</version>

   <commonContainer>
<!--
                        ...Event ID...(no Message ID)
-->
    <eventInfo>
     <eventID>00005d88</eventID>
<!--
                        ...Message segmentation...
-->
     <msgSegmentInfo>
      <totalMsgSegments>2</totalMsgSegments>
      <thisSegmentNum>1</thisSegmentNum>
     </msgSegmentInfo>
<!--
                        ...Event start Date & Time...
-->
     <startDateTime>
      <year>2018</year>
      <month>1</month>
```

```xml
      <day>31</day>
      <hour>6</hour>
      <minute>30</minute>
      <offset>-300</offset>
    </startDateTime>
<!--
                ...Event end Date and Time...
-->
    <endDateTime>
      <year>2018</year>
      <month>2</month>
      <day>2</day>
      <hour>19</hour>
      <minute>45</minute>
    </endDateTime>
<!--
                ...Cause/Sub cause codes...
-->
    <causeCode>3</causeCode>
    <subCauseCode>0</subCauseCode>
   </eventInfo>
<!--
                ...Region Info Section...
-->
   <regionInfo>
<!--
                ...Applicable Heading / Tolerance...
-->
    <applicableHeading>
      <heading>145</heading>
      <tolerance>20</tolerance>
    </applicableHeading>
<!--
                ...Reference Point - Lat/Long in Micro Degrees...
-->
    <referencePoint>
      <lat>425730230</lat>
      <long>-832353725</long>
      <elevation>254</elevation>
    </referencePoint>
<!--
                ...Reference Point Type...
-->
    <referencePointType><startOfEvent/></referencePointType>
    <descriptiveName>Woodward SB Near Long Lake Rd.</descriptiveName>

<!--
                 ...Speed Limit at the Ref. Point...
-->
    <speedLimit>
      <type><vehicleMaxSpeed/></type>
      <speed>35</speed>
      <speedUnits><mph/></speedUnits>
    </speedLimit>

<!--
               ...Event Length...
-->
    <eventLength>3528</eventLength>

<!--
```

```
                    ...Start of Approach Region...
-->
<!--   ...APPROACH LANES: Map Waypoints...
        Total nodes per lane - 4
-->
     <approachRegion>
      <roadwayGeometry>
       <scale>1</scale>
       <rsmLanes>
<!--
                      Approach Lane #1
-->
        <RSMLane>
         <laneID>1</laneID>
         <lanePosition>1</lanePosition>
         <laneName>Lane #1</laneName>
         <laneGeometry>
          <nodeSet>
           <NodeLLE>                                        <!--  Approach Lane#/Node# - 1/1  -->
            <nodePoint>
             <node-3Dabsolute>
              <lat>425730573</lat>
              <long>-832353512</long>
              <elevation>254</elevation>
             </node-3Dabsolute>
            </nodePoint>
           </NodeLLE>
           <NodeLLE>                                        <!--  Approach Lane#/Node# - 1/2  -->
            <nodePoint>
             <node-3Dabsolute>
              <lat>425768395</lat>
              <long>-832389221</long>
              <elevation>263</elevation>
             </node-3Dabsolute>
            </nodePoint>
           </NodeLLE>
           <NodeLLE>                                        <!--  Approach Lane#/Node# - 1/3  -->
            <nodePoint>
             <node-3Dabsolute>
              <lat>425775783</lat>
              <long>-832396167</long>
              <elevation>262</elevation>
             </node-3Dabsolute>
            </nodePoint>
           </NodeLLE>
           <NodeLLE>                                        <!--  Approach Lane#/Node# - 1/4  -->
            <nodePoint>
             <node-3Dabsolute>
              <lat>425776429</lat>
              <long>-832396720</long>
              <elevation>262</elevation>
             </node-3Dabsolute>
            </nodePoint>
           </NodeLLE>
          </nodeSet>
         </laneGeometry>
        </RSMLane>
<!--
                      Approach Lane #2
-->
        <RSMLane>
```

```
        <laneID>2</laneID>
        <lanePosition>2</lanePosition>
        <laneName>Lane #2</laneName>
        <laneGeometry>
          <nodeSet>
            <NodeLLE>                                    <!--  Approach Lane#/Node# - 2/1  -->
              <nodePoint>
                <node-3Dabsolute>
                  <lat>425730388</lat>
                  <long>-832353873</long>
                  <elevation>254</elevation>
                </node-3Dabsolute>
              </nodePoint>
            </NodeLLE>
            <NodeLLE>                                    <!--  Approach Lane#/Node# - 2/2  -->
              <nodePoint>
                <node-3Dabsolute>
                  <lat>425768211</lat>
                  <long>-832389583</long>
                  <elevation>263</elevation>
                </node-3Dabsolute>
              </nodePoint>
            </NodeLLE>
            <NodeLLE>                                    <!--  Approach Lane#/Node# - 2/3  -->
              <nodePoint>
                <node-3Dabsolute>
                  <lat>425775605</lat>
                  <long>-832396535</long>
                  <elevation>262</elevation>
                </node-3Dabsolute>
              </nodePoint>
            </NodeLLE>
            <NodeLLE>                                    <!--  Approach Lane#/Node# - 2/4  -->
              <nodePoint>
                <node-3Dabsolute>
                  <lat>425776266</lat>
                  <long>-832397100</long>
                  <elevation>262</elevation>
                </node-3Dabsolute>
              </nodePoint>
            </NodeLLE>
          </nodeSet>
        </laneGeometry>
      </RSMLane>
<!--
                    Approach Lane #3
-->
      <RSMLane>
        <laneID>3</laneID>
        <lanePosition>3</lanePosition>
        <laneName>Lane #3</laneName>
        <laneGeometry>
          <nodeSet>
            <NodeLLE>                                    <!--  Approach Lane#/Node# - 3/1  -->
              <nodePoint>
                <node-3Dabsolute>
                  <lat>425730202</lat>
                  <long>-832354233</long>
                  <elevation>254</elevation>
                </node-3Dabsolute>
              </nodePoint>
```

```
        </NodeLLE>
        <NodeLLE>                                  <!--  Approach Lane#/Node# - 3/2  -->
          <nodePoint>
            <node-3Dabsolute>
              <lat>425768027</lat>
              <long>-832389945</long>
              <elevation>263</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                  <!--  Approach Lane#/Node# - 3/3  -->
          <nodePoint>
            <node-3Dabsolute>
              <lat>425775427</lat>
              <long>-832396902</long>
              <elevation>262</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                  <!--  Approach Lane#/Node# - 3/4  -->
          <nodePoint>
            <node-3Dabsolute>
              <lat>425776103</lat>
              <long>-832397480</long>
              <elevation>262</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
      </nodeSet>
    </laneGeometry>
  </RSMLane>
<!--
                    Approach Lane #4
-->
  <RSMLane>
    <laneID>4</laneID>
    <lanePosition>4</lanePosition>
    <laneName>Lane #4</laneName>
    <laneGeometry>
      <nodeSet>
        <NodeLLE>                                  <!--  Approach Lane#/Node# - 4/1  -->
          <nodePoint>
            <node-3Dabsolute>
              <lat>425730017</lat>
              <long>-832354594</long>
              <elevation>254</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                  <!--  Approach Lane#/Node# - 4/2  -->
          <nodePoint>
            <node-3Dabsolute>
              <lat>425767843</lat>
              <long>-832390306</long>
              <elevation>263</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                  <!--  Approach Lane#/Node# - 4/3  -->
          <nodePoint>
            <node-3Dabsolute>
```

```
                <lat>425775249</lat>
                <long>-832397269</long>
                <elevation>262</elevation>
              </node-3Dabsolute>
            </nodePoint>
          </NodeLLE>
          <NodeLLE>                                   <!--  Approach Lane#/Node# - 4/4  -->
            <nodePoint>
              <node-3Dabsolute>
                <lat>425775940</lat>
                <long>-832397859</long>
                <elevation>262</elevation>
              </node-3Dabsolute>
            </nodePoint>
          </NodeLLE>
        </nodeSet>
      </laneGeometry>
    </RSMLane>
   </rsmLanes>
  </roadwayGeometry>
 </approachRegion>
</regionInfo>
</commonContainer>

<!--
                ...END of COMMON CONTAINER...                -->

<!--   ...Work Zone Lanes: Map waypoints...   -->

 <rszContainer>
  <laneStatus>
   <LaneInfo>
    <lanePosition>1</lanePosition>
    <laneClosed><true/></laneClosed>
    <laneCloseOffset>1009</laneCloseOffset>
   </LaneInfo>
   <LaneInfo>
    <lanePosition>2</lanePosition>
    <laneClosed><false/></laneClosed>
    <laneCloseOffset>0</laneCloseOffset>
   </LaneInfo>
   <LaneInfo>
    <lanePosition>3</lanePosition>
    <laneClosed><true/></laneClosed>
    <laneCloseOffset>464</laneCloseOffset>
   </LaneInfo>
   <LaneInfo>
    <lanePosition>4</lanePosition>
    <laneClosed><true/></laneClosed>
    <laneCloseOffset>0</laneCloseOffset>
   </LaneInfo>
  </laneStatus>                       <!---  End of Lane Status  -->

  <peoplePresent><true/></peoplePresent>

  <speedLimit>
   <type><vehicleMaxSpeed/></type>
   <speed>35</speed>
   <speedUnits><mph/></speedUnits>
  </speedLimit>
```

```
<!--       ...S T A R T  of  L A N E  G E O M E T R Y...
           Total node points per lane - 40
-->
    <rszRegion>
     <roadwayGeometry>
      <scale>10</scale>
      <rsmLanes>
<!--
            ...Work Zone Lane #1...
-->
       <RSMLane>
        <laneID>1</laneID>
        <lanePosition>1</lanePosition>
        <laneName>Left Lane: Lane #1</laneName>
        <laneWidth>360</laneWidth>
        <laneGeometry>
         <nodeSet>
          <NodeLLE>                                        <!--  WZ Lane#/Node# - 1/1  -->
           <nodePoint>
            <node-3Dabsolute>
             <lat>425730414</lat>
             <long>-832353363</long>
             <elevation>254</elevation>
            </node-3Dabsolute>
           </nodePoint>
          </NodeLLE>
          <NodeLLE>                                        <!--  WZ Lane#/Node# - 1/2  -->
           <nodePoint>
            <node-3Dabsolute>
             <lat>425708985</lat>
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...  -->
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... Workers Present ...  -->
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    <LaneID>2</LaneID>
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...  -->
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... Workers Present ...  -->
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        </connectsTo>
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          ...Work Zone Lane #4...
-->
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          <long>-832322198</long>
          <elevation>247</elevation>
        </node-3Dabsolute>
      </nodePoint>
    </NodeLLE>
    <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/4 ... Lane is closed ...
-->
      <nodePoint>
        <node-3Dabsolute>
          <lat>425665047</lat>
          <long>-832293202</long>
          <elevation>243</elevation>
        </node-3Dabsolute>
      </nodePoint>
    </NodeLLE>
    <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/5 ... Lane is closed ...
... Workers Present ...  -->
      <nodePoint>
        <node-3Dabsolute>
          <lat>425662909</lat>
          <long>-832291177</long>
          <elevation>242</elevation>
        </node-3Dabsolute>
      </nodePoint>
      <nodeAttributes>
        <speedLimit>
          <type><vehicleMaxSpeed/></type>
            <speed>25</speed>
            <speedUnits><mph/></speedUnits>
        </speedLimit>
        <peoplePresent><true/></peoplePresent>
      </nodeAttributes>
    </NodeLLE>
    <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/6 ... Lane is closed ...
... Workers Present ...  -->
```

```
          <nodePoint>
            <node-3Dabsolute>
              <lat>425655683</lat>
              <long>-832284483</long>
              <elevation>240</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/7 ... Lane is closed ...
... Workers Present ...  -->
          <nodePoint>
            <node-3Dabsolute>
              <lat>425651350</lat>
              <long>-832280707</long>
              <elevation>240</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/8 ... Lane is closed ...
... Workers Present ...  -->
          <nodePoint>
            <node-3Dabsolute>
              <lat>425645438</lat>
              <long>-832275866</long>
              <elevation>238</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/9 ... Lane is closed ...
... Workers Present ...  -->
          <nodePoint>
            <node-3Dabsolute>
              <lat>425639488</lat>
              <long>-832271309</long>
              <elevation>237</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/10 ... Lane is closed ...
... Workers Present ...  -->
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            <node-3Dabsolute>
              <lat>425632329</lat>
              <long>-832266203</long>
              <elevation>235</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/11 ... Lane is closed ...
... Workers Present ...  -->
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            <node-3Dabsolute>
              <lat>425627495</lat>
              <long>-832262770</long>
              <elevation>234</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/12 ... Lane is closed ...
-->
          <nodePoint>
```

```
        <node-3Dabsolute>
          <lat>425624540</lat>
          <long>-832260672</long>
          <elevation>234</elevation>
        </node-3Dabsolute>
      </nodePoint>
      <nodeAttributes>
        <speedLimit>
          <type><vehicleMaxSpeed/></type>
            <speed>35</speed>
            <speedUnits><mph/></speedUnits>
        </speedLimit>
        <peoplePresent><false/></peoplePresent>
      </nodeAttributes>
    </NodeLLE>
    <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/13 ... Lane is closed ...
-->
      <nodePoint>
        <node-3Dabsolute>
          <lat>425620322</lat>
          <long>-832257711</long>
          <elevation>234</elevation>
        </node-3Dabsolute>
      </nodePoint>
    </NodeLLE>
    <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/14 ... Lane is closed ...
-->
      <nodePoint>
        <node-3Dabsolute>
          <lat>425614883</lat>
          <long>-832253757</long>
          <elevation>234</elevation>
        </node-3Dabsolute>
      </nodePoint>
    </NodeLLE>
    <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/15 ... Lane is closed ...
-->
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        <node-3Dabsolute>
          <lat>425600260</lat>
          <long>-832243529</long>
          <elevation>234</elevation>
        </node-3Dabsolute>
      </nodePoint>
    </NodeLLE>
    <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/16 ... Lane is closed ...
-->
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        <node-3Dabsolute>
          <lat>425566445</lat>
          <long>-832219738</long>
          <elevation>233</elevation>
        </node-3Dabsolute>
      </nodePoint>
    </NodeLLE>
    <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/17 ... Lane is closed ...
-->
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          <long>-832217297</long>
```

```
              <elevation>233</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/18 ... Lane is closed ...
-->
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            <node-3Dabsolute>
              <lat>425560068</lat>
              <long>-832214648</long>
              <elevation>233</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/19 ... Lane is closed ...
-->
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            <node-3Dabsolute>
              <lat>425556486</lat>
              <long>-832211291</long>
              <elevation>233</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/20 ... Lane is closed ...
-->
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            <node-3Dabsolute>
              <lat>425553051</lat>
              <long>-832207819</long>
              <elevation>233</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 4/21 ... Lane is closed ...
-->
          <nodePoint>
            <node-3Dabsolute>
              <lat>425550350</lat>
              <long>-832204760</long>
              <elevation>232</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
      </nodeSet>
    </laneGeometry>
    <connectsTo>
      <LaneID>4</LaneID>
      <LaneID>3</LaneID>
    </connectsTo>
   </RSMLane>
  </rsmLanes>
 </roadwayGeometry>
</rszRegion>
</rszContainer>
</RoadsideSafetyMessage>
</value>
</MessageFrame>
```


A.2 EXER File: Message Segment 2 of 2

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!--
		CAMP xml file for RSZW/LC Mapping Project
		Message segment file 2 of 2...

		Version 1.5 - June, 2018
		for RSMv5.1 ASN
		File Name: ./WZ_MapMsg/RSZW_MAP_xml_File-20181023-221025-2_of_2.exer
		Created: 10/23/2018 - 22:10:07
-->
<MessageFrame>
  <messageId>33</messageId>
  <value>
    <RoadsideSafetyMessage>
      <version>1</version>

      <commonContainer>
<!--
				...Event ID...(no Message ID)
-->
        <eventInfo>
          <eventID>00005d88</eventID>
<!--
				...Message segmentation...
-->
          <msgSegmentInfo>
            <totalMsgSegments>2</totalMsgSegments>
            <thisSegmentNum>2</thisSegmentNum>
          </msgSegmentInfo>
<!--
				...Event start Date & Time...
-->
          <startDateTime>
            <year>2018</year>
            <month>1</month>
            <day>31</day>
            <hour>6</hour>
            <minute>30</minute>
            <offset>-300</offset>
          </startDateTime>
<!--
				...Event end Date and Time...
-->
          <endDateTime>
            <year>2018</year>
            <month>2</month>
            <day>2</day>
            <hour>19</hour>
            <minute>45</minute>
          </endDateTime>
<!--
				...Cause/Sub cause codes...
-->
          <causeCode>3</causeCode>
          <subCauseCode>0</subCauseCode>
        </eventInfo>
<!--
				...Region Info Section...
-->
        <regionInfo>
```

```
<!--
                    ...Applicable Heading / Tolerance...
-->
      <applicableHeading>
        <heading>145</heading>
        <tolerance>20</tolerance>
      </applicableHeading>
<!--
                    ...Reference Point - Lat/Long in Micro Degrees...
-->
      <referencePoint>
        <lat>425550778</lat>
        <long>-832204100</long>
        <elevation>232</elevation>
      </referencePoint>
<!--
                    ...Reference Point Type...
-->
      <referencePointType><startOfEvent/></referencePointType>
      <descriptiveName>Woodward SB Near Long Lake Rd.</descriptiveName>
    </regionInfo>
  </commonContainer>

<!--
                   ...END of COMMON CONTAINER...          -->

<!--   ...Work Zone Lanes: Map waypoints...   -->

  <rszContainer>
    <laneStatus>
      <LaneInfo>
        <lanePosition>1</lanePosition>
        <laneClosed><true/></laneClosed>
        <laneCloseOffset>1009</laneCloseOffset>
      </LaneInfo>
      <LaneInfo>
        <lanePosition>2</lanePosition>
        <laneClosed><false/></laneClosed>
        <laneCloseOffset>0</laneCloseOffset>
      </LaneInfo>
      <LaneInfo>
        <lanePosition>3</lanePosition>
        <laneClosed><true/></laneClosed>
        <laneCloseOffset>464</laneCloseOffset>
      </LaneInfo>
      <LaneInfo>
        <lanePosition>4</lanePosition>
        <laneClosed><true/></laneClosed>
        <laneCloseOffset>0</laneCloseOffset>
      </LaneInfo>
    </laneStatus>                         <!---  End of Lane Status  -->

    <peoplePresent><true/></peoplePresent>

    <speedLimit>
      <type><vehicleMaxSpeed/></type>
      <speed>35</speed>
      <speedUnits><mph/></speedUnits>
    </speedLimit>

<!--      ...S T A R T  of  L A N E  G E O M E T R Y...
```

```
        Total node points per lane - 40
-->
    <rszRegion>
      <roadwayGeometry>
        <scale>10</scale>
        <rsmLanes>
<!--
            ...Work Zone Lane #1...
-->
          <RSMLane>
            <laneID>1</laneID>
            <lanePosition>1</lanePosition>
            <laneName>Left Lane: Lane #1</laneName>
            <laneWidth>360</laneWidth>
            <laneGeometry>
              <nodeSet>
                <NodeLLE>                                    <!--  WZ Lane#/Node# - 1/21  -->
                  <nodePoint>
                    <node-3Dabsolute>
                      <lat>425550992</lat>
                      <long>-832203769</long>
                      <elevation>232</elevation>
                    </node-3Dabsolute>
                  </nodePoint>
                </NodeLLE>
                <NodeLLE>                                    <!--  WZ Lane#/Node# - 1/22  -->
                  <nodePoint>
                    <node-3Dabsolute>
                      <lat>425548287</lat>
                      <long>-832200390</long>
                      <elevation>232</elevation>
                    </node-3Dabsolute>
                  </nodePoint>
                </NodeLLE>
                <NodeLLE>                                    <!--  WZ Lane#/Node# - 1/23  -->
                  <nodePoint>
                    <node-3Dabsolute>
                      <lat>425545761</lat>
                      <long>-832196846</long>
                      <elevation>232</elevation>
                    </node-3Dabsolute>
                  </nodePoint>
                </NodeLLE>
                <NodeLLE>                                    <!--  WZ Lane#/Node# - 1/24  -->
                  <nodePoint>
                    <node-3Dabsolute>
                      <lat>425543181</lat>
                      <long>-832192843</long>
                      <elevation>232</elevation>
                    </node-3Dabsolute>
                  </nodePoint>
                </NodeLLE>
                <NodeLLE>                                    <!--  WZ Lane#/Node# - 1/25  -->
                  <nodePoint>
                    <node-3Dabsolute>
                      <lat>425540039</lat>
                      <long>-832187494</long>
                      <elevation>231</elevation>
                    </node-3Dabsolute>
                  </nodePoint>
                </NodeLLE>
```

```
<NodeLLE>                                        <!--  WZ Lane#/Node# - 1/26  -->
  <nodePoint>
    <node-3Dabsolute>
      <lat>425524621</lat>
      <long>-832160292</long>
      <elevation>232</elevation>
    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
<NodeLLE>                                        <!--  WZ Lane#/Node# - 1/27  -->
  <nodePoint>
    <node-3Dabsolute>
      <lat>425522466</lat>
      <long>-832156874</long>
      <elevation>233</elevation>
    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
<NodeLLE>                                        <!--  WZ Lane#/Node# - 1/28  -->
  <nodePoint>
    <node-3Dabsolute>
      <lat>425521852</lat>
      <long>-832155963</long>
      <elevation>233</elevation>
    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
<NodeLLE>                                        <!--  WZ Lane#/Node# - 1/29  -->
  <nodePoint>
    <node-3Dabsolute>
      <lat>425518933</lat>
      <long>-832151826</long>
      <elevation>233</elevation>
    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
<NodeLLE>                                        <!--  WZ Lane#/Node# - 1/30  -->
  <nodePoint>
    <node-3Dabsolute>
      <lat>425516453</lat>
      <long>-832148723</long>
      <elevation>233</elevation>
    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
<NodeLLE>                                        <!--  WZ Lane#/Node# - 1/31  -->
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      <lat>425513094</lat>
      <long>-832144857</long>
      <elevation>234</elevation>
    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
<NodeLLE>                                        <!--  WZ Lane#/Node# - 1/32  -->
  <nodePoint>
    <node-3Dabsolute>
      <lat>425510347</lat>
      <long>-832142048</long>
      <elevation>234</elevation>
    </node-3Dabsolute>
```

```
  </nodePoint>
</NodeLLE>
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      <long>-832138836</long>
      <elevation>234</elevation>
    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
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      <long>-832136242</long>
      <elevation>235</elevation>
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  </nodePoint>
</NodeLLE>
<NodeLLE>                                        <!--  WZ Lane#/Node# - 1/35  -->
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      <long>-832132468</long>
      <elevation>236</elevation>
    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
<NodeLLE>                                        <!--  WZ Lane#/Node# - 1/36  -->
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      <lat>425489856</lat>
      <long>-832125861</long>
      <elevation>237</elevation>
    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
<NodeLLE>                                        <!--  WZ Lane#/Node# - 1/37  -->
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      <long>-832123445</long>
      <elevation>238</elevation>
    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
<NodeLLE>                                        <!--  WZ Lane#/Node# - 1/38  -->
  <nodePoint>
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      <lat>425482869</lat>
      <long>-832121513</long>
      <elevation>238</elevation>
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  </nodePoint>
</NodeLLE>
<NodeLLE>                                        <!--  WZ Lane#/Node# - 1/39  -->
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      <long>-832118174</long>
```

```
              <elevation>239</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 1/40  -->
          <nodePoint>
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              <lat>425470618</lat>
              <long>-832115459</long>
              <elevation>238</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
      </nodeSet>
    </laneGeometry>
  </RSMLane>
<!--
        ...Work Zone Lane #2...
-->
  <RSMLane>
    <laneID>2</laneID>
    <lanePosition>2</lanePosition>
    <laneName>Lane #2</laneName>
    <laneWidth>360</laneWidth>
    <laneGeometry>
      <nodeSet>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 2/21  -->
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            <node-3Dabsolute>
              <lat>425550778</lat>
              <long>-832204100</long>
              <elevation>232</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 2/22  -->
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              <elevation>232</elevation>
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        </NodeLLE>
        <NodeLLE>                                    <!--  WZ Lane#/Node# - 2/23  -->
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          </nodePoint>
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        <NodeLLE>                                    <!--  WZ Lane#/Node# - 2/24  -->
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          </nodePoint>
```

```
</NodeLLE>
<NodeLLE>                                    <!--  WZ Lane#/Node# - 2/25  -->
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    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
<NodeLLE>                                    <!--  WZ Lane#/Node# - 2/26  -->
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</NodeLLE>
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    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
<NodeLLE>                                    <!--  WZ Lane#/Node# - 2/28  -->
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    </node-3Dabsolute>
  </nodePoint>
</NodeLLE>
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</NodeLLE>
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  </nodePoint>
</NodeLLE>
<NodeLLE>                                    <!--  WZ Lane#/Node# - 2/31  -->
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      <long>-832145196</long>
      <elevation>234</elevation>
```

```
      </node-3Dabsolute>
    </nodePoint>
  </NodeLLE>
  <NodeLLE>                                         <!--  WZ Lane#/Node# - 2/32  -->
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        <long>-832142403</long>
        <elevation>234</elevation>
      </node-3Dabsolute>
    </nodePoint>
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  <NodeLLE>                                         <!--  WZ Lane#/Node# - 2/33  -->
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        <long>-832139203</long>
        <elevation>234</elevation>
      </node-3Dabsolute>
    </nodePoint>
  </NodeLLE>
  <NodeLLE>                                         <!--  WZ Lane#/Node# - 2/34  -->
    <nodePoint>
      <node-3Dabsolute>
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        <long>-832136620</long>
        <elevation>235</elevation>
      </node-3Dabsolute>
    </nodePoint>
  </NodeLLE>
  <NodeLLE>                                         <!--  WZ Lane#/Node# - 2/35  -->
    <nodePoint>
      <node-3Dabsolute>
        <lat>425498710</lat>
        <long>-832132853</long>
        <elevation>236</elevation>
      </node-3Dabsolute>
    </nodePoint>
  </NodeLLE>
  <NodeLLE>                                         <!--  WZ Lane#/Node# - 2/36  -->
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      <node-3Dabsolute>
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        <long>-832126250</long>
        <elevation>237</elevation>
      </node-3Dabsolute>
    </nodePoint>
  </NodeLLE>
  <NodeLLE>                                         <!--  WZ Lane#/Node# - 2/37  -->
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        <long>-832123843</long>
        <elevation>238</elevation>
      </node-3Dabsolute>
    </nodePoint>
  </NodeLLE>
  <NodeLLE>                                         <!--  WZ Lane#/Node# - 2/38  -->
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      <node-3Dabsolute>
        <lat>425482748</lat>
```

```
              <long>-832121921</long>
              <elevation>238</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                         <!--  WZ Lane#/Node# - 2/39  -->
          <nodePoint>
            <node-3Dabsolute>
              <lat>425476411</lat>
              <long>-832118586</long>
              <elevation>239</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
        <NodeLLE>                                         <!--  WZ Lane#/Node# - 2/40  -->
          <nodePoint>
            <node-3Dabsolute>
              <lat>425470516</lat>
              <long>-832115876</long>
              <elevation>238</elevation>
            </node-3Dabsolute>
          </nodePoint>
        </NodeLLE>
      </nodeSet>
    </laneGeometry>
  </RSMLane>
<!--
        ...Work Zone Lane #3...
-->
  <RSMLane>
    <laneID>3</laneID>
    <lanePosition>3</lanePosition>
    <laneName>Lane #3</laneName>
    <laneWidth>360</laneWidth>
    <laneGeometry>
      <nodeSet>
        <NodeLLE>                                         <!--  WZ Lane#/Node# - 3/21 ... Lane is closed ...
-->
          <nodePoint>
            <node-3Dabsolute>
              <lat>425550564</lat>
              <long>-832204430</long>
              <elevation>232</elevation>
            </node-3Dabsolute>
          </nodePoint>
          <nodeAttributes>
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  </connectsTo>
</RSMLane>
<!--
      ...Work Zone Lane #4...
-->
<RSMLane>
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  </rszRegion>
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 </RoadsideSafetyMessage>
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</MessageFrame>
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