Transportation Systems Management & Operations

District Five

Connected Vehicle Configuration Plan for Standardization

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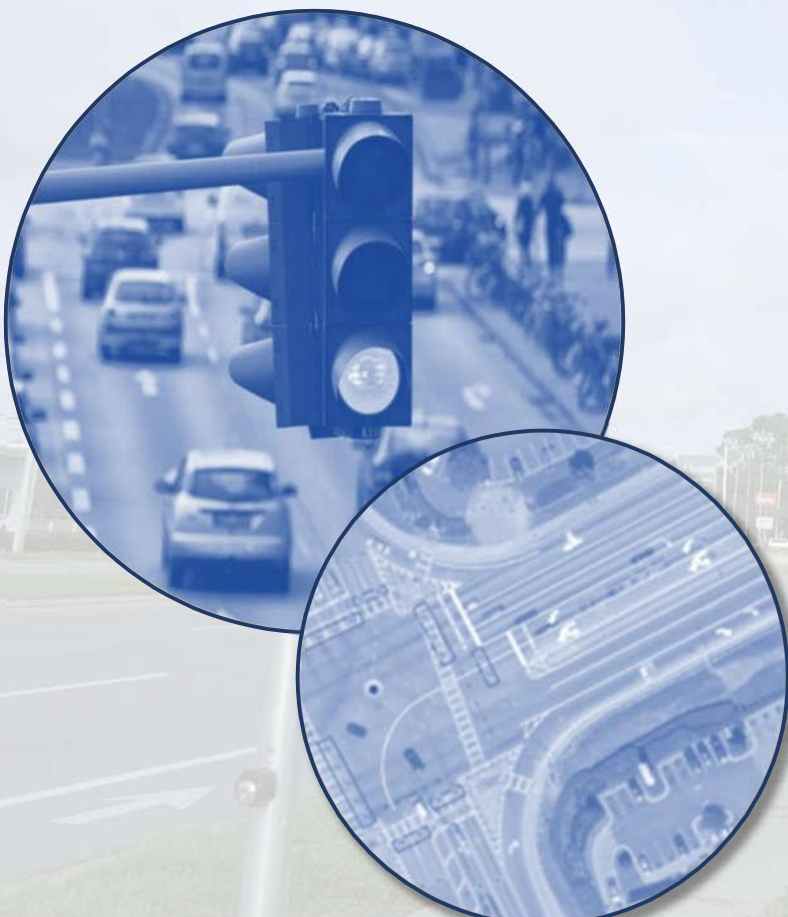

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DISCLAIMER:

All *italicized* text within this document was pulled directly from the *Guidance Document for MAP Message Preparation, Revision 02 – June 2023* created by the University of Virginia Center for Transportation Studies.

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List of Acronyms and Abbreviations

CV	Connected Vehicle
D5	District 5
EBL	Eastbound Left
EBR	Eastbound Right
EBT	Eastbound Through
FCC	Federal Communications Commission
FDOT	Florida Department of Transportation
Ft	Feet
GPS	Global Positioning System
IOO	Infrastructure Owner and Operator
ISD	Intersection Situation Data
ISS	Integrated Security System
ITS	Intelligent Transportation Systems
M	Meter
Mi	Mile
NBL	Northbound Left
NBR	Northbound Right
NBT	Northbound Through
OBU	On Boarding Unit
RSU	Road Side Unit
RSU ID	Road Side Unit Identification
SAE	Society of Automotive Engineers
SBL	Southbound Left
SBR	Southbound Right
SBT	Southbound Through
SPaT	Signal Phase and Timing
USDOT	United States Department of Transportation
WBL	Westbound Left
WBR	Westbound Right
WBT	Westbound Through

Introduction

Purpose

The purpose of this document is to promote standardization within the various Florida Department of Transportation (FDOT) District Five (D5) Connected Vehicle (CV) deployments, specifically related to the development of MAP messages and the configuration of roadside units (RSU). The intended audience for this document is personnel directly related to the installation, configuration, maintenance, and operation of CV equipment.

This is intended to be a living document, periodically adjusted for changes within the CV environment or at the direction of D5.

Background

As defined within the Society of Automotive Engineers (SAE) Standard J2735, the MapData Message (or MAP message) contains intersection information regarding the physical geometry of the intersection and the allowable maneuvers of each lane of traffic. Within the MapData, there are three levels of hierarchical information: intersection level, approach level, and lane level. Elements at the lane level are the most basic, including information about vehicle lanes, such as lane width, allowable maneuvers, and centerline positions via nodes. Information within the MAP message provides the basic location input for many vehicle-to-infrastructure applications.

MAP messages are developed utilizing the United States Department of Transportation (USDOT) Intersection Situation Data ISD Message Creator (https://webapp.connectedvcs.com/isd/).

Assemble Data

The MAP message creation process can proceed quickly when all the needed information is available, especially in situations when a comprehensive MAP creation tool (e.g., the USDOT Tool or a vendor tool) is used. Later steps in creating a MAP message will require information and/or data from multiple offices or groups within a transportation agency. Therefore, this step is focused on preparation to enable the MAP creator to efficiently create a MAP message.

Objective

The objective of assembling data is to gather the specific data and information needed as input for generating MAP messages.

To assemble the data, the information needs to be obtained from an authoritative source, needs to be current, and an understanding of the data and role in MAP creation is needed.

Guidance

MAP creators are encouraged to assemble data elements to support later steps of the MAP creation process. As part of this step, MAP creators should consider the specific goal of the connected intersection deployment, including any local applications that may be supported (e.g., transit signal priority) when determining what additional, optional data elements to include.

Understanding of Minimum Required Elements of the MAP Message

During data assembly, MAP creators should become familiar with the minimum required elements of the MAP message. MAP creators using a tool for creating the MAP message will be assisted in creating most, if not all, of the required elements. There are two levels of element requirements, including:

- *Those elements identified in SAE J2735 as mandatory for a valid SAE J2735 message to support in-vehicle applications of production vehicles; and*
- *Additional MAP message elements recommended as required based on industry experience and anticipated applications use of the MAP messages.*

J2735 Minimum Required Elements:

The SAE J2735 MAP message (within the standard and message denoted as the MSG_MapData) contains several sets of data elements, which may themselves contain further sets of elements. At the topmost level, the required element is the revision number for the MapData (msgIssueRevision). The intersections and road segments elements are optional within the standard, but for the purposes of this guidance document, at least one intersection (IntersectionGeometry) or one road segment (RoadSegments) should be created.

The data elements required for intersections (IntersectionGeometry) and road segments (RoadSegments) are identical. They are an ID, a revision number, a reference point (refPoint), and a set of lanes (laneset/roadLaneSet) comprising the lane definitions for the intersection or road segment. Each laneset/roadLaneSet may contain 1 to 255 lane (GenericLane) definitions. The required fields for a GenericLane are an ID (laneID); attributes applicable to the lane (laneAttributes) including direction of travel, sharing of lanes by travel modes, and lane type (for example, *to distinguish vehicle lanes from crosswalks; and the list of nodes (nodeList) defining the lane-center path geometry.*

Additional MAP Message Elements Recommended as Required:

From review of the optional elements in SAE J2735, and considering the resources reviewed through this project, it is recommended that a number of optional elements be considered mandatory by this guidance document for creating a MAP message as described below.

Elements General to the Intersection:

- *intersections (Intersection Geometry)*
  - *Data about intersection geometry is essential for MAP messages in the context of this document. A MAP message must contain the intersection lane geometry and location so that a vehicle can determine its own location in relation to the intersection lanes and stop line.*
- *region (Road Regulator Identifier)*
  - *This data element is within the intersection reference identifier and is used in conjunction with the Intersection Identifier to uniquely describe an intersection. This value supports the intersection identifier to support the vehicle in uniquely identifying the intersection in order to associate the correct data.*
- *laneWidth (Lane Width)*
  - *The laneWidth data element is specified within IntersectionGeometry and RoadSegment. Its value represents the most common lane width for the geometry being defined. This guidance recommends specifying the laneWidth so that paths can be defined as completely as possible. Most applications need to determine lane width, so it makes sense to include it upfront. Feedback from application developers has indicated that the lane width is used to locate the lane the vehicle is traveling.*

Elements Related to Specific Lanes:

- *maneuvers (Lane Maneuvers)*
  - *This data element is used to identify each lane maneuver that is allowed for that lane at the stop line for ingress lanes and at the downstream lane end point for egress lanes. The maneuvers defined in SAE J2735 are a combination of movements (e.g., a left turn movement is allowed in this lane, a right turn movement is allowed in this lane, a straight movement is allowed in this lane) and control at the intersection (e.g., right turn on red allowed, U turn movement is allowed in this lane). This guidance recommends including this data element in order to identify conflicting movements, such as crosswalks that may have pedestrians.*
- *connectsTo (Lane Connections)*
  - *The connectsTo data frame lists the connection relationships between lanes. The interior of an intersection is not modeled by lanes, so the connectsTo data frame is used to define the relationship between ingress and egress lanes and allowed maneuvers. This data element also specifies the signal group (signalGroup) data, which relates the lane to a signal group of a SPaT message. This data frame is required to include several data elements that are recommended for inclusion to the MAP message based on feedback from early deployments suggesting that these data elements are valuable.*

Elements Specific to Connections (between lanes)

- *maneuvers (Connection Maneuvers)*
  - *This data element describes each connection between an ingress lane and an egress lane to identify the maneuver that the connection allows. This data element is required to support lane connections for identifying allowed maneuvers from each ingress lane to respective egress lanes.*
- *remoteIntersection (Remote Intersection Reference Identifier)*
  - *This data element is required when a lane connects to a lane defined for an adjacent SPaT-enabled intersection, in order to provide the intersection reference identifier of the remote intersection. Showing a connection in the MAP message between an egress lane and an ingress lane of an adjacent intersection allows vehicles to know the intersection reference ID of the next intersection it will encounter. This can aid the vehicle in situations where it may be in range of broadcasts from multiple SPaT-enabled intersections.*
- *signalGroup (Connection Signal Group)*
  - *This data element notes each connection between an ingress lane and an egress lane to identify the SPaT signal group that provides traffic signal control for that movement. It is critical that applications identify the signal group representing their path of travel in order to properly interpret the SPaT message.*

MAP Message and Intersection Revision Counters

The MAP message includes two counters (i.e., values that increase by one each time a revision is made). The counters are used because vehicles with on-board applications often drive the same intersections frequently and may choose to store MAP content about an intersection within the application. This would then allow the application to receive a MAP message for a specific intersection with a revision counter that has not increased since the last time it was received and avoid needing to reprocess the MAP data. The two counters that are included are as follows:

- *A MAP Message revision counter. This counter is incremented by one every time any data element in the MAP message changes, except the time stamp.*
- *An intersection revision counter. This counter is incremented every time an element describing an intersection change except the time stamp. In situations where two or more intersections are described, it is possible that only one intersection would be changed.*

Most MAP messages will describe only one intersection and typically the message revision counter and intersection revision counters will have the same increment number.

During data assembly, any previous MAP messages that may have been created for the intersection should be identified in order to understand whether this is the first MAP message created for the intersection or if the revision number included in the previous MAP message needs to be incremented by the value of one (1). The revision number value will increase by one, even if a major intersection reconstruction results in a drastically changed intersection, as long as the intersection reference ID was used in the previous MAP it would increment. This is a function that MAP creators should be looking for in MAP creation tools. In situations where one MAP message represents multiple intersections, the MAP creator would need to understand the revision numbers of the intersections.

During the assembly of data, clarify if there is only one intersection represented by the MAP message. If two or more intersections are represented, understand the revision status of each. During the assembly of data, identify whether any MAP message has previously been created for the intersection as this will be needed to increase the *revision number by one, so long as the same intersection reference IDs are being used. Recognize that if the agency updates time stamps on the MAP message without changing the content of the message, the revision counters do not increment.*

Road Regulator ID

The road regulator identifier (ID) portion of the Intersection Reference ID identifies the agency that regulates or operates the intersection controls. The road regulator ID is defined as two bytes storing values from 0 to 65535 (0 is reserved for testing). During data collection, it is important to gain understanding of the numbering approach that the MAP creator will use when creating the MAP messages.

Determine the Road Regulator ID that is to be assigned for each intersection prior to creating the MAP message and ensure that the MAP message Road Regulator ID matches that of the SPaT message. Follow national/international progress on defining an overall strategy and numbering approach for Road Regulator ID. Activities of the Geographic Names Information System (GNIS) is referenced in the most recent version of the SAE J2735 standard (November 2022). The combination of each road regulator identifier and intersection identifier must be a unique value (not used by other intersections) and values 1 to 65535 are possible for the road regulator ID. Attempts to preempt a national/international strategy with an intermediate approach would be replaced when a future numbering approach is defined.

Intersection ID

The intersection identifier portion of the Intersection Reference ID is defined as two bytes storing values from 0 to 65535 (values 0 to 255 are reserved for testing). Large cities may have more than 65,000 intersections, if non-signalized intersections are included. The Intersection Reference ID (combined Road Regulator ID and Intersection ID) is how OBUs ensure that they are processing the MAP and SPaT message for the same intersection. It is critical that the combination of these two data elements be unique to any other intersections.

During data assembly, determine the Intersection ID that is to be assigned for each intersection when creating the MAP message and ensure that the Intersection ID is assigned for each intersection and that the MAP message Intersection ID matches that of the SPaT message. Develop a local numbering approach (or use a numbering approach that has already been developed (such as by the traffic signals group in the agency)) that can be used to create unique intersection reference identifiers for each intersection. The fact that the OBUs will receive both a road regulator ID and an intersection ID will allow the OBU to consider these two values (e.g., concatenate them together) to properly identify intersections. The combination of road regulator ID and intersection ID in a MAP message must be unique and specific to a particular intersection. Within a given agency (road regulator) road network, each intersection ID must be unique.

Intersection Geometry

Information describing each ingress lane into the intersection and each egress lane out of the intersection will be used when creating the MAP message. During data assembly, it is recommended that MAP creators assemble and understand this information. Information to understand and assemble for each intersection includes:

- *All motor vehicle approaches and lanes (i.e., ingress and egress lanes).*
- *Crosswalk lanes at the intersection.*
- *Sidewalk lanes that represent pedestrian landings at the curbs near crosswalks.*
- *Stop lines – whether painted stop lines are used or when painted stop lines do not exist.*

- Lane assignment (i.e., understanding of allowed maneuvers for each ingress lane, e.g., through only, exclusive left-turn, etc.).
- Presence and length of turn bays.
- Speed limit for each approach.

Assembling the resources in data assembly will support later activities. For example, there is not one action in MAP content creation to enter intersection geometry, but rather there are various actions in MAP content creation where the intersection geometry will be added to the MAP message content (e.g., First Node Point – Ingress Lane, First Node Point – Egress Lane, Length of Ingress Lane, Length of Egress Lane, etc.).

Intersection geometry and control information may be obtained from a variety of sources and will be required during MAP content creation. Typically, this data and information will be available through intersection control diagrams and signal timing plans. Other sources include:

- Screenshots or exports from central signal control software interfaces.
- Online mapping solutions with aerial imagery such as Bing Maps or Google Maps.
- GIS outputs.
- Survey grade mapping.
- Imagery captured from Unmanned Aerial Systems (UASs), also referred to as drones, where drone flying is allowed.
- As-built drawings.
- Roadway design documents for intersections that are not yet constructed or operational.
- Speed limit information to determine both reference speed limits and delta speed limit values.

Note that the MAP message will contain one reference speed limit for each intersection. This will be the assigned speed limit for each lane and node unless a lane/node has a delta value assigned to it, indicating a change from the reference speed. For example, one road traveling through an intersection may have a speed limit of 55 mph, while the cross-traffic road may have a speed limit of 35 mph. One speed limit will need to be assigned as the reference speed limit, and the other will be defined by the delta value (20 mph in this case). It is also possible for a lane to have a change in speed limit. For example, the roadway speed may be 40 mph, but as the lane approaches the intersection, it may change to 30 mph. If the ingress lane extends into the segment of road that is 40 mph, a delta value would be used at the node point where the speed limit change occurs. Input and feedback from interviews conducted with transportation agencies that have created MAP messages formed the basis of this guidance.

Lane Width

The lane width element in the MAP message contains one value to represent the width of all lanes in the intersection, including ingress lanes, egress lanes, crosswalks, and bike lanes. The lane width element is used by nodes as a reference lane width. A lane width deviation (also referred to as a delta value) may be applied to adjust the lane width value for each node. For example, an intersection with similar and regular lanes widths can use the reference lane width value (e.g., 300 cm) for all lanes, while another intersection having dedicated bike lanes would reduce the lane width at the first node of the bike lane by including a deviation value for the bike lane (e.g., -200 cm). If a deviation value is assigned to the first node of a lane and the lane has a consistent width, that deviation value should not be repeated on any subsequent node.

During data assembly, determine the most common lane width of the ingress and egress lanes to be used as the lane width value. Determine if any ingress/egress lanes differ from the reference lane width value by 0.2 meters or *more and assemble these values for use in MAP content creation. Differences less than 0.2 meters should not be entered as deviations from the reference lane width. It is strongly recommended that the lane width value source should be based on IOO-verified sources for the lane width (e.g., design document, as-built, surveys, LiDAR-recorded data, etc.). If trusted sources for measurements of lane widths are not possible, lane width values may be approximated using an online mapping resource if this solution is acceptable for local applications, but this is not recommended as a primary or default solution. IOOs should only enter node point deviations if verified sources are available. Once a node point deviation is entered for the first node of a lane, only include additional deviation values if the lane width of subsequent nodes differs from the first node of the lane. Use the most common lane width for the reference lane width. Measure lane width from centerline of painted stripes, when available. Guidance on lane width determination (including guidelines for outside lanes) can be found in the Model Inventory of Roadway Elements.*

The guidance above advises MAP creators to perform physical measurements of lane widths to be input into the MAP Creation Tool being used because current online mapping and digital imagery solutions that require users to click on two lane lines to compute a distance will likely return inaccurate lane widths that are critical to vehicle lane determination). Calculating and determining an accurate lane width at the location of each node is not practicable for all IOOs. There is a trade-off between MAP message size, processing required to interpret the MAP message, and accuracy needed by the applications. The minimum of 20 cm deviation addresses this trade-off.

Lane ID

Each lane at a connected signalized intersection must have an identifier that is unique for the intersection. During MAP content creation, the MAP creator will need to enter lane ID values for each lane. During data assembly, the MAP creator should familiarize themselves with any agency approach for consistency in selecting lane IDs. For example, an agency may decide to begin lane numbering with the southbound egress lane from the intersection as #1 and continue numbering the lanes in a counterclockwise order around the intersection.

There is no national approach for lane numbering, nor is there a need for consistency between intersections or agencies. However, consistency within an agency may be desired. Lane identifiers must be numerical whole values, between 1 and 254, inclusive. There are no pre-defined patterns for creating lane identifiers, but each agency is recommended to follow a consistent pattern for all intersections (e.g., start with the curbside, south-bound egress lane, and number sequentially in a counter-clockwise order). Lane identifiers will also need to be defined for crosswalks and sidewalk lanes. Each agency should identify an approach. Suggested approach is to begin numbering crosswalks as one value higher than the highest value of a motor vehicle lane and to begin numbering sidewalks as one value higher than the highest value of a crosswalk. SAE J2735 requires 1-byte integer values. SAE J2735 identifies that the value 0 shall be used when the lane ID is not available or not known. SAE J2735 identifies that the value 255 is reserved for future use.

Direction of Travel

The direction of travel (Lane Direction) for each lane must be described in the MAP message. This value may be used by an OBU to determine the lane of travel and/or to identify wrong way operations. During data assembly, the MAP creator should familiarize themselves with the direction of travel for each lane. In MAP content creation, the MAP creator will need to place the nodes of lanes to respect the direction of travel. The MAP creator should identify any lanes that support bi-directional travel (two-way lanes), note that these would include reversible lanes. Crosswalk lanes and sidewalk lanes will also be assigned as bi-directional travel lanes, as per the SAE J2735 standard.

Connections Between Motor Vehicle Lanes

The data in the SPaT message will define the current signal state and status for each signal group operated by the controller. For a device receiving both the MAP message and SPaT message to understand which signal group is associated with their path of travel, each MAP message connection (e.g., a connection between one ingress lane and one egress lane) is assigned to the appropriate signal group. It is important that all connections are defined (e.g., a through lane may connect to the through egress lane as well as the right turn egress lane). More details will be described on this in MAP content creation. When assembling the data in data assembly that will be used in MAP content, use care to understand all connections between ingress and egress lanes (e.g., protected turns, permissive turns, etc.).

During the future MAP content creation, the MAP creator will need to identify all legal intersection movements. This includes consideration of legal U-turn movements from a left-turn lane, for example. Preparation in data assembly will help ensure the MAP creator does not omit any connections. Specifying the connections between ingress and egress lanes is required as part of a complete intersection map description for use in conjunction with SPaT messages. Assembling information about connections will support MAP content creation in MAP content creation.

Crosswalk Lanes

Crosswalks are defined in the MAP message as pedestrian crosswalk lanes. Applications may use the boundaries. defined by the crosswalk lane to issue warnings to drivers when pedestrians are (or may be) in the crosswalk or to advise when protected crosswalk movements are active (e.g., a "walk" indication). Crosswalks defined in the MAP message may be also used by applications to provide information to pedestrians about the allowed movements from the curb into the crosswalk. This topic has seen limited deployment to date and requires additional experience and research to determine more definitive guidance. There are two aspects of crosswalks that must be understood during data assembly to properly develop the crosswalks in the MAP messages in MAP content creation:

- ***Pedestrian crosswalk lanes** – These are the lanes defining the areas designated for pedestrians to cross the road, particularly during pedestrian signal indications (e.g., "walk").*
- ***Sidewalk lanes defining pedestrian landings** – Sidewalk lanes, also referred to as pedestrian landings, can be used for various sidewalk geometries. Regarding crosswalks, sidewalk lanes are used to describe locations on the curb where pedestrians will be located prior to their entry into the crosswalk lane. A pedestrian signal advises pedestrians that they can maneuver from the sidewalk lane to the crosswalk (i.e., a "walk" sign indicates it is safe for the pedestrian to step from the curb into the crosswalk and begin crossing the road), therefore the sidewalk lane serves as a type of ingress lane and the crosswalk lane serves as an egress lane for connections defining pedestrian movements.*

During data assembly, the location of the centerline of striped crosswalk lanes should be understood, as well as the width of each crosswalk. Each crosswalk lane will be defined by two coordinates, representing the centerline ends of the crosswalk (i.e., where the crosswalk meets the curb). Each crosswalk lane will need to be assigned a number, therefore activities in data assembly should understand the agency approach to numbering crosswalks. In lieu of an agency approach to numbering crosswalk lanes, it is recommended to continue numbering by incrementing one number above the highest numbered motor vehicle lane for crosswalk lanes. During data assembly, MAP creators should understand where each sidewalk lane (acting as a pedestrian landing) will occur and assign numbers to the sidewalk lanes. Each sidewalk lane will need to be described by at least two node points and the coordinates of these node points should be the same as the coordinates of the start/end points of the crosswalk lane. In lieu of an agency approach to numbering sidewalk lanes, it is recommended to continue numbering by incrementing one number above the highest numbered crosswalk lane. When crosswalks include a median divider (i.e., a place for *pedestrians to stop in the median before crossing the remainder of the road) with a walk sign activation button, MAP creators are encouraged to consider if two crosswalks should be coded to represent the entire crossing of the road, and each assigned to the appropriate signal group controlling the movement. This guidance is based on the SAE J2735 standards and requirements in the CTI 4501 v01.01, Connected Intersections Implementation Guide.*

Connections Between Sidewalk Lanes (Pedestrian Landings) and Crosswalk Lanes

Connections from sidewalk lanes (pedestrian landings) to crosswalk lanes identify locations where pedestrians can move from the pedestrian landing (sidewalk lane) into the crosswalk lane and allow for these connections to be assigned to the appropriate signal group. By assigning a connection between a sidewalk lane and a crosswalk lane to a signal group, this will allow the "walk" indications described in the SPaT message to be related to the appropriate movement from sidewalk lane to crosswalk lane. This topic has seen limited deployment to date and requires additional experience and research to determine more definitive guidance. When assembling the data that will be used in MAP content creation, use care to understand all pedestrian signals, crosswalks, and pedestrian landings (to be coded as sidewalk lanes). Specifically, ensure that connections between sidewalk lanes (pedestrian landings) and the crosswalk lanes are understood.

During the future MAP content creation, the MAP creator will need to identify the starting and ending nodes of the sidewalk lanes and crosswalk lanes. Preparation in data assembly will help ensure the MAP creator does not omit any connections. Specifying the connections from sidewalk lanes to crosswalk lanes is required as part of a complete intersection map description for use in conjunction with SPaT messages. Assembling information about connections will support MAP content creation in MAP content creation.

Phase Numbering and Signal Groups

The SPaT message that is broadcast together with the MAP message will provide information about the current signal indications. This is done by identifying a series of signal groups and then describing the state of each signal group. The MAP message makes it possible for applications receiving the SPaT message to understand what signal group applies to the imminent movement through the intersection. To do this, the MAP message will define a series of connections and also must identify the appropriate signal group that matches the connection. The signal group is not always the same number as the signal phase, and it is important in Step 1 – Assemble Data for the MAP creator to understand which signal group numbers relate to each connection. To be prepared to create this information in MAP content creation, the MAP creator needs to assemble information about the signal phases, signal groups, and allowable vehicle movements. Specifically, the information that is needed is as follows:

- *The movements for each of the intersection phases. These are generally depicted by a signal phase diagram or represented in a signal timing plan.*
- *Information about any movements that are allowed using overlaps. These are identified overlaps allowed by signal indications (and the overlap name (e.g., Overlap A, Overlap B, etc.)).*
- *Information about pedestrian crosswalk movement phases.*
- *Controller phase to signal group assignments. Relating the signal controller phases and overlaps to signal groups is done by programming in the signal controller and/or RSU and may vary by equipment manufacturer. This information may be included in signal timing plans or design document for the signal controller or may be information that must be obtained by the traffic signal engineer responsible for the signal. The most common signal phase to signal group assignments are as follows:*
    - *Phases 1-8 are typically assigned to signal group 1-8;*
    - *Overlaps A, B, C, and D are typically assigned to signal groups 9, 10, 11, and 12, respectively;*

and

- *Pedestrian signals in phases 2, 4, 6, and 8 are typically assigned to signal groups 13, 14, 15, and 16, respectively.*

The Signal Timing Plan for an intersection is the primary source for this information. Central signal control software outputs, imagery, or screenshots are alternate sources for this information. The MAP creator should seek information about which phases, overlaps, or pedestrian signal indications are assigned to which signal groups by the signal controllers and/or RSU (these may also be referred to as 'channels'). It is important not to assume the typical values identified above are used, but rather to verify the channel numbers with either the signal controller design document or the traffic engineer responsible. This guidance is based on requirements in the CTI 4501 v01.01, Connected Intersections Implementation Guide.

Lane Use Variations

When intersections include lanes with usage that varies at different times (e.g., revocable, restricted), the MAP message must provide the information to accompany the SPaT message to convey these variations of use. During data assembly, the MAP creator should understand if any lanes in the intersection include lane use variations (e.g., if left turns are not allowed during peak periods or if travel in a lane is one direction part of the day and another direction during the other) and document the variations of use to support MAP content creation in when placing nodes and create MAP content. During data assembly, the MAP creator should also verify that the SPaT message that is/will be created dynamically for this intersection will broadcast status of all revocable lanes. Assembling information about lane use variations will support creation when placing nodes and create MAP content.

Reference Point

A reference point is needed to allow the node points to be identified as offsets from the reference point. This minimizes the file size by avoiding full latitude/longitude numbers for all node points. The reference point must be located inside the intersection defined by the MAP message. The latitude, longitude, and elevation description of the reference point is used to determine the same values of all node points that are defined as offsets from the reference point. In addition to a reference point, a verified point marker is a key element for defining detailed locations of node points.

During data assembly, consider using a verified point marker (i.e., a point with a known latitude/longitude and that is visible from any aerial mapping solution) to serve as an "anchor" by which the reference point that is inside the intersection can be determined and used when creating the MAP message. The reference point for the intersection can be determined by adding a known latitude and longitude offset to the verified point marker to determine the reference point. It is not critical that this be the center point of the intersection, just that the latitude and longitude be known and that the point is inside the intersection. Identify one or more landmarks near the intersection (e.g., a corner of signal controller cabinet, a light pole, etc.) that may already have been surveyed in as a known location. If none are found, arrange for an object near the intersection (that is visible from aerial maps) to be surveyed. The known location of the verified point marker will help minimize errors caused by aerial mapping solutions when selecting node points or placing lanes and crosswalks.

Computed Lanes

The SAE J2735 MAP message can specify lane geometries lane by lane, or as a set of computed lanes. Computed lanes may be appropriate if an intersection has lanes that are similar enough that the nodes of one lane can be geometrically transformed to represent additional lanes. The transformations to a specific reference lane are used *to define a set of lanes as a means of reducing the total MAP message size. Computed lanes are challenging to specify and cannot be used unless there are only translation, scaling, and rotation differences among the lane geometries.*

The MAP creator should determine in data assembly whether they are going to use computed lanes or lane-by-lane specifications. The map creation tool(s) used by the MAP creator may assist in this determination. Computed lanes should be considered if it will reduce the MAP message file size and if a reduction in the MAP message file size is needed. Computed lanes have the most benefit if there are long, straight ingress or egress lanes with a minimum of two (preferably three) lanes in each approach that have similar geometries that can be computed. For example, a lane that splits into a through lane and a left-turn lane cannot be computed to represent a through lane (with no turn split). A lane is selected to serve as the reference lane. This reference lane should be the lane with the least number of external influences (e.g., parking allowed or uncertainty over the lane markings). Typically, the reference lane will be the left-most through lane as the right lane is typically the curb lane and may have parking. The centerline of the reference lane (i.e., line formed by the connecting the node points) will serve as the basis for offsets (computed lanes will have offsets from the reference lane center line) and rotation (i.e., computed lanes will be rotated from the centerline of the reference lane. Transformation values to be specified include translation (x and y offsets from the original lane), scaling (expanding or contracting the lane width values), and rotation (path rotation for the entire lane). The rotational transformation values are unsigned units of 0.0125 degrees from 359.9875 degrees (i.e., integer values from 1 to 28799). A value of 1 would add 0.0125 degrees to 359.9875, yielding 360.0000 degrees, or 0 degrees of rotation from the centerline of the reference lane; a value of 7201 indicates a 90-degree clockwise rotation). The X and Y scaling are independently set. Transformations are relative to the reference lane's initial point and NOT the MAP reference point. Computed lanes inherit lane attributes from the referenced lane. Computed lanes are recommended only when the reference lane has a similar shape and identical attributes. MAP creation tools should determine computed lanes automatically or enable the user to directly create them. A decision to use computed lanes should be made as part of data gathering rather than being deferred to the map assembly. The computed lanes data needs are described in SAE J2735.

Allowed Lane Maneuvers

In MAP content creation, the MAP creator will need to identify and define all allowed maneuvers for each lane. During data assembly, the MAP creator should assemble information about the maneuvers allowed at the end of each lane (for ingress lanes, this is the stop line; for egress lanes, this is the furthest downstream node). Information gathered in this step will ensure that the actions in MAP content creation create a comprehensive list of maneuvers. Note that the identification of all possible maneuvers for each lane is a different activity than assigning a specific maneuver for each connection.

During data assembly, the MAP creator should identify all maneuvers for each lane. For example: verify if U-turns are allowed from any left-turn or through lanes or when right turns are allowed from rightmost lanes or through lanes.

Geodetic Reference Systems

MAP creators will be selecting and determining the location of a verified point marker for each map. Each such location is expressed as a global latitude, longitude, and elevation position relative to a specific geodetic frame of reference.

Geographic positions in the U.S. are generally determined using the U.S.'s Global Positioning System (GPS) implementation of a global navigation satellite system (GNSS). Positions determined from GPS are typically *expressed using the World Geodetic System (WGS) 84 standard coordinate frame of reference. SAE J2735 further specifies that position data in its messages are to be expressed using WGS 84 coordinates.*

Geodetic reference systems other than WGS 84 are frequently used for surveying and associated map locations. In particular, the U.S. National Geodetic Survey uses the North American Datum of 1983 (NAD 83). As another example, the Federal Communications Commission (FCC) license application process for roadside unit (RSU) licensing requires coordinates of the RSU reported in NAD 83. This should not be confused with the SAE J2735 requirement to use WGS 84 as the standard coordinate frame of reference.

It is important to ensure that either 1) the tools used to determine the location of the verified point marker are using the WGS 84 standard, or 2) that the location coordinates are transformed from the source system to WGS 84 for use in MAP messages.

The MAP creator should identify the geodetic reference system used for determining the location of the verified point marker. If the reference system is not WGS 84, the MAP creator needs to transform the coordinates from the source reference system to the WGS 84 frame of reference. The MAP creator should then confirm that the coordinates for the verified point marker are recorded using the WGS 84 standard coordinate frame of reference.

Connected Vehicle ISD Map Developer

The following steps provide guidance for the development of MAP messages specific to CV deployments within D5 utilizing the ISD Builder Tool for J2735/2016 (UPER encoding), version 2.3.1, released on October 14, 2019.

Prior to development of the MAP message, the Engineer is responsible for the completion of the "Connected Vehicle MAP Form." Refer to Appendix A for additional information.

Parent Map

Development of Parent Maps will require both a Reference Point Marker and a Verified Point Marker. The Reference Point Marker is normally a chosen location at the middle of the intersection, while the Verified Point Marker is a location set where a global positioning system (GPS) unit obtains latitude and longitude.

The Verified Reference Point latitude, longitude, and elevation are incorporated in the *Connected Vehicle Map Form*.

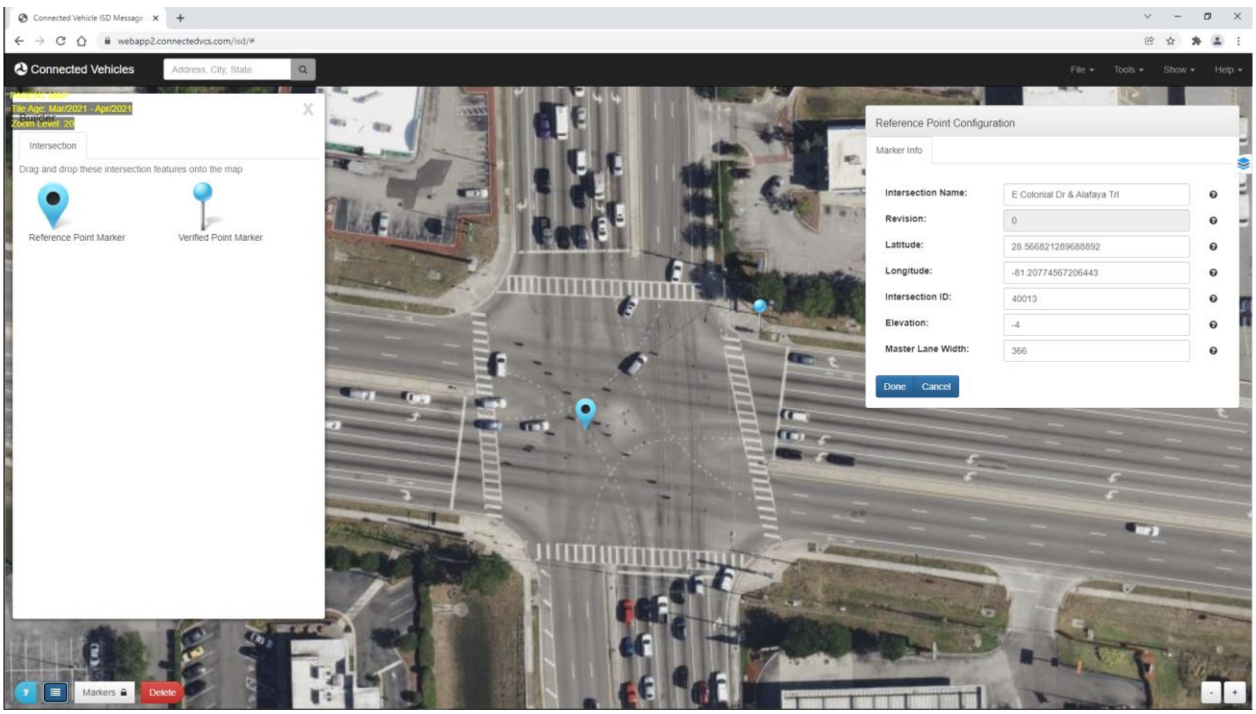


Figure 1: Example Parent Map development with USDOT ISD Message Creator Tool

The ISD Message Creator will automatically generate an **Intersection ID** correlated to the position of the Reference Point Marker within the image tile; however, the value can be overwritten with a user-defined value established by a regional authority (typically a regional department of transportation (DOT) authority). D5 has established blocks of Intersection ID numbers by County and a master list of Intersection ID assignments for use throughout D5. The map developer must use the Intersection ID assignment provided by the District ("RSU ID") in order to ensure that the value is unique within the D5 region. The Intersection ID field is limited to integers between 0 and 65535.

D5 will not require professional survey markers to be utilized in the development of the Parent Map; however, each Parent Map will include a **Verified Point Marker** that indicates the known true position of a point visible in the aerial images within the USDOT ISD Message Creator Tool. The true position of this point should be obtained using field-collected data and differential GPS technology. Alternate methods may be approved by the District. Each Verified Point Marker will be located at a consistent and easily identifiable point within the intersection (e.g., corner of detectable warning surface pad, corner of the traffic signal controller cabinet). A field visit will be required to collect the pertinent information required to accurately georeferenced the Verified Point Marker using differential GPS at each signalized intersection. This information—including intersection title, intersection global identification number, description of field reference point, photo of the reference point location, latitude / longitude values, and elevation—will be collected and inserted in the *Connected Vehicle MAP Form*. The Engineer of Record shall sign, date, and seal the *Connected Vehicle MAP Form* (see Appendix A).

The latitude and longitude of the field reference point must be collected using differential GPS. The field collected information will be utilized as input to the Verified Point Marker: Verified Latitude, Verified Longitude, and Verified Elevation data fields to override the assumed latitude, longitude, and elevation values within the "Verified Point Configuration" window. If the elevation provided by the differential GPS cannot be verified or does not match the actual above mean sea level elevation for the region, use Google Earth with the "Terrain" layer enabled and enter the elevation indicated in the lower right corner.

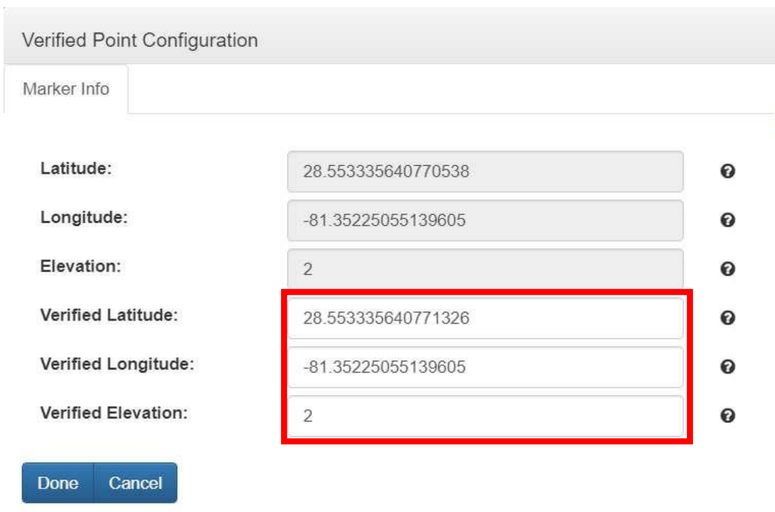


Figure 2: Example Verified Point Configuration with input values for verified latitude / longitude / elevation from differential GPS

The **Reference Point Marker** shall be centered within the signalized intersection. This is the ideal location for this point. However, in several instances, the center of the signalized intersection did not produce the correct intersection name. Therefore, where appropriate, locate the Reference Point Marker to display the proper intersection name. The ISD Message Creator will automatically generate an Intersection Name related to the local street names identified from the base map layer (e.g., N Bumby Ave & E Colonial Dr). The Intersection Name is not transmitted or encoded during the encoding process.

The initial Parent Map file shall be saved as version "0." All subsequent revisions of the original Parent Map shall be recorded in sequential numerical order. For specific saving instructions, see **Saving MAP Files, Revision Control, and File Repository**.

Child Map

Each signalized intersection will require its own Parent Map and its associated Child Map. All Child Maps shall include **Approaches** to denote a lane or a group of lanes as either ingress or egress points within the intersection. Ingress refers to movements entering the signalized intersection, while egress denotes points leaving the intersections.

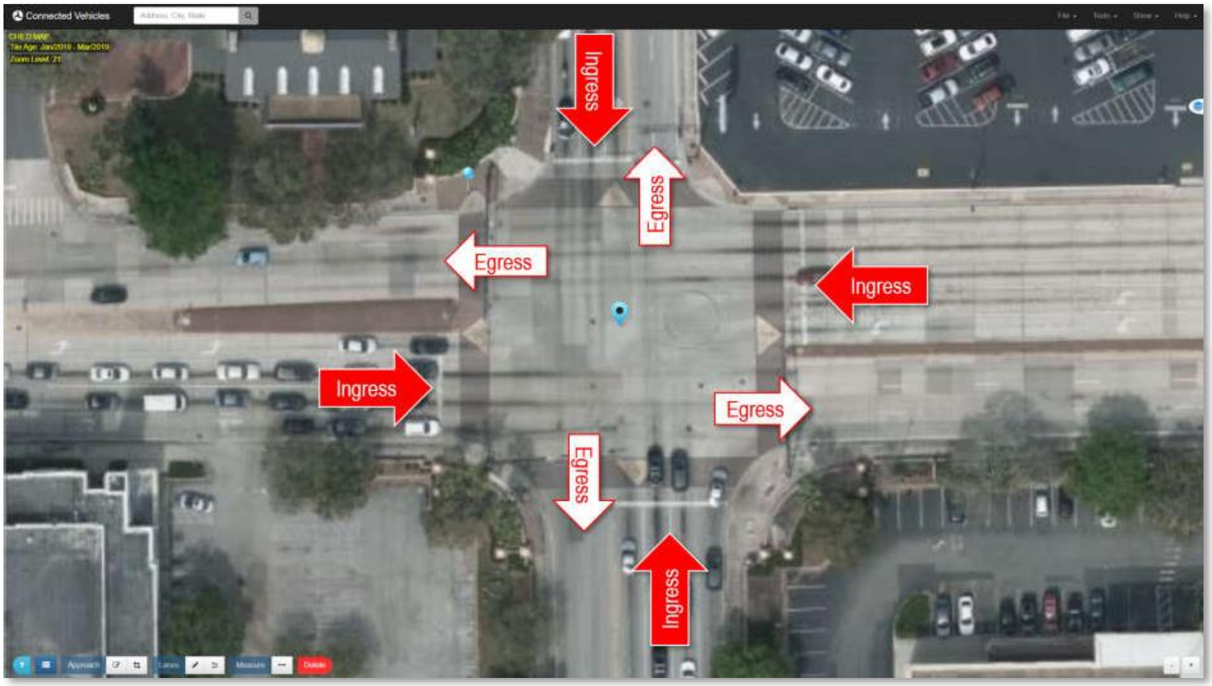


Figure 3: Ingress and egress points within an intersection

Drawings of Approaches

Each **Approach** shall encompass the entire width of the lane(s) from inside lane edge to the far outside edge of travel lane. Approaches for egress lanes shall be located beyond the return of the curb radius, located on the tangent section of the roadway. Approaches for ingress lanes shall completely encompass the stop bar. Within the Child Map, approaches are noted as bounding red boxes. To draw an approach, click on the inside lane, then drag to the far outside edge of the lane.

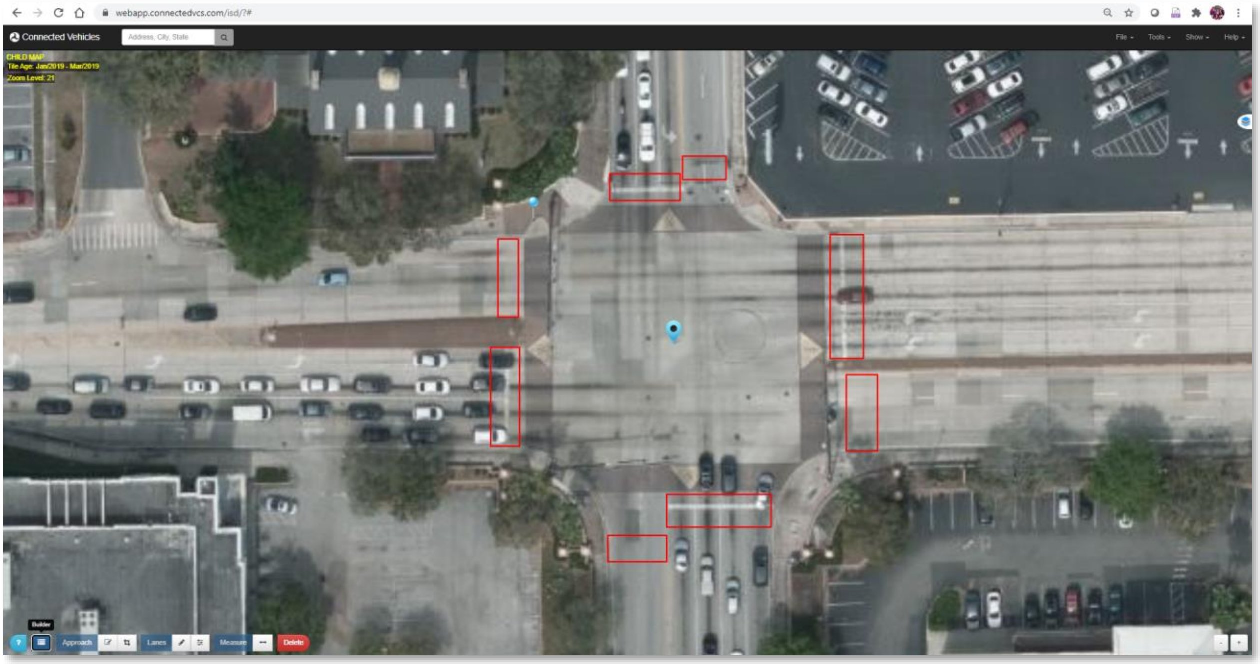


Figure 4: Example Child Map with constructed approaches

Each constructed approach will need to be configured with information concerning the Approach Type and Approach ID. Click on the Approach to enter the specified data. Within the **Approach Type** field, select whether each approach serves as an "Ingress," "Egress," "Both," or "None" for the intersection. Additionally, each approach will need an assigned **Approach ID** between 1 and 15. The suggested approach naming convention within D5 is to assign Approach IDs for the ingress points using the even number corresponding to the thru movement signal phases (e.g., mainline 2 and 6; intersecting roadway 4 and 8). Apply the same naming convention for the egress points using the odd numbers (1, 3, 5, 7) moving clockwise. For normal intersections, the egress should be numbered one less than the adjacent ingress. In cases where the intersection traffic signal controller is configured with non-standard phasing (e.g., using an odd phase to control a through movement), the ingress Approach ID should still be configured with an even number. For example, a side street through controlled by phase 3 would have an ingress Approach ID of 8, a main street through controlled by phase 1 would be Approach 6, etc. Refer to **Figure 5** for additional information.

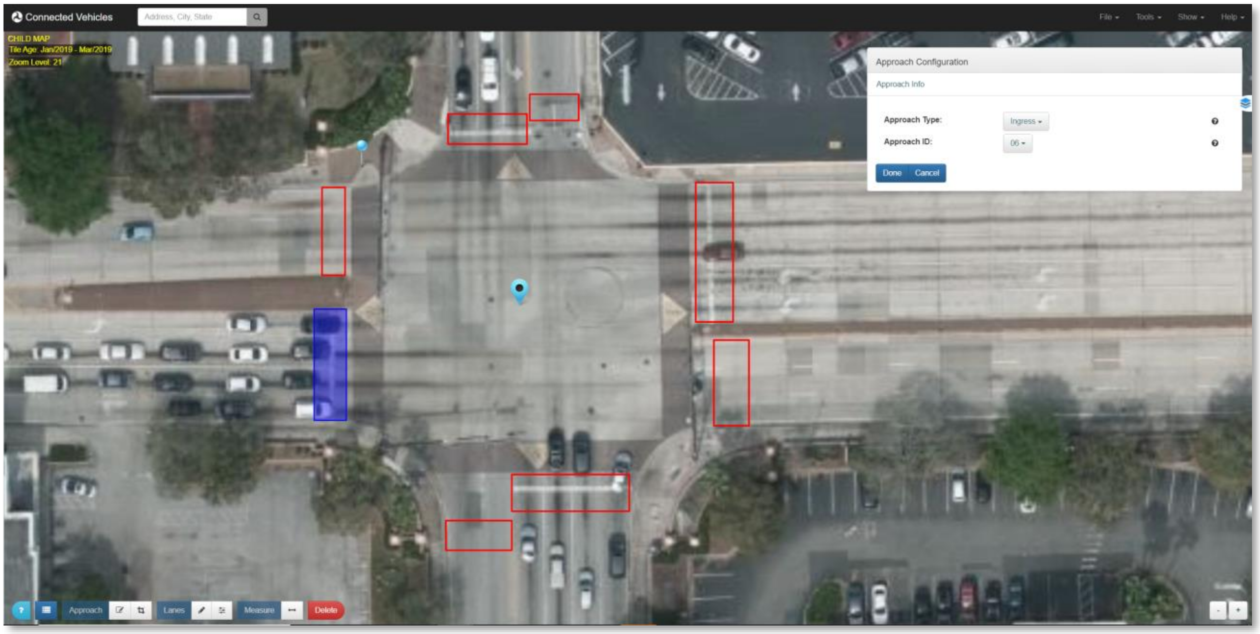


Figure 5: Suggested Approach IDs nomenclature for a standard intersection

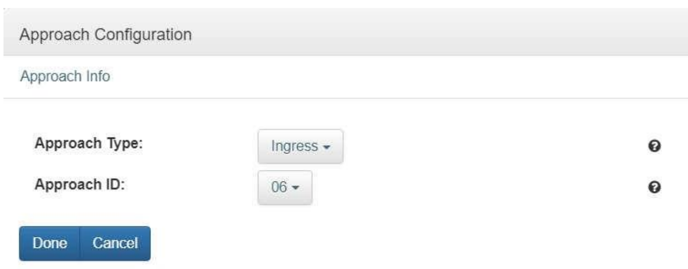


Figure 6: Example Approach Configuration Menu

Drawing of Lanes

After all Approaches have been completed, **Lanes** shall be constructed within the Child Map. Each Lane must originate within the associated Approach bounding box and be centered within the roadway lane. Each lane shall begin on or beyond (closer to the crosswalk) the stop bar. Each Child Map is anticipated to be unique and engineering judgement will need to be applied to the development of lanes; however, the following provides general guidance:

- Verify all intersection signages, whether posted or electronic, for turning movement restrictions prior to developing Lanes.
- Construct Lanes as straight as possible by minimizing the number of nodes (double-click mouse to end lane).
- Construct ingress Lanes to extend as far back from the stop bar as feasible, but no less than 600 feet (180 m) in length, with the following exceptions:
  - Ingress Lanes in dedicated left and/or right turn bays shall extend the entire length of the bay.
  - Ingress Lanes shall not extend into neighboring signalized intersections. Provide a minimum of 75 feet (25 m) from the neighboring intersection to allow for development of egress Lanes. The 75-foot (25 m) buffer shall be measured from the stop bar of the neighboring intersection.

- Egress Lanes shall be no less than 75 feet (25 m) and no greater than 300 feet (100 m).

After drawing each lane, verify there is no gap in the lane coverage by clicking “Show” and then “Toggle Lane Widths” to verify there is complete coverage for the approach. If the lane is unusually large, the default lane width can be adjusted to provide 100 percent coverage for all approaches. An On Boarding Unit (onboard unit) must be in a drawn “lane” in order to display signal phase and timing (SPaT).

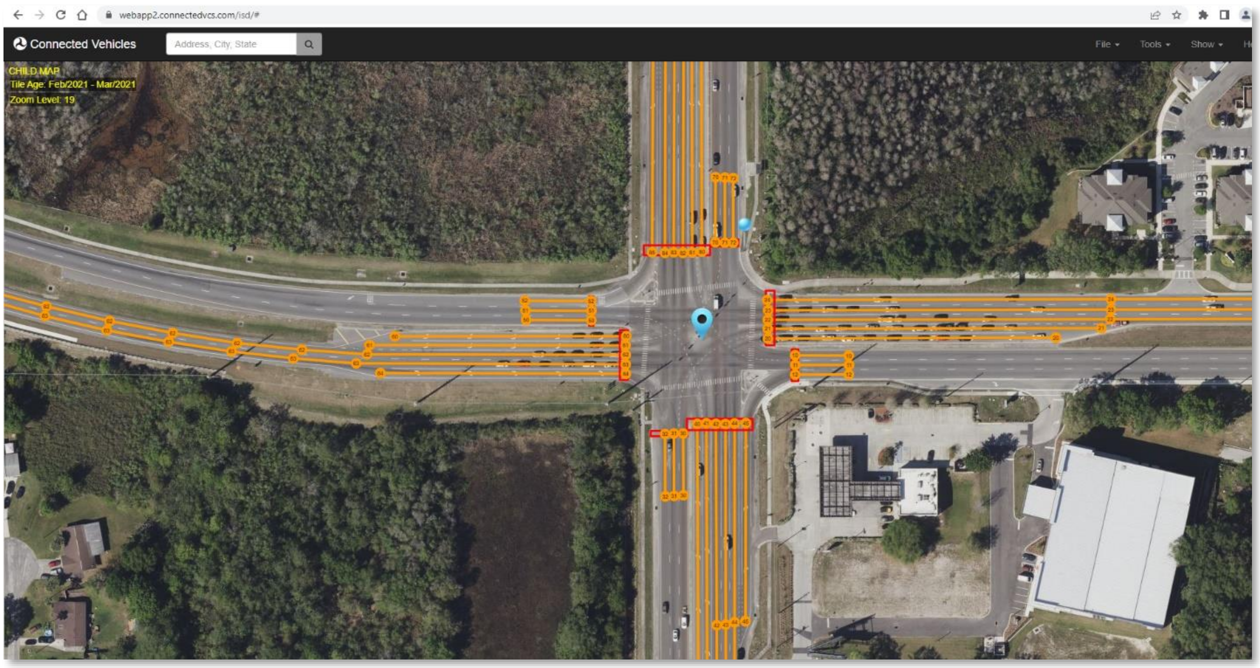


Figure 7: Example Child Map with constructed Lanes

Following construction of all Lanes for an intersection, each Lane will need input information within the **Lane Configuration** menu. To populate the lane information, click on the node inside the approach for a lane. The Lane Configuration window appears. It should indicate three tabs: Lane Info, SPaT, and Connections.

Lane Info Tab

Under the **Lane Info** tab, the developer will need to complete the following parameters:

- **Lane Attributes –** Utilize the Builder window (lower left corner of the screen, click the icon with the four bars). Select the appropriate maneuver by clicking and dragging and dropping it in the Lane Attribute box. Repeat this process if multiple lane attributes are necessary (a through movement and a right turn). Note, multiple maneuvers can be selected for each lane. Refer to Table 1 for additional information on commonly utilized symbology within the Builder tool.
- **Descriptive Name –** A human readable and recognizable name for the feature that follows. For vehicular travel lanes, D5 uses the descriptive name to indicate the primary maneuver for the lane. Choose one of these

maneuvers: NBT, NBR, NBL, EBT, EBR, EBL, SBT, SBR, SBL, WBT, WBR, or WBL. Spaces and dashes are not permitted. These abbreviations stand for: NBR to indicate Northbound Right Turn, or EBL to indicate Eastbound Left Turn. Follow the instructions below to choose the lane movement.

- **Lane Direction** – Identifies the nearest cardinal direction of travel the vehicle is heading; when the municipality timing plan indicates a direction other than the closest compass direction, the direction indicated in the timing plan (or the overall direction of the roadway) shall be used. For example, the lane direction of an eastbound route is always “EB” even if its actual compass heading is northeastward or southeastward.
- **Movement** – Identifies the primary maneuver for the specified lane. Most common movements will be left and through; occasionally there may be a dedicated right turn lane. Left turn movements will be denoted by “L”; through movements will be denoted by “T”; right turn movements will be denoted by “R”. For lanes that have multiple movements, identify only the primary use, such that a through/right lane is labeled “T.” There is no need to identify U-turns as possible movements. All egress lanes will be identified as through movements.

- **Lane Type** – Select the type of lane (“Vehicle,” “Crosswalk,” “Bike,” “Sidewalk,” “Parking”).
- **Type Attributes** – Utilize only if there are unique circumstances, such as a flyover ramp or bus only lane; otherwise, leave field empty.
- **Shared With** – Select the potential lane users. For standard vehicle-only lanes, please select “(3) Individual Motorized,” “(4) Bus,” and “(5) Taxi.” For roadway lanes shared with bicyclists, add “(7) Cyclist.” For bicycle lanes, select only “(7) Cyclist.”
- **Lane Number** – Select the lowest available lane number in adherence with the following nomenclature. The first digit of the Lane Number assignment will match the associated Approach. The second digit will represent the lane number within the Approach, starting from the innermost lane (“0”) and increasing by one working outwards. Note, there may be additional lane numbers not utilized. These numbers are reserved for future use. Pedestrian crosswalks shall utilize digits 0-9 for Lane Number assignments. Refer to **Figure 10** for additional information.
- **Latitude** – Do not change the data in this field.
- **Longitude –** Do not change the data in this field.
- **Elevation –** Do not change the data in this field.
- **Lane Width Delta –** Do not change the data in this field.
- **Done -** To accept and close the lane entry dialog box, click “Done.”

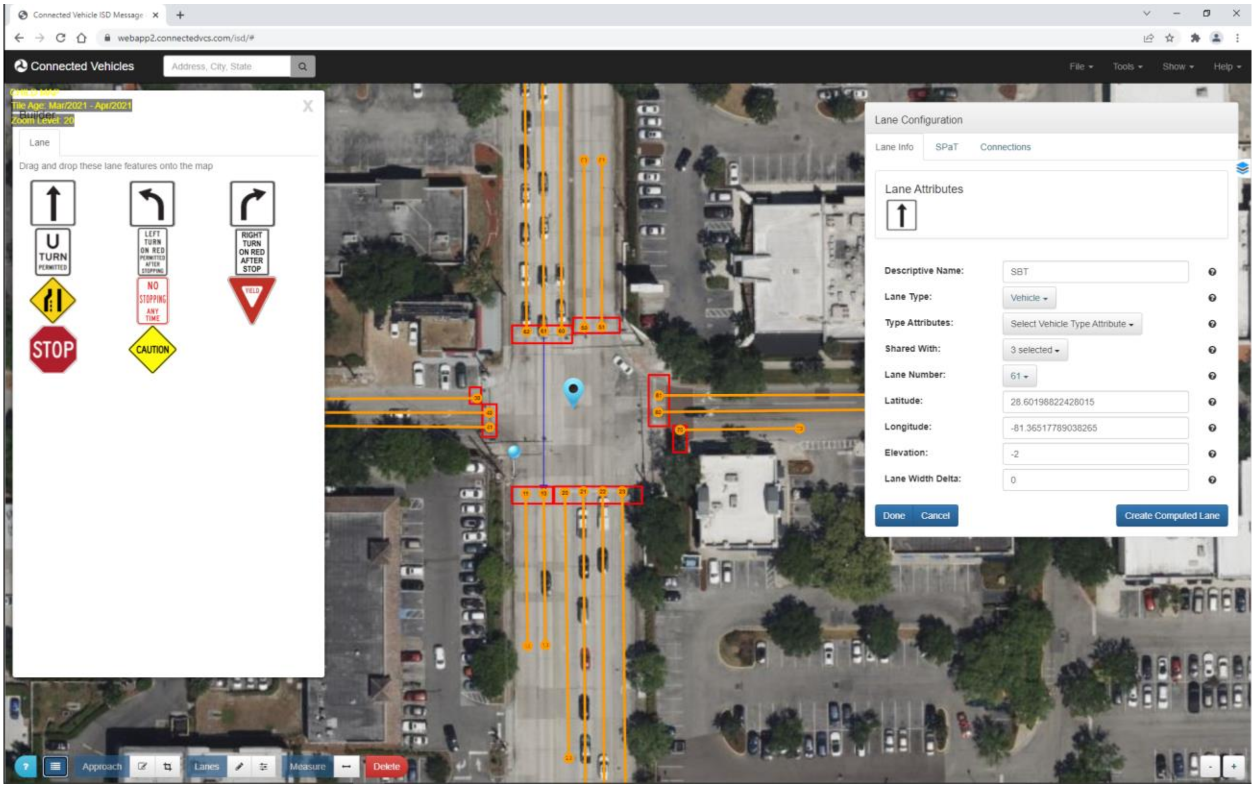


Figure 8: Example Lane Configuration menu and Lane Info tab with Builder window

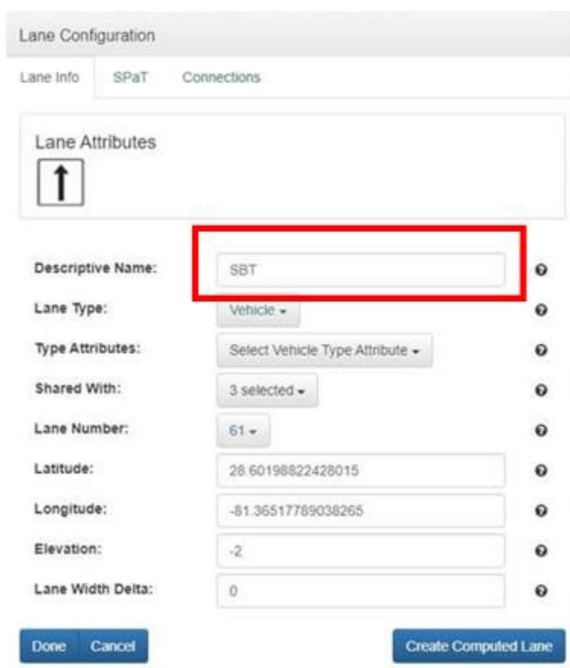


Figure 9: Example Lane Configuration with completed Descriptive Name field

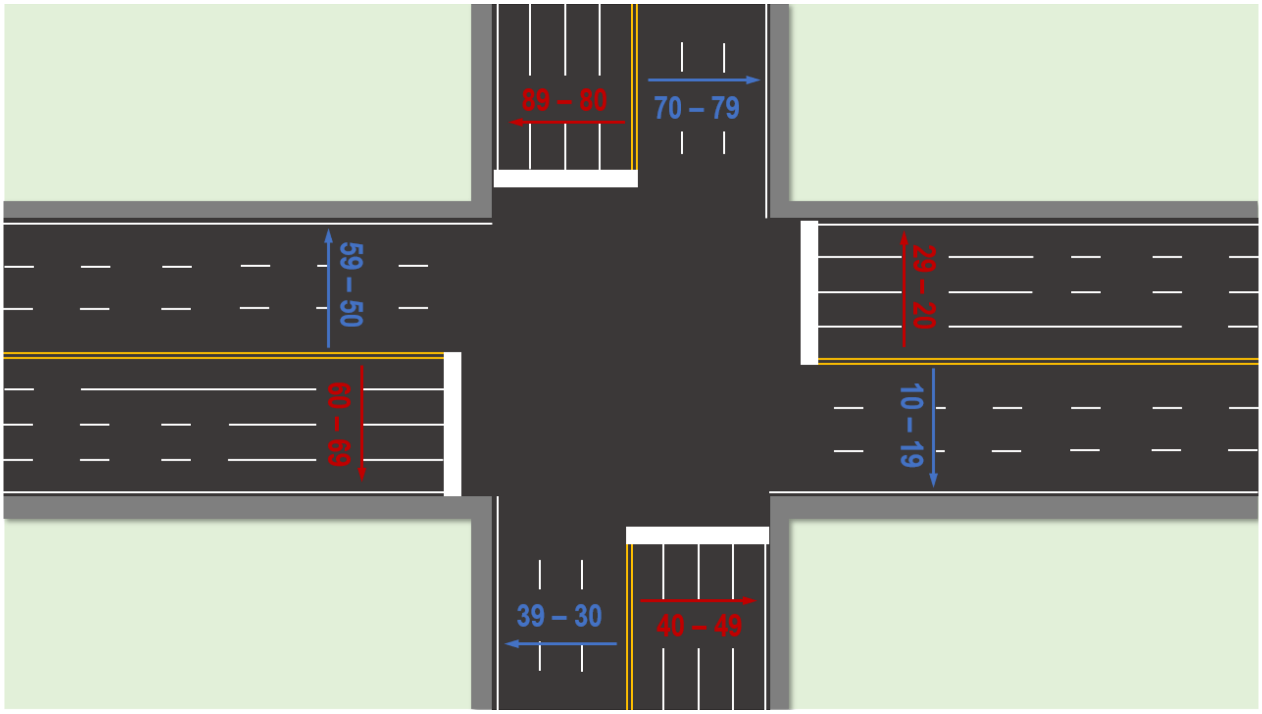


Figure 10: Lane Number assignment nomenclature, digits increase from inside lane working out

Node Placement for Through Lane Splits into Through Lane and Turn Lane

A turn lane at an intersection approach is generally split from the through approach. Similarly, turn and through lanes may merge at the intersection egress. Consistency is needed for how these splits and merges are represented in MAP messages. At locations where an ingress through lane splits into two lanes, a node point should be located along the centerline path of the through lane at the end point of the turn lane (ingress lane node points start at the stop line). There is no need for the through lane to include an overlapping node point at the location of this node. At locations where an egress merge lane joins an egress through lane, a node point should be located along the centerline path of the through lane for the end point of the egress merge lane. There is no need for the through lane to include an overlapping node point at the location of this node. At locations where through lanes split into two or more lanes, overlapping nodes for the end points of each new lane should be created at the separation from the through lane.

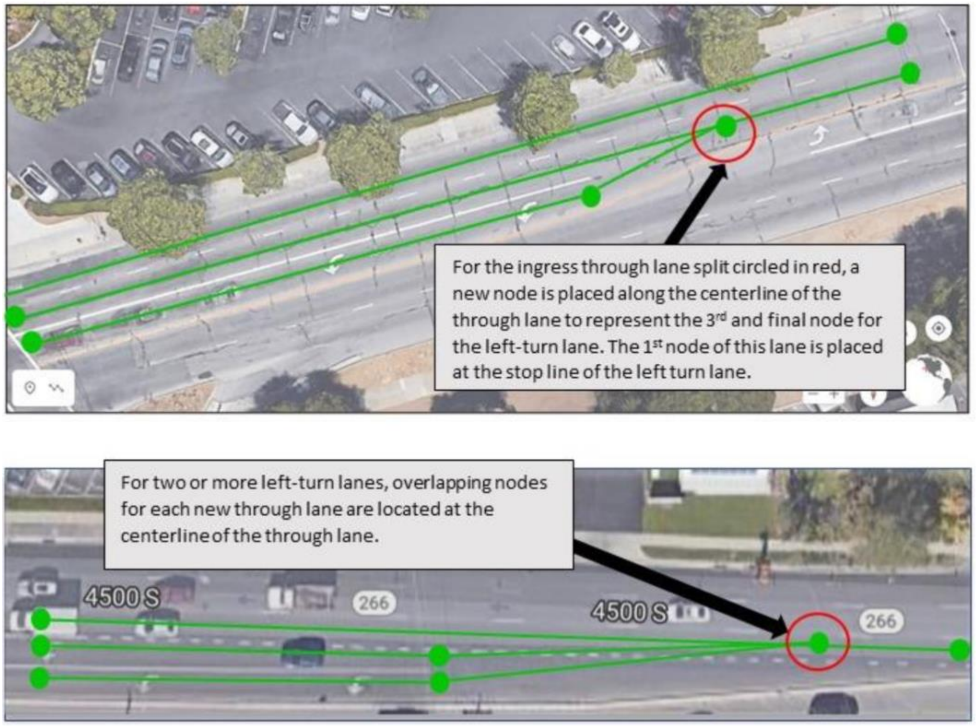


Figure 11: Node Placement for Through Lane Splits

Non-Signalized Intersections

There are situations where non-signalized intersections occur between two signalized intersections. Most agencies have not developed MAP messages for non-signalized intersections, but as the number of in vehicle applications increases, it is possible that in-vehicle applications will increasingly rely upon the receipt of MAP messages for non-signalized intersections. Common examples of non-signalized intersections include:

- *A left-turn lane upstream of the connected intersection (e.g., into a driveway);*
- *An ingress from public or private driveways; and*
- *Intersections (signalized or non-signalized) where two or more approaches intersect (e.g., a four-way stop).*

When there are in-vehicle applications relying upon MAP messages at non-signalized intersections, IOOs shall represent non-signalized intersections by MAP messages. Even when the primary flow of traffic is not interrupted by stop signs or signals, turning lanes still represent ingress to the intersection and egress out of the intersection. IOOs may develop the MAP message and broadcast it as part of SPaT/MAP broadcasts of upstream or downstream connected intersections. The portion of the MAP message that defines the signal groups that each connection is assigned to will not be possible (as there are no signal control phases or groups). The functions of on-board applications may include vehicle navigation or pedestrian warnings. While not signalized or marked, these are intersections.

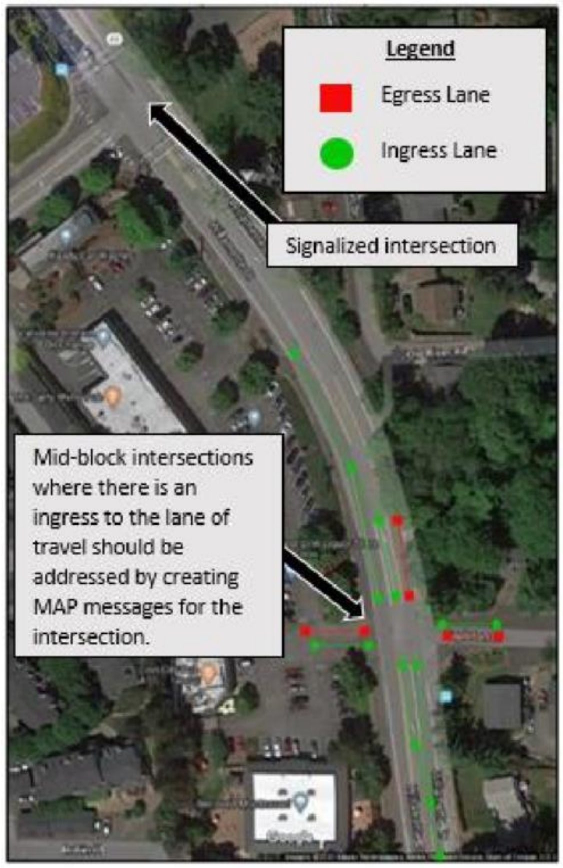


Figure 12: Non-Signalized Intersections

Flyover Lanes

Flyover lanes enable roads to cross with grade separation such that there is no conflict at an intersection. A flyover should not be represented as an intersection in a MAP message. An OBU may however have difficulty locating itself on the proper roadway if there is insufficient elevation information available from the map or from GPS. This topic has seen limited deployment to date and requires additional experience and research to determine more definitive guidance. A flyover that crosses a roadway with grade separation and no access should not be represented in the roadway's MAP message. If separate MAP messages are created for both the at grade lane(s) and one or more lanes that cross over the at grade lane(s) at some elevation above the intersection, any node point of the at grade lane should be at least 30 meters away from the projected edge of the crossover lane(s). This will help to minimize vehicles erroneously identifying the wrong road in the location of the crossover. A 30-meter distance was selected (without quantitative basis for the value) as a distance that would avoid on-board applications confusing the grade separated roads.

Channelization and Traffic Islands

Intersections with right turn lanes that involve channelization and traffic islands typically do not have a stop line, nor is there a clear distinction between the ingress and egress. The right turn lane conflicts with the crossing traffic only at the merge and does not directly enter the intersection. If a stop line is present, locate the last ingress node point at the upstream start of the stop line. If a crosswalk is present after a stop line, locate the first node point of the egress lane immediately downstream of the crosswalk. If no stop line is present and a crosswalk is present, locate the last node of the ingress at the start of the crosswalk and the first node of the egress at that downstream side of the crosswalk. If no crosswalk or stop line is present, locate the last node of the ingress lane at the merge point with the downstream lane. In this situation, there is no egress lane. On-board applications may rely on the last node of the ingress lane to identify stopping locations before entering intersections. In this approach, either stop lines or crosswalks provides an interruption between ingress and egress. Approach used and documented in the Ohio Smart City project (Smart City Intersection Digitization Update, 2019).

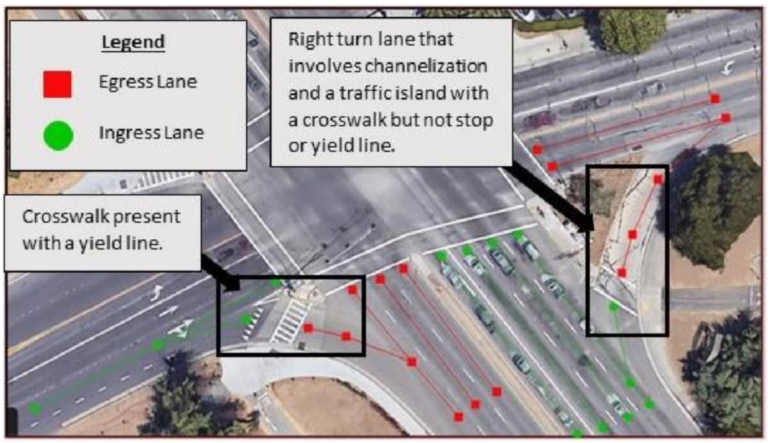


Figure 13: Example Node Placement for an Intersection with Channelization and a Traffic Island

Egress Merge Lanes

Intersections with dedicated or continuous right turn lanes will often merge into other lanes. The merge will typically be either:

- *The merge adding a new through lane that is either an auxiliary lane that merges downstream or is a new lane that continues; or*
- *An immediate merge into an existing lane.*

If the merge point is an immediate merge into an existing lane, the last egress node point should be at the centerline of the existing through lane. The last node point is at the centerline of the through lane (i.e., an egress out of the intersection). If the merge involves a lane add or an auxiliary lane that merges downstream with a downstream merge, the egress lane should extend until a position where the new lane exists and is established. The final egress node point should be in the center of the newly established lane. On-board applications may rely on the last node of the egress lane to identify conflicts/merges with other flows of traffic. Approach used and documented in the Ohio Smart City project (Smart City Intersection Digitization Update, 2019).

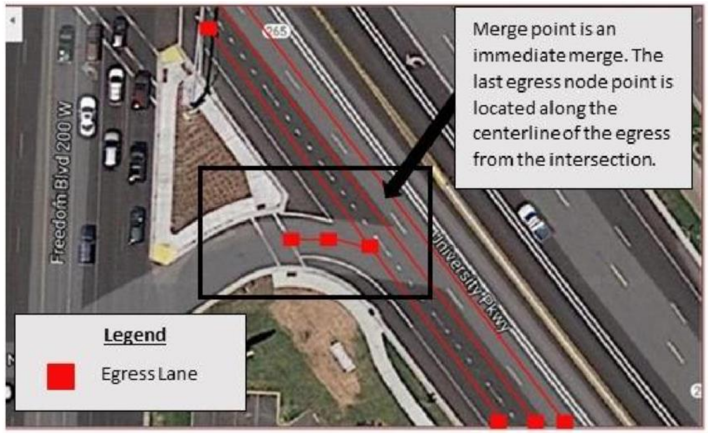


Figure 14: Example Egress Node Placement for an Intersection Where the Merge Point is an Immediate Merge

Mid-Block Left-Turn Lanes

There are situations where the ingress lanes of a connected intersection separate into a left-turn lane that allows traffic to turn left before the signalized intersection (e.g., into a shopping area). Mid-block situations that include left-turn lanes should be represented by a separate MAP message, with ingress and egress lanes. Even when the primary flow of traffic is not interrupted by stop signs or signals, these lanes still represent a left-turn ingress to an intersection, whether the connection is to another road or a parking lot. IOOs may develop the MAP message and broadcast it as part of SPaT/MAP broadcasts of upstream or downstream connected intersections. The portion of the MAP message that defines the signal groups that each connection is assigned to will not be possible (as there are no signal control phases or groups). The functions of on-board applications may include vehicle navigation or pedestrian warnings. While not signalized or marked, these are intersections.

Two-Way Left-Turn Lanes

Two-way left-turn lanes (TWLTL) allow traffic performing left turns in both directions to use the median, creating an ambiguity in how these lanes are coded in MAP messages. TWLTLs should be treated as ingress lanes (left turn lanes) into the intersection where the left turns will occur. Note that separate MAP messages would still be created for each intersection and there would not be a separate MAP message for the TWLTLs. The length of the ingress shall extend a distance such that the opposing left-turn (other direction of travel) lanes do not overlap (a 20-meter ingress length was used in the Franklin County Ohio Smart City application). If the total length of the TWLTL is less than 40 meters, reduce the length of both turn lanes to one-half of the total length. The approach with the least issues is to represent the left-turn movements. Without a designated end to the turn bay, a distance for the left-turn lane must be assigned. Approach used and documented in the Ohio Smart City project (Smart City Intersection Digitization Update, 2019).

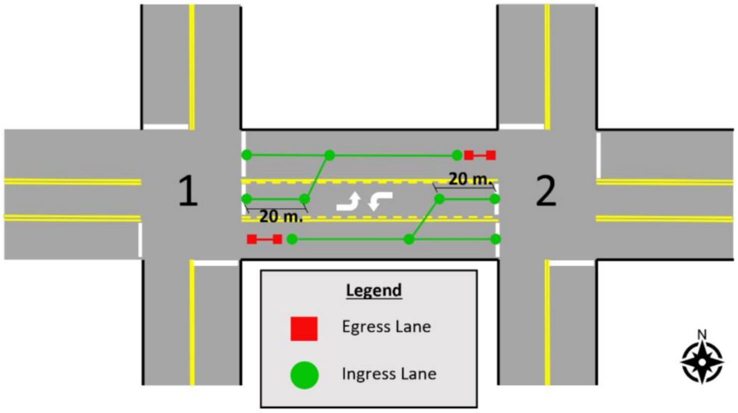


Figure 15: Two-Way Left-Turn Lanes

Multiple Intersections in Close Proximity

There are various locations where the signalized intersection is in close proximity to one or more other intersections or traffic control activities. Creation of MAP messages can be challenging, and the industry would benefit by consistent coding of these situations. Signal control may be performed by one common controller or separate controllers. Even if one controller is used, a typical phase pattern may be used to protect specific movements (e.g., signalized intersection with rail crossings may locate the stop line before the rail crossing with phase designations to allow any queues to clear, creating additional phases).

If multiple intersections are in close proximity and use one common signal controller, develop an overall MAP message for all approaches into and out of the common intersection. Phase designations may vary by agency (e.g., use of overlaps or exclusive movements during train detections).

If two or more intersections are in close proximity, and have separate controllers that are synchronized, separate MAP messages should be used:

- *The ingress for the downstream intersection may overlap the egress lane for the upstream intersection.*
- *In situations where there is an upstream signalized non-connected intersection that does not allow the ingress lane to the downstream intersection to be long enough to provide at least 10 seconds of vehicle travel time without extending into the conflict area of the upstream intersection, consider creating a MAP message for the upstream intersection and broadcasting the MAP message using the RSU for the downstream intersection (i.e., the downstream connected intersection will broadcast MAP messages for both intersections). This will enable applications (e.g., signal priority applications) to recognize they are approaching the signalized intersection sooner and begin determining if they need to send a priority request.*

MAP messages assign movements to specific signal groups. The CTI 4501 v01.01, Connected Intersections Implementation Guide recommends that a downstream connected intersection broadcast the MAP information for upstream non-connected intersections.

Pre-Signals

There are locations where an intersection (i.e., signalized junction of two highways) is in close proximity to a railroad crossing. In these situations, one or more approaches to the intersection may include a traffic signal to stop traffic prior to the crossing and/or avoid a queue backing up to the crossing. The signals located on the approach to the intersection may be Pre-Signals that are controlled by the common controller that is used for the intersection. In contrast, Queue-Cutter Signals are typically operated by separate controllers and considered mid-block intersections. Locations with pedestrian or bicycle crossings in advance of the primary intersection may also operate pre-signals. Creation of MAP messages can be challenging and there may not be correct or incorrect ways to code pre-signals, however consistent coding of these situations will be beneficial.

In situations where an approach to a connected intersection includes a pre-signal and the pre-signal is operated by the same controller as the intersection:

- *The approach should include an ingress lane with the first node of the ingress lane at the stop line controlled by the pre-signal, with connections assigned to the appropriate signal group of the intersection signal.*
- *The approach should include a second ingress lane, with the first ingress node at the stop line controlled by the signal at the intersection, with connection assigned to the appropriate signal group of the intersection signal.*
- *The pre-signal ingress lanes "connects to" fields should be populated with the lane number of the ingress lane that follows the pre-signal stop line.*
- *The second set of ingress lanes "connects to" fields should be populated with one or more lane numbers of the egress lanes out of the intersection that represent allowed movements.*

This procedure avoids confusion by OBU applications expecting Ingress to egress connections. Additionally, vehicles waiting in the area beyond the pre-signal could benefit from SPaT information to support on-board applications.

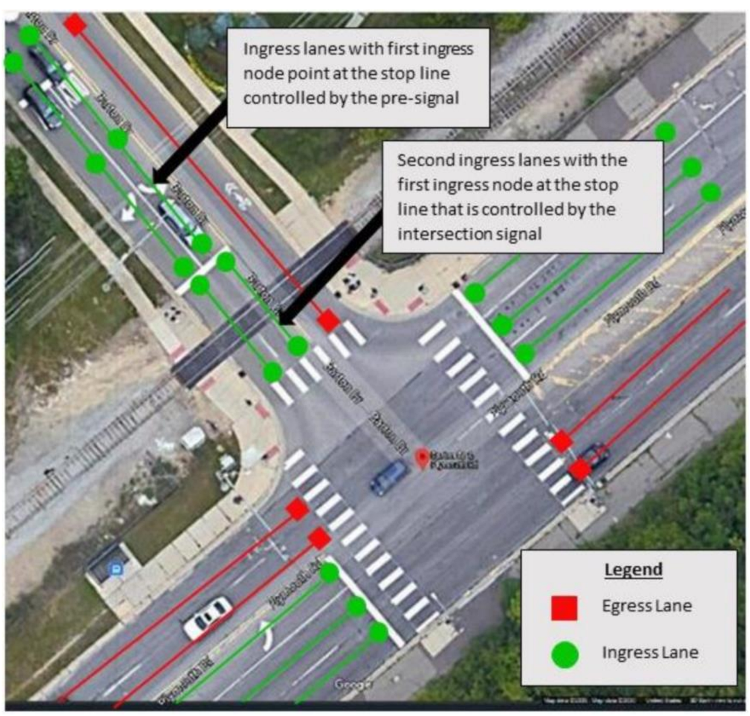


Figure 16: Pre-Signals

Divided Highway – Multiple Signals Per Approach

There are locations where at least one highway intersecting at an intersection (i.e., signalized junction of two highways) is a divided highway. In situations where space is allowed between the lanes of the divided highway (e.g., often referred to as "storage lanes") vehicles may be stopped at red lights in this interim location. When there is:

- *A first signal-controlled stop line for any approach.*
- *A second signal-controlled stop line for the same approach.*

The creation of MAP messages can be challenging, and the industry would benefit by consistent coding of these situations.

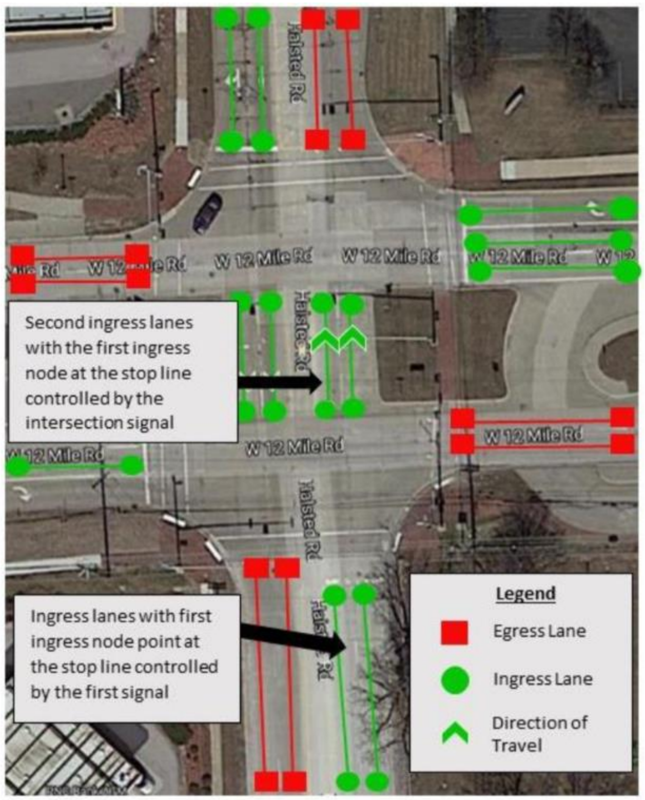


Figure 17: Divided Highway - Multiple Signals Per Approach

In situations where a storage lane exists within a divided highway and vehicles encounter a first signal-controlled stop line and a second signal control stop line, with space in between, and:

- *The first signal-controlled stop line is at an intersection that either allows turns or does not allow turns.*
- *Vehicles proceeding straight at the first signal-controlled stop line encounter a second signal-controlled stop line before exiting the intersection.*
- *The same signal controller controls all signals.*

Then, the following recommendations apply:

- *An ingress lane is recommended to be placed on the approach to the first signal with the first node point at the stop-line before the first signal.*
- *A second ingress lane is recommended to be in the area between the divided lanes, with the first ingress node at the second signal-controlled stop line.*
- *The "connects to" field of the ingress lanes before the first signal are recommended to be populated with one or more lane numbers of the ingress lanes in the storage area, as well as any allowed movements at the first signal (e.g., if right-turn is allowed at the first signal).*
- *The "connects to" fields of the ingress lanes in the area between the divided lanes should be populated with one or more lane numbers of the egress lanes out of the intersection that represent allowed movements (e.g., left turn, straight, etc.)*

Ingress lane to ingress lane connections are allowed in SAE J2735. Vehicles waiting in the area between the divided lanes could benefit from SPaT information (e.g., crosswalk status, time to green start).

Jug Handle Intersections

There are various locations where the left turn is accomplished by exiting to the right into a "jug handle" lane and turning left outside of the intersection (typically at a non-signalized stop sign). A MAP message should be created for the primary intersection. All movements allowed at the intersection should be included in the MAP message. The 'top of the jug handle' may be created as a separate MAP message (typically if signalized) or may not depending upon local deployment. These movements would not be part of the primary intersection MAP message. The exit ramp would not be described by a MAP message. Distinct intersections need their own intersection definitions in a MAP message.

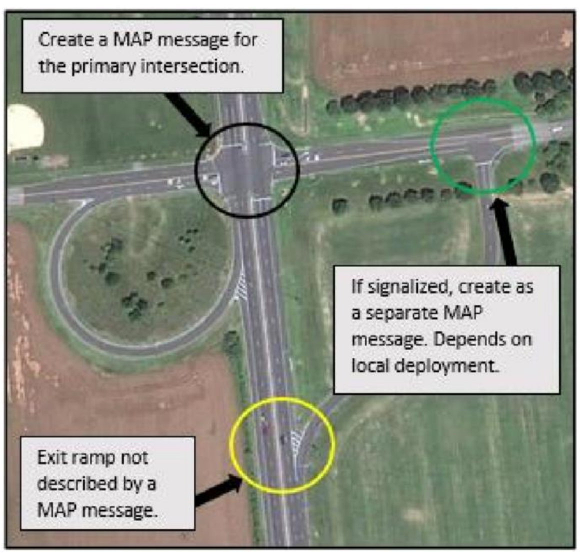


Figure 18: Aerial View of Jug Handle Intersection

SPaT Tab

All data fields within the SPaT tab must remain blank unless otherwise coordinated with D5 and/or the local maintaining agency.

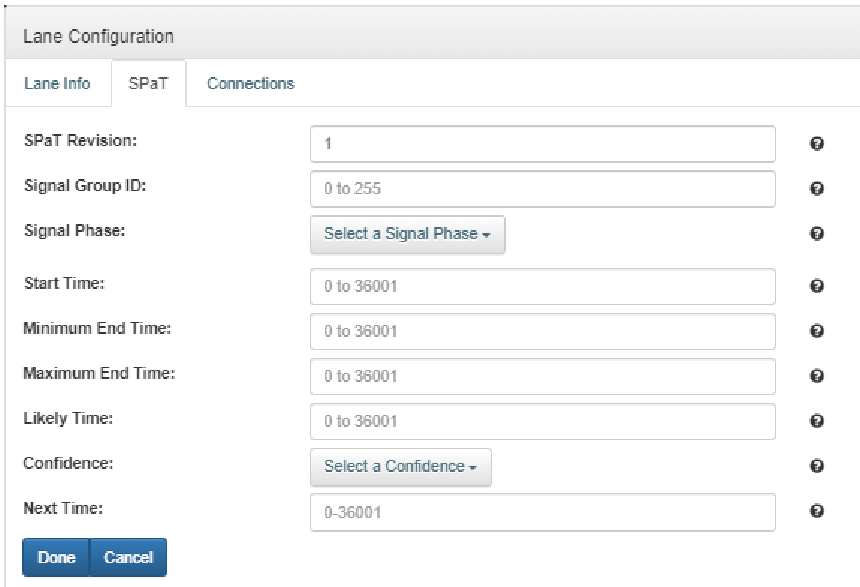


Figure 19: Lane Configuration menu with SPaT tab

Connections Tab

Under the **Connections** tab, the developer must complete the following parameters:

Once all Lanes have been constructed and the appropriate SPaT configuration parameters have been made, the **Connections tab must be completed.** Connections will <u>only</u> need to be configured for ingress lanes. Please note, nodes often have multiple connections (e.g., receiving lane for right turns and through movements). Per Florida Highway Safety and Motor Vehicles guidelines, right turn should only be connected to the outermost receiving lane.

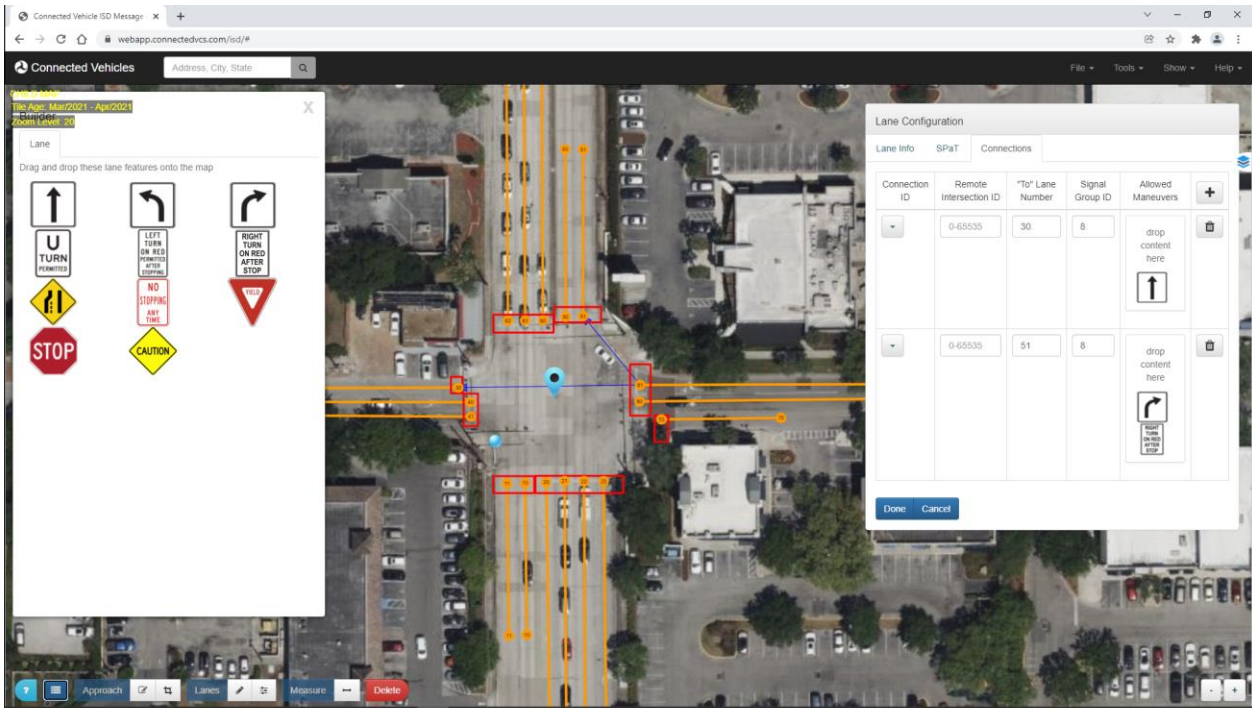


Figure 20: Lane Configuration menu with Connections tab

The following provides general guidance for development of Connections:

- For a single left ingress lane where there is no striping directing traffic to a specific egress lane, add a single Connection to the nearest egress lane in the intended direction.
- For a single left ingress lane where striping directs traffic to one or more egress lanes, add a single Connection to the nearest egress lane that matches the striping path.
- For a single right ingress lane, add a single connection to the nearest right egress lane in the intended direction.
- For ingress lanes with multiple left or right turn options where striping directs traffic to one or more egress lanes, add a single Connection for each turn lane to the nearest egress lane to match the striping paths.
- For ingress lanes with a single permitted U-turn option, add Connections to all available egress lanes in the intended direction.
- **Connection ID** and **Remote Intersection ID** fields can be left empty.
- **To Lane Number** – Insert the appropriate egress lane number to complete this connection.
- **Signal Group ID** - Utilize the as-built drawings or local agency-provided documentation, such as a signal timing plan, to determine the associated signal phase with each ingress lane. For ease of reference, use the

signal phase or overlap for each lane. The Signal Group ID for a non-signalized, dedicated right turn lane shall be 255.

Allowed Maneuvers

Utilize the Builder tool to assign the appropriate **Allowed Maneuvers** for each Connection. To build a Connection for each allowed maneuver, click the "+" sign button at the top right of the screen in the Connections tab, then insert the data in the required fields.

Table 1: Commonly Utilized Symbology Within Builder Tool

Symbology	Definition	Use Case(s)
	Through Maneuver	• Straight movement from ingress lane to egress lane across intersection in the same direction (e.g., WB to WB)
	Left Turn Maneuver	• Counterclockwise movement from ingress lane to egress lane in different directions (e.g., NB to WB)
	Right Turn Maneuver	• Clockwise movement from ingress lane to egress lane in different directions (e.g., NB to EB)
	U-Turn Maneuver	• 180-degree movement from ingress lane to egress lane in the opposite direction (e.g., NB to SB)
	Right Turn On Red Permitted	• No restrictions on right turns during red phase (e.g., posted signage or blankout signs)
	Yield	• Ability to make left turns on permissive phase (e.g., flashing yellow arrow, five-section head) • Ability to make right turns on permissive phase (e.g., five-section head, unsignalized right turns)

Saving MAP Files, Revision Control, and File Repository

The file should be saved once all map components have been added. To save the initial Parent or Child Map, select File in the top right corner, and then choose "Save." A pop-up will display requesting the revision number. For the initial Parent and Child map file, be sure to enter "0," if the file is not the initial revision, enter the next sequential number.

WARNING: <u>The user must click the **"Continue"** button to save the file. Using the "Enter" key on the keyboard will clear the map and **all previously unsaved data will be lost**.</u> As such, it is recommended to save more often, simply keep using the same revision number until all elements pertinent to the current version are entered.

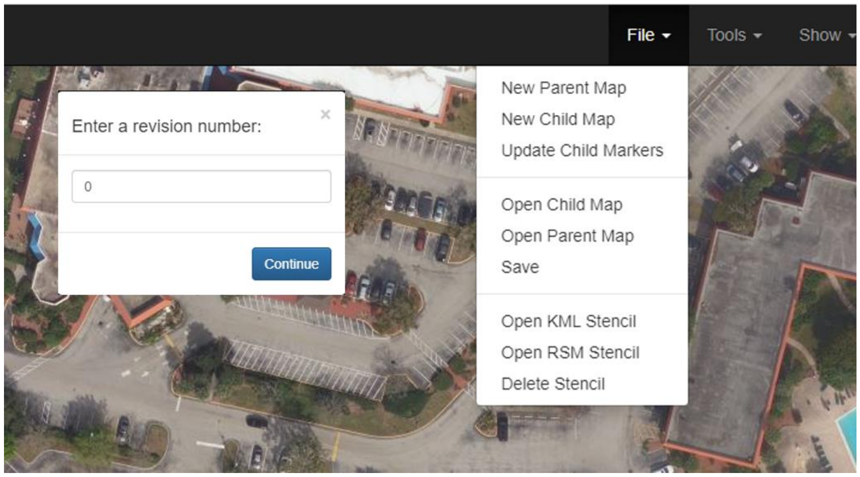


Figure 21: File menu and revision selection box

The ISD tool will save the file in the Downloads folder on the computer. The file name will be "AAAAAA_BBBBB_ISD_child_rC.geojson," for the Child Map, where "AAAAAA" represents the "Intersection ID" (a.k.a. "Global ID" for D5) and "BBBBB" represents the "RSU ID" (for D5); "rC" is the revision number entered during the saving process. If you have multiple versions of the same revision, choose the most recent version, and remove the ending "(#)" from the file name.

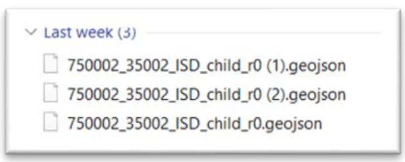


Figure 22: Multiple versions of the same revision

Move the Child Map file to the designated FDOT-approved repository. In the case where the user does not have access to the repository, they shall email the file to the appropriate FDOT representative.

Apply the same saving and storing procedures above to the Parent Map.

Encoding the MapData FileMAP Data File

To encode the MapData file for upload to the end device (e.g., RSU), select **Encoder** from the **Tools** menu at the top left corner of the ISD Map Creator. The encoder window opens. At the bottom of the window, perform the following activities:

Message Type – The Message Type choices are ISD, MAP, Frame+Map, SPaT, Frame+SPaT, and SpatRecord. To properly encode the data provided in the MAP file as described in this document, choose the appropriate selection as noted in Table 2. Typically, this will be "Frame+Map" or "Map," which will include SAE J2735 MessageFrame message with MapData or just the MapData contents but will omit bits related to SPaT.

Node Offsets – Available options In Node Offsets are Explicit (64 bit), Standard (32 bit), Compact, and Tight. Select "Standard (32 bit)."

Enable Elevation – Ensure **Enable Elevations?** is checked.

Encode – To encode the Child Map file, click the "Encode" button. The Encoder tool will populate ASN.1 and UPER Hex coding information. If this encoder page displays an error message, the encoding button does not activate.

Note, if the message size exceeds 1400 bytes, some RSUs may not be able to support the payload size. MapData file sizes can be reduced by reducing the total number of nodes within the Lanes. Also, warning messages similar to "SPaT message empty for lane XX" will not impact the MAP file and can be ignored.

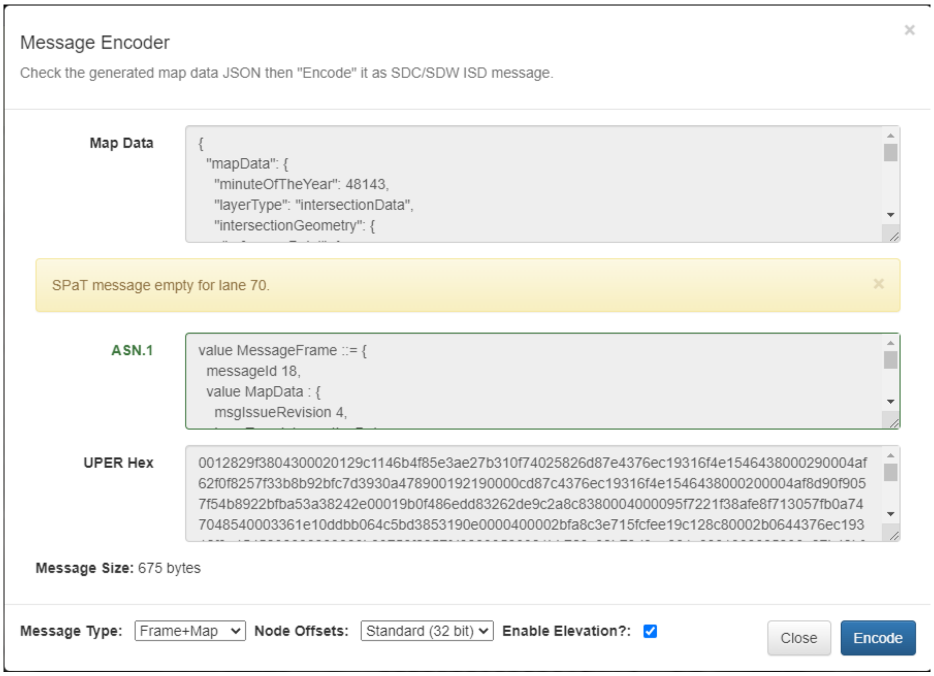


Figure 23: Encoder tool with appropriate settings

Each RSU manufacturer has its specific input of coded MAP files. See below for quick instructions for each manufacturer. If the manufacturer utilizes the ASN.1 data, click in the ASN.1 field, press "Ctrl+A" to select all the data, then press "Ctrl+C" to copy the data. This data must be pasted in a file. Open Notepad, then open the appropriate file provided by the manufacturer to paste the data. Save the new file in the same folder.

The file must be named "Map-cv2x-Intersection ID.xx," where Intersection ID is the identification of the intersection, and "xx" is the specific file extension to the manufacturer. Example: "Map-cv2x-40217.db" is the intersection at 434@Carrigan.

If the manufacturer utilizes the UPER Hex code, double-click in the UPER Hex field and press "Ctrl+C." Follow the same steps above to save the encoded data in the RSU file. It is suggested to refer to the manufacturer specifications and manual for further detailed instructions.

Table 2: Manufacturer - Specific Encoding Method

Manufacturer	Model	Message Type	Radio	Encoding	Entry Method	File Naming
Iteris	Spectra RSU	Frame+Map	DSRC	UPER Hex	File Payload	map16_0x8002_####.txt
Iteris	Spectra RSU	Frame+Map	C-V2X	UPER Hex	File Payload	map-cv2X-#####.db
Siemens	ESCoS	Map	DSRC	ASN.1	File Payload	map.xml

Note: For Iteris ONLY, after pasting the encoded data in the "Payload=" field, ensure there is an empty line after the end of the data (meaning hit the Return button). Siemens accepts a file with nothing more than the encoded ASN.1 data. RSUs can accept any file name, provided it is the correct format (e.g. .txt, .db, .xml) and do not require the **Intersection ID** be included in the name; however, it is recommended the **Intersection ID** be included in the file name for easy cross-reference.

Federal Communications Commission Licensing

Each RSU location must have Federal Communications Commission (FCC) approved license before it can transmit or broadcast traffic information. FDOT Central Office Intelligent Transportation Systems (ITS) Communications has a form to complete that requires site-specific antenna and RSU manufacturer-specific information. The site specific information includes, but is not limited to, Site Name, Antenna Latitude, Antenna Longitude, and State County and City names. The site name is limited to 20 characters with no spaces, dashes, or special characters allowed. For the purpose of the FCC licensing, FDOT specifies the minimum site naming format DXRSUIDMajMin, where:

- DX is the FDOT District number
- RSUID is the ID number of the RSU
- Maj is the first 5 letters of the major street
- Min is the first 5 letters of the minor street

The antenna latitude and longitude must be the actual antenna location and be recorded in degrees, minutes, and seconds along with the direction.

Once the RSU manufacturer and model are selected, obtain the transmitter antenna data from the manufacturer. After all data is collected, and populated in the FCC site form, submit the form to the Central Office for FCC licensing. The RSU shall not be turned on until after FCC approval is granted for each specific site.

Site Data	
Site Name:	D50219OrlanGayRd
Antenna Latitude (XX° XX' XX.X" N):	28°36'06.4"N
Antenna Longitude (XX° XX' XX.X" W):	81°21'54.9"W
City:	Winter Park
County:	Orange
State:	Florida
Main Street:	US 17/92 (Orlando Ave.)
Side Street:	Gay Rd
Elevation of Site Above Mean Sea Level (AMSL) in meters:	26.5
Overall Height Above Ground Level (AGL) without appurtenances of the support structure in meters:	8.2
Overall Height Above Ground Level (AGL) with appurtenances on the support structure in meters:	8.2
Support Structure Type:	Mast Arm (UPOLE)

Imperial Elevation Reference Information		
Elevation of Site AMSL:	87.00	Feet
Pole Height w/out App:	27.00	Feet
Pole Height with App:	27.00	Feet
Elevation of Device AGL:	25.00	Feet
Center Line of Antenna AGL:	26.00	Feet

Transmitter Antenna Data	
Manufacturer of the Antenna:	L-Com
Model Number of the Antenna:	HGV-4958-06U
Antenna Gain in dBi:	6.0
Beamwidth in degrees:	360.0
Center Line of Antenna height AGL in meters:	7.9
Azimuth in degrees:	90.0
Elevation Angle in Degrees:	90.0

Transmitter Data		
Equipment Class: Choose the output power for the corresponding equipment class from drop down. A= 0 dBm Max Output Power (15-meter communication zone) B= 10 dBm Max Output Power (100-meter communication zone) C= 20 dBm Max Output Power (400-meter communication zone) D= 28.8 dBm Max Output Power (1000-meter communication zone)	28.8	
	Max EIRP = 23 dBm Channels	Max EIRP = 40 dBm Channel
Frequency Channel(s): Check all desired channels for operation	☑ 180: 5895 - 5905 MHz ☑ 182: 5905 - 5915 MHz ☑ 181: 5895 - 5915 MHz	☑ 184: 5915 - 5925 MHz
Maximum Output Power:	17.0	28.8
EIRP:	23.0	34.8
Do you need to file a separate application for Channel 184?	**YES**	

Figure 24: FCC Site Data Form

Security and Credentials Management System Enrollment

FDOT requires all RSUs to be Security and Credentials Management System (SCMS) enrolled by the manufacturer before delivery to FDOT or the contractor. RSUs receive and maintain two weeks of certificates and must receive top-offs from ISS Certificate Management Service on a weekly basis and will need a network configured with access to the Internet. Networks that limit Internet connectivity will need to have access to 64.22.157.108 and port 8892 open for inbound and outbound traffic. Ensure the local agency has provisions to open traffic to and from this address and port for RSU certificate top-off.

Modifications and Updates to Parent and/or Child Map Files

When re-alignment changes are made at an intersection or if a verified reference point is changed, the existing Parent and Child Maps must be redrawn or modified. Ensure the most recent file is retrieved from the official file repository for the MAP file to be modified. Use the USDOT ISD Message Creator to open the appropriate Parent or Child Map. Add, modify, or delete approaches and lanes, as necessary.

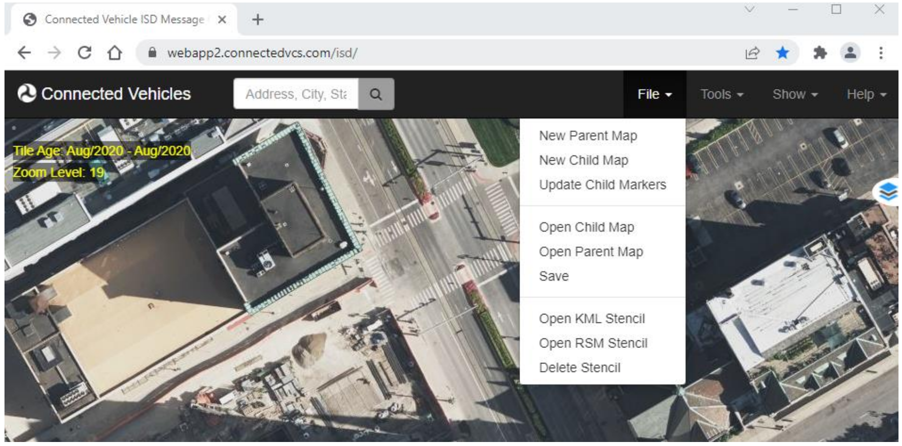


Figure 25: "Open" dialog box in the ISD Message Creator tool

Modifications and Updates to Parent Map File

To modify a Parent Map, open it in the ISD Message Creator; then click the Markers button in the lower left corner to unlock it for modifications. Modify the Reference Point Marker and the Verified Point Marker, as necessary. Then save the file per the file naming convention as previously explained.

Figure 26: Parent Map Marker Button

Modifications and Updates to Child Map File

Modifications of the Child Map require more due diligence. To change a Child Map, open it in the ISD Message Creator, click File, and then click "Update Child Markers." Changes will appear on the screen. At this stage, none of the approaches and lanes have been changed. If this is necessary, please follow the steps previously outlined for the approaches and lanes.

If a Parent Map is modified, the Child Map must be updated to the new Parent Map. To update the Child Map, open the Child Map file, select File, and choose "Update Child Markers" button. The ISD Message Creator will display a window to confirm the update. Choose "OK" to continue.

Modifications of Approach

To modify an approach, select the edit approach button (see Figure 27), which resembles a photo edit and looks like a square that has lines outside the box on the top left and bottom right corners. Next, select the approach that needs to be modified and make the necessary changes. When all approach changes are modified, deselect the edit approach button.

Figure 27: Edit approach tool in the ISD Message Creator

Modifications of Lanes

To modify a lane, select the edit lane button (see Figure 28), which is three horizontal lines. Next, select the lane and make the appropriate changes. When all lane modifications are complete, deselect the edit lane button.

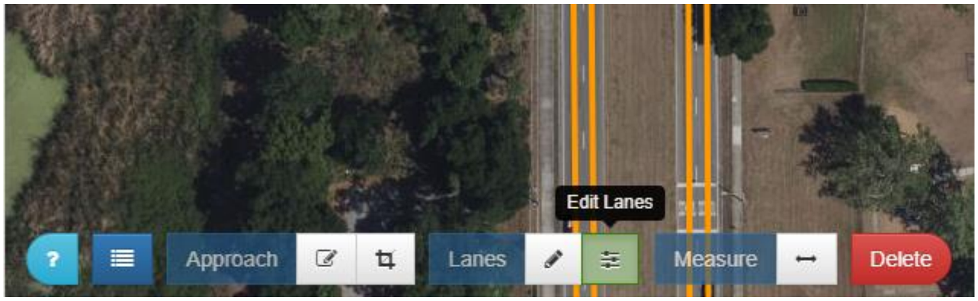


Figure 28: Edit Lane tool in the ISD Message Creator

Deletion of Approaches and Lanes

To delete an approach or a lane, click the delete button to activate, then select the lane or approach to delete. Once all features to be deleted have been removed, deselect the delete button by clicking it. If an approach is deleted, this means that all its prior information is also deleted. Therefore, to draw a new approach, one must populate the Approach Configuration tab.

WARNING: As long as the “Delete” button is activated, it will delete an approach or a lane when selected. The ISD Message Creator does not provide the “Undo” button. When an approach or a lane is deleted, it is gone and cannot be retrieved. To deactivate the Delete button, click it again.

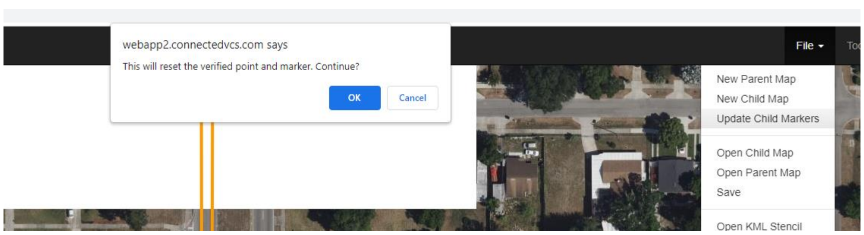


Figure 29: Display showing Update Child Marker and pop-up for verification to continue

After all parent and/or child MAP modifications are complete, save the file as previously detailed. Choose the next number above the current version, such that if the previous child was r7, the new child will be r8.

Stencil (Special Circumstances)

In certain circumstances, limited visibility created by overhead structures or trees, or recent construction not yet represented in the map due to an outdated location in the embedded map used by the ISD tool, there may be a need to use a stencil to accurately draw approaches and/or lanes. To apply a stencil to an open MAP, select File and choose the appropriate type of stencil to be applied (see Figure 31). When the use of the stencil is no longer required, delete the stencil by choosing the "Delete Stencil" button from the File menu.

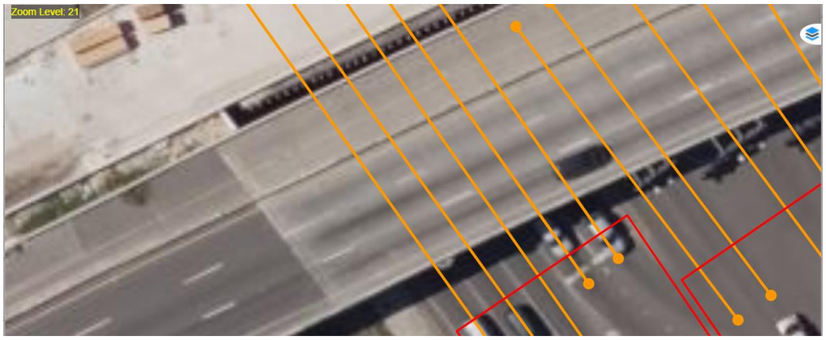


Figure 30: Obstructed view of lanes will require use of a stencil

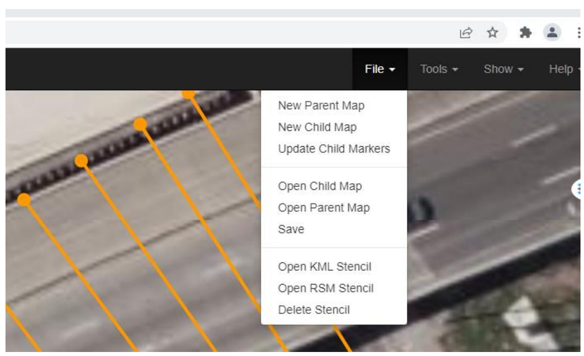


Figure 31: Open stencil interface

KML Stencil (Special Circumstance)

To be determined.

RSM Stencil (Special Circumstance)

To be determined.

Field Validation

The objective of field validation is to validate and verify MAP messages at the intersections where they are to be deployed. It verifies that the appropriate MAP message(s) are being broadcast and confirms that MAP messages are correct, appropriate, and available for their intended deployments.

Objective

There are two levels of verification possible in this step. The first level is to confirm that the received messages are appropriate for the RSU point-of-presence and match what was loaded to the RSU. The second level is to verify the encoded geometry elements are consistent with the physical infrastructure at the time of receipt.

The requirements for this step include:

- *MAP messages deployed and being broadcast at the locations to validate, or*
- *At a minimum, MAP message contents to be confirmed in the field (without broadcast).*
- *Performance criteria for:*
    - *Node point and path accuracy, and*
    - *Reliability of perceived lane location.*

Guidance

Verifying received MAP messages against expected MAP messages is a straight-forward process. An OBU in geo-tagged data logging mode can be driven along roadways and through intersections with associated MAP messages for vehicle position driving data collection. The logged messages can then be quickly compared to source messages and their reference points to confirm that the OBU is able to accurately determine the lane of travel and detect other errors.

A cooperative effort between automakers and Utah DOT led to a field validation process supported by an automated utility. For vehicle position driving data collection, follow the data collection method described in the resource titled "Connected Intersection MAP Data Assessment Supporting Basic Red Light Violation Warning" to collect data by driving each approach at least 16 times (and more for multi-lane approaches). This is conducted with one set of eight driving runs positioned in the right portion of the lane (i.e., R) and a second set of eight driving runs positioned in the left portion of the lane (i.e., L). The assessment requires 7 of 8 runs for R and 7 of 8 runs for L to match the through lane for each approach. This is assessed using CAMP's bounding box analysis tools as OBU errors occur in certain situations that may be the result of proprietary algorithms. CAMP estimates the drives for data collection to take 2.5 - 3 hours. During the driving tests, the drivers should maintain position close to the left/right lane boundaries of the combined set of lanes (associated with the same signal group) without the tire touching the lane. This process is outlined in more detail in the Connected Intersection MAP Data Assessment Supporting Basic Red Light Violation Warning.

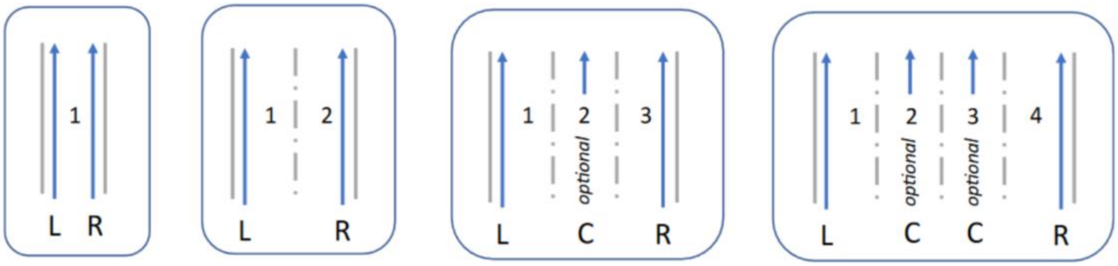


Figure 32: Illustrative Sets of Driving Runs for Vehicle Position Driving Data Collection

Uploading data to the CAMP "SPaT/MAP Utility, version 1" on-line tool then allows:

- *Visual inspection of vehicle path data compared to bounding boxes of each lane.*
- *Path Data Analysis, which displays:*
  - *Purple dots if outside lane*
  - *Yellow dots if on left ¼ of lane*
  - *Blue dots if in middle ½ of lane*
  - *Cyan dots if on right ¼ of lane*

For each connected intersection approach, a Pass/Fail is generated. Pass is if MAP matches to group of through lane movement for at least 7 of 8 runs. A decision tree is available that supports determination of whether the MAP message may be skewed left or right, or lane width is too narrow or wide. Position correction using RTCM data might be needed for the OBU to operate properly to perform this test. The second level of verification can be much more in-depth. MAP messages could be loaded into viewing software different from the originating software and spot checked. A test plan could be developed for each MAP message and then an OBU used to log paths driven could record movements with the output compared to MAP message geometry. If survey crews or point-cloud vendors are used to generate the MAP messages, then subsequent geometry verification can be skipped.

Equipment and software needed for field verification might include:

- *Vehicle OBUs;*
- *Vendor-provided management tools;*
- *OEMs driving vehicles through the intersections, then providing feedback;*
- *GPS units for locating vehicles as they drive through the intersection; and*
- *Portable suitcase testers to verify SPaT and MAP messages (available from multiple vendors).*

The simplest field verification might be visual confirmation of centerlines and stop lines consistent with the MAP data interpretation as received by an OBU. Field verification might also include decoding the MAP messages received from the RSU to confirm match with the intended maps. Field validation is needed to confirm that the MAP message conforms to the requirements of the CTI 4501 v01.01, Connected Intersections Implementation Guide.

Scenarios

This section describes what typically happens in each of the seven steps described above for creating MAP messages for the following five scenarios. Each scenario includes details on what is expected from both the contractor and IOO perspectives.

Scenario #1: Complete basic MAP message content for a Simple Intersection

There are seven steps that can be followed to produce a MAP message. Assembling required information, determining a reference point, and placing lane nodes are necessary to define the geometry of the subject roadway or intersection. Converting the geometric information to a UPER encoded SAE J2735 message and loading that information to roadside equipment are necessary for deployment. Visual and field validation steps are optional but recommended to verify that what the MAP message describes accurately reflects reality.

Step 1 - Assemble Data

Assembling the required information is a valuable first planning step that makes subsequent steps much easier. Key pieces of information include:

- *the road regulator and intersection reference identifiers;*
- *the revision number for the MAP message;*
- *the extent of the geometry to be represented in the message, including information described below;*
- *signal phase information;*
- *Agency agreed intersection numbering scheme; and*
- *Agency agreed lane numbering scheme.*

Step 2 - Determine Verified Point Marker

The next step is to determine a verified point marker. This allows a landmark with an accurately known location to be used as an adjustment to software-projected aerial views. As illustrated in Figure 33, the verified point marker should be a landmark that can be surveyed in the field and also viewed through available aerial images (e.g., an on-line MAP creation tool using aerial imagery).

Note that the guidance of this document recommends using the Verified Point Marker to calculate known coordinates of a reference point that is located inside the intersection (without trying to identify the center of the intersection as the reference point). Placing a reference point inside the intersection minimizes the distance offset to each lane's initial node, but there is unlikely to be a verifiable landmark at that location. In either case, be sure to record the measured geo-coordinates of the verified position and the horizontal and vertical distance between the verified position and reference point.

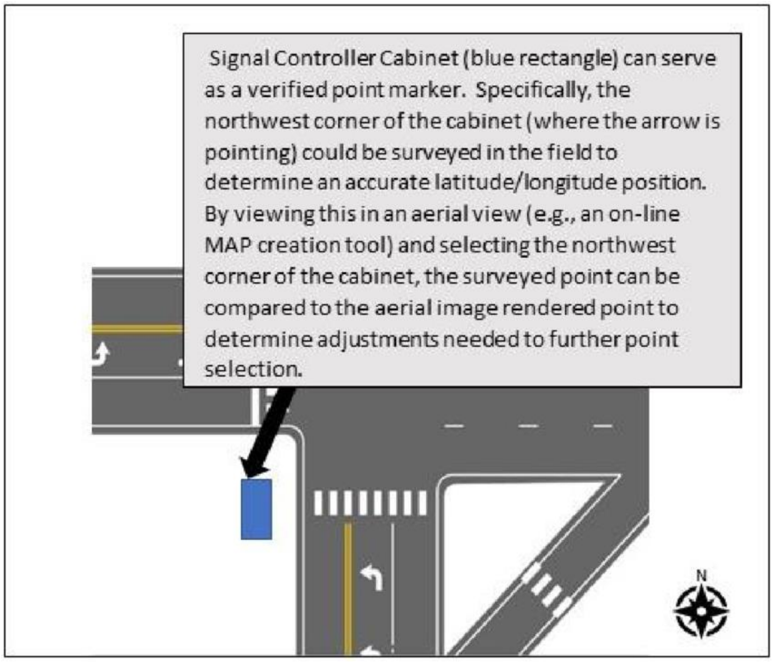


Figure 33: Intersection Reference Point

Step 3 - Place Nodes and Create MAP Content

Examples of how to place nodes and describe node attributes:

Nodes define geometrically significant locations along a lane and include lane width change and speed limit attributes. The initial node of a lane is typically placed at the upstream edge of a stop line, the upstream edge of a crosswalk, or before the nearest intersecting lane. Subsequent nodes offsets are calculated moving away from the intersection. Software tools should automatically determine the offsets.

Figure 34 depicts a lane number scheme starting from the southwest lane and proceeding counterclockwise for the vehicle lanes, followed by crosswalks also starting from the southwest and proceeding counterclockwise. Ingress lanes are denoted as green circles, egress lanes are denoted as red squares, and crosswalks are denoted by amber triangles. Lanes are required to have at least two nodes, but egress lanes can be kept short.

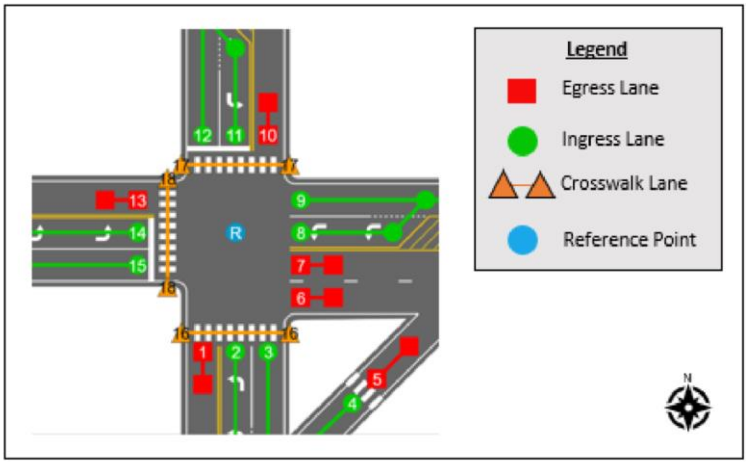


Figure 34: Intersection Lane Numbers

Initial node information is recorded as a distance offset from the previously defined reference point, and subsequent nodes are recorded as distance offsets from the previous node in the lane. The maximum offset distance between nodes is 327 meters. Long lane definitions may need multiple nodes even if the lane has no curve. Figure 35 shows the nodes defining the lanes within the example intersection. Most of the lanes contain three nodes, but the ingress lanes from the west need extra nodes to capture the longer curve.

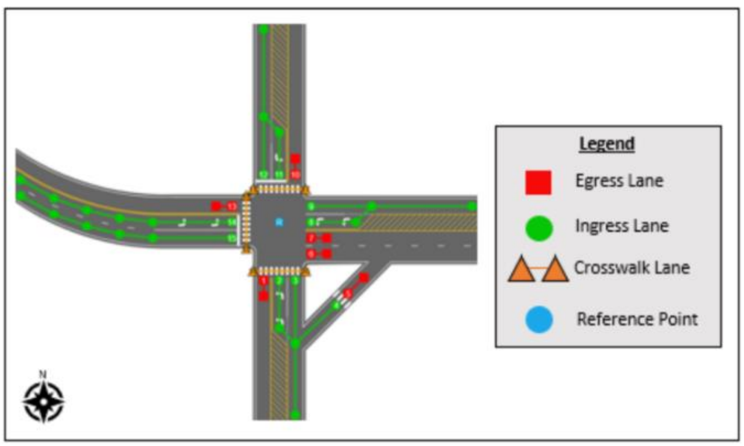


Figure 35: Intersection Lane Nodes

Figure 36 focuses on the westbound and northbound ingress lanes to show that there are repeated (same position but separate instance) nodes for lanes 2, 3, and 4; as well as lanes 8 and 9. The repeated nodes (3 times) for lanes 2, 3, and 4 occur at the left-turn and channelized right-turn gore points. The repeated nodes for lanes 8 and 9 occur at the left-turn gore point. The handling of channelized turn lanes is described later in this section.

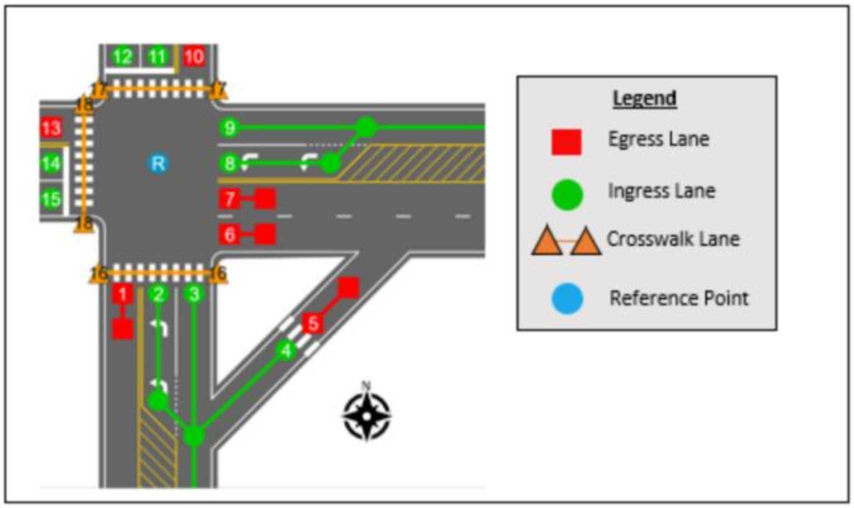


Figure 36: Intersection Repeated Nodes

If lane 6 is wider than the other lanes, the initial node for lane 6 would include a "delta value" representing change in width from the default lane width for the intersection. Similarly, if the reference speed limit for the intersection is set to 35 MPH and ingress lanes 2 and 3 have speed limits of 30 MPH, then changes to the initial node attribute for each of those lanes could lower the speed limit. A lane could be simply represented by two nodes, but if lanes contain lane width or speed limit changes between the end points, then internal nodes are added to contain the attributes and apply them to the lane segment. The J2735 standard includes a "speed limit type" data element. The most common speed limit type is "maximum speed." However, other types, such as "Maximum Speed in School Zone When Children are Present" can be used to indicate additional speed limits. As noted earlier, additional nodes would be needed to indicate the start and end of these areas where additional speed limits apply.

Examples of how to define lane attributes:

There are lane attributes in addition to node attributes. A lane contains the set of nodes that define the physical lane geometry and also determines the path direction and type of traffic expected. For the example intersection, the ingress lanes have the ingress path attribute set, the egress lanes have the egress path attribute set, and the crosswalks have both the ingress and egress attributes set as they are bi-directional. Additionally, most of the lanes contain the lane type attribute for vehicle traffic, while the crosswalks contain the crosswalk lane type for pedestrian traffic.

Examples of how to link a Signal Phase Diagram with Allowed Movements in the MAP Message:

In order for the MAP message to enable application to understand which signal control group is controlling flow in their lane of travel, the MAP developer needs to identify and define attributes for allowable connections from each ingress lane to corresponding egress lanes that represent movements through the intersection. To define the connections, the MAP developer must:

- Identify the ingress lane and corresponding egress lane that make up the connection.
- Assign the appropriate signal phase (signal control) and maneuvers to each connection.

Initial Activity: Identifying the ingress lane and corresponding egress lane that make up the connection.

First, using the resources gathered in Step 1, the MAP developer should start with an ingress lane and identify all connections to egress lanes. Using illustrations in Figure 37 as an example:

- The MAP developer could first identify all connections that originate from lane 11:
    - Figure 37a illustrates a yellow line connecting lane 11 to lane 10 (a U-turn).
    - Figure 37a also illustrates a yellow line connecting lane 11 to lane 7.

  Collectively these two connections define the possible connections from lane 11.

- Next, the MAP developer could identify all connections that originate from lane 15:
    - Figure 37b illustrates a yellow line connecting lane 15 to lane 7.
    - Figure 37b also illustrates a yellow line connecting lane 15 to lane 6.
    - Figure 37b also illustrates a yellow line connecting lane 15 to lane 1.

  Collectively these three connections define the possible connections from lane 15.

- Next, the MAP developer could identify all connections that originate from lane 2:
    - Figure 37c illustrates a yellow line connecting lane 2 to lane 1.
    - Figure 37c also illustrates a yellow line connecting lane 2 to lane 13.

  Collectively these three connections define the possible connections from lane 15.

A few specific notes about the example illustrated in Figure 37:

- Identifying connections between ingress and egress lanes is straightforward for an intersection with a single lane at each egress, however, can get more complicated for larger, multi-lane intersections. For instance, anytime a single left- or right-turn lane or a through lane connects to an intersection egress with multiple lanes (e.g., lane 15 or lane 11), a separate connection must be created for each egress lane.
- Additionally, even though it may not be apparent in the satellite view of the intersection, a left turn lane may also be used for U-turns. Unless a U-turn is prohibited at the intersection (e.g., on signage or per local regulations), connections should be created from the appropriate, inner-most left-turn ingress lane to all available egress lanes to represent this movement (e.g., the U-turn defined for lane 11).
- The MAP creation tools will typically have user interfaces that make selection of connecting lanes extremely easy if the MAP creator has identified all the applicable connections for each lane.

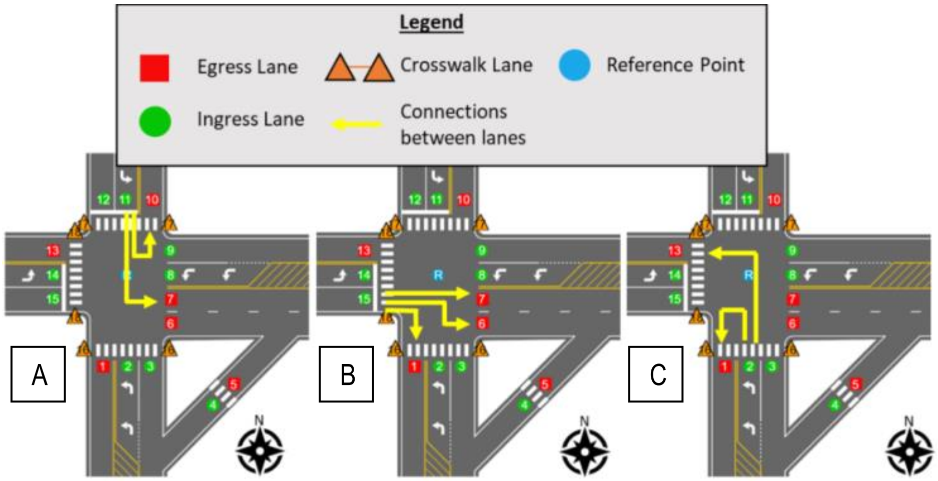


Figure 37: Sample Intersection

Second Activity: Assigning Signal Phase and Maneuvers to each Connection.

Once all the connections are defined, the MAP developer must then relate these connections to the signal phase diagram for the intersection, which may be like the one shown in Figure 38. In this scenario, the MAP creator had access to the phase diagram shown below and was able to understand each phase. The MAP creator then contacted the traffic engineer responsible for the intersection and was able to verify that Phases 1-8 are represented as signal groups 1-8 in the SPaT message that is output to the RSU. With this information, the MAP creator can assign the signal group to each connection. Similarly, the MAP creator was able to identify the maneuver that is permitted or protected for each connection using the signal phase diagram. For example, using the phase diagram illustrated in Figure 38, the signal groups for previous movements identified above:

- *The connection from lane 11 to lane 7 corresponds to Phase 5 and therefore is assigned to Signal Group 5 and has the maneuver "Left allowed";*
- *Also, the connection from lane 11 to lane 10 corresponds to Phase 5, is assigned to Signal Group 5, and has the maneuver "U Turn allowed".*
- *As another example, the connection from lane 15 to lane 7 corresponds to Phase 8, is assigned to Signal Group 8, and has the maneuver straight allowed.*
- *Finally, the connection from lane 15 to lane 1 corresponds to Phase 8, is assigned to Signal Group 5, and has the maneuver right allowed.*

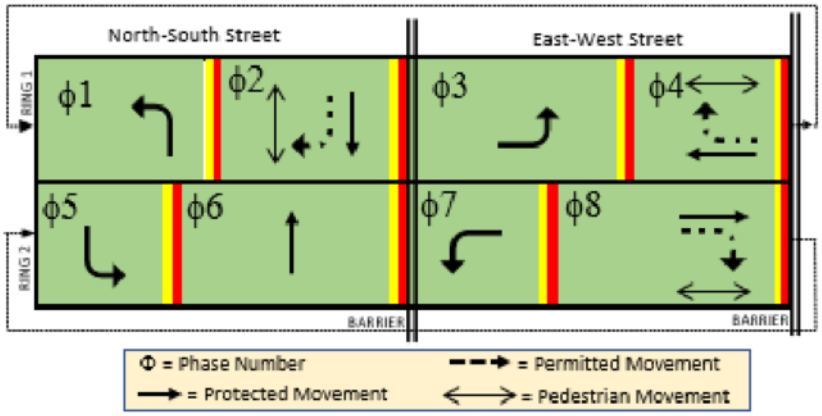


Figure 38: Example Signal Phase Diagram

Table 3: Relationship of Lanes and Connections to Signal Groups for MAP Message

Connection #	(Ingress) Lane	Connects To (Egress) Lane	Signal Group ID	Allowed Maneuver(s)
1	2[+]	13	1	LeftAllowed
2	2[+]	1	1	UTurnAllowed
3	3	10	6	StraightAllowed
4	4	5	6	yieldAllwaysRequired
5	8	1	7	LeftAllowed
6	8[*+]	6	7	UTurnAllowed
7	8[*+]	7	7	UTurnAllowed
8	9	10	4	RightAllowed
9	9	13	4	StraightAllowed
10	11[*]	6	2	LeftAllowed
11	11[*]	7	2	LeftAllowed
12	11[*]	6	5	LeftAllowed
13	11[*]	7	5	LeftAllowed
14	11[+]	10	5	UTurnAllowed
15	12	1	2	StraightAllowed
16	12	13	2	RightAllowed
17	14	10	3	LeftAllowed
18	14[+]	13	3	UTurnAllowed
19	15	1	8	RightAllowed
20	15[*]	6	8	StraightAllowed
21	15[*]	7	8	StraightAllowed

[*]For instances where a single left- or right-turn lane or through lane connects to an egress with multiple egress lanes, a separate connection is required to each egress lane.

[+]A left-turn lane may also need to include one or more connections to consider U-turns

[#]Note whether turning maneuvers are permitted on red

Table 3 is intended to be comprehensive in detail, however it should be noted that the information presented may not be entered in this manner, depending on what tool is used to create the MAP message. For example, the information for allowed maneuvers may not be entered with a linkage to the egress lane connection and may be entered as a single entry instead of multiple rows. An example of how allowable maneuvers, signal group ID, and connections to egress lanes for a sample intersection are entered and displayed for a MAP creation tool is shown in Figure 8 for the USDOT Tool.

Step 4 - Visual Validation

Visual validation of the MAP message content is straightforward and cost-effective. If a software application that includes an aerial view is being used, visual validation is continuously available and is part of the MAP message creation. A reviewer could use a different aerial view to get an independent, perspective. Alternatively, a software tool that can read the input format and render the MAP information on an aerial view could be used, as illustrated in Figure 39.

Figure 39: Visual Validation of Confirmation of Nodes

Step 5 - Convert to SAE J2735 Format

The conversion from a human-readable message to an UPER-encoded binary package is not trivial and software tools are needed. A tool used to enter MAP message data and place node points will be able to generate the UPER-encoded message. If not, the encoding tool needs to be able to import the format used to define the MAP message in the previous steps. The tool used to encode the message should also perform quality checks against the SAE J2735 specification and report any errors. If no errors are encountered, the tool should optimally encode the MAP message and geometry information in the most compact form possible and produce output that can be saved to an engineering document management system.

<u>Step 6 - Load to RSU</u>

Once the UPER-encoded message has been created, it should be able to be deployed to roadside equipment. This step can be vendor-dependent, so there may be a process to convert the UPER encoded message to the format needed by roadside equipment. Follow vendor instructions for conversions as needed, as well as the instructions for deploying the final MAP message to the equipment.

<u>Step 7 - Field Validation</u>

Now that the created MAP message is deployed, field validation can be performed. Field validation should include confirming that deployed messages are being broadcast, that received MAP message identifiers match those expected, and that the defined geometry agrees with the physical roadway arrangement. The first two checks verify functioning roadside equipment and eliminate possible clerical errors. The geometry check catches construction changes that may not have been available or known at the time MAP information was recorded.

Scenario #2: Description of how Scenario #1 changes for an intersection with channelized turn lanes

In the case of an intersection where there are dedicated or channelized turn lanes, there can be intervening paths, such as cross walks, bike lanes, or even light rail. When this situation occurs, the lane definition methodology is the same, except that an ingress lane's initial node is placed at the near edge of the intervening path and the initial node of an egress lane is placed at the far edge of the intervening path. Figure 40 depicts an example of this arrangement.

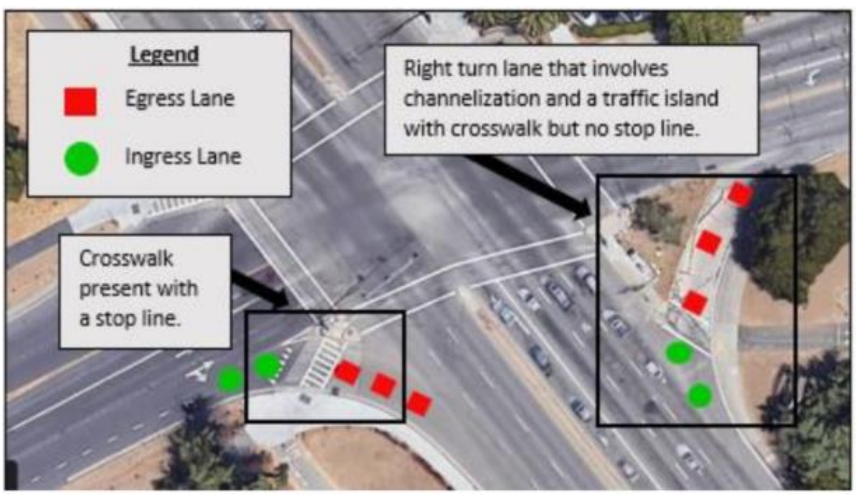


Figure 40: Intervening Paths Where There Are Dedicated or Channelized Turn Lanes

Scenario #3: Description of how Scenario #1 changes for an intersection with a horizontal curve on the approach

Many roadways and intersections include horizontally curved pavement to accommodate widely varying terrain, geographic features, and adjoining geometries affected by similar influences. When horizontally curved lanes are encountered, typically there is a need for additional ingress node points to maintain the accuracy of the node points in relation to the center of the lane. Guidance #3.16: Node Spacing in Horizontal Curves defines an iterative process that the MAP creator can follow to determine how many nodes are required and to verify when enough nodes have been located. While MAP creation tools make the process of adding additional nodes easy, MAP creators should also try to avoid creating more nodes than are needed, as the size of the MAP file is constrained. See Figure 41.

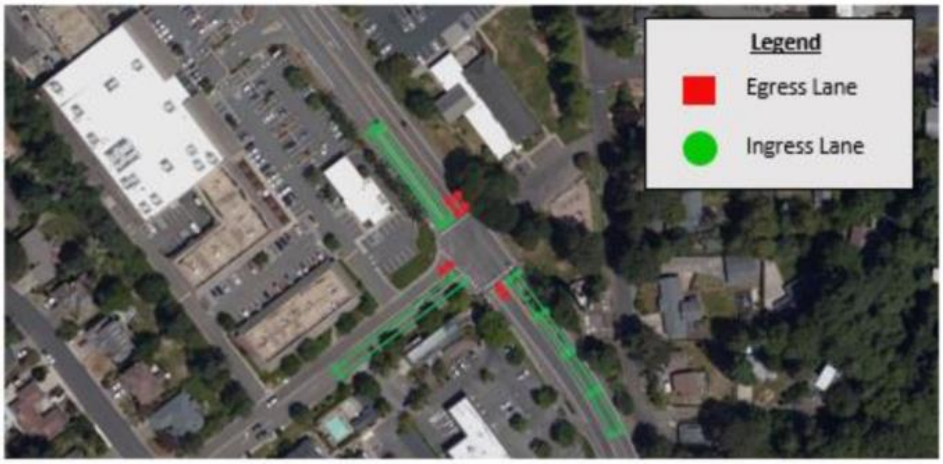


Figure 41: Horizontal Curve Node Spacing

Scenario #4: Description of how Scenario #1 changes for an intersection with pedestrian controls

Many intersections include pedestrian controls that can be incorporated into the MAP message to make it more robust for use in a broader set of safety applications. Specifically, sidewalks, crosswalks, and pedestrian signals can be represented in the MAP message as described by this scenario.

First, there are two types of lanes that are used to fully represent pedestrian movements in the MAP message.

- *Crosswalk lanes in the MAP message replicate the area marked by painted striping at the intersection that is designated for pedestrians to cross the road, specifically during pedestrian signal indications (e.g., "walk"). In the MAP message, this area is used by applications to understand potential conflict areas between vehicles and pedestrians.*
- *Sidewalk lanes defining pedestrian landings are used to describe protected, pedestrian-only locations at*

or behind the curb where pedestrians will be located before entering a crosswalk lane.

The MAP creator should identify these locations used by pedestrians at the intersection in step 1 to be prepared for creating these lanes in step 3. Specifically, the centerline of striped crosswalk lanes and the width of each crosswalk will be used to create the MAP message. When placing the nodes in step 3, each crosswalk lane will be defined by two coordinates, representing the centerline ends of the crosswalk where the crosswalk meets the curb. Next, sidewalk lane nodes will be placed at the exact same location of the end nodes of the crosswalk lane where it meets the curb. The sidewalk lane nodes will connect all crosswalks at that corner of the intersection.

As illustrated in Figure 42 , for example, nodes for crosswalk lane 18 will be located at the same points as a node for sidewalk lane 19 in the bottom left corner of the intersection and a node for sidewalk lane 20 in the top left corner of the intersection. When there is only one crosswalk at a given corner of the intersection, only one node of the sidewalk lane will have the same coordinates as a crosswalk node at the curb. For example, in the top right corner of the intersection in Figure 42, the node for crosswalk lane 17 connects to one node of sidewalk lane 21, while the second node of sidewalk lane 21 is located at the curb and does not connect to any other node (as there is no crosswalk on the right side of the intersection). Note that the nodes for sidewalk and crosswalk lanes in Figure 42 are placed in adjacent locations for illustrative purposes, but for the MAP message should be the same coordinates.

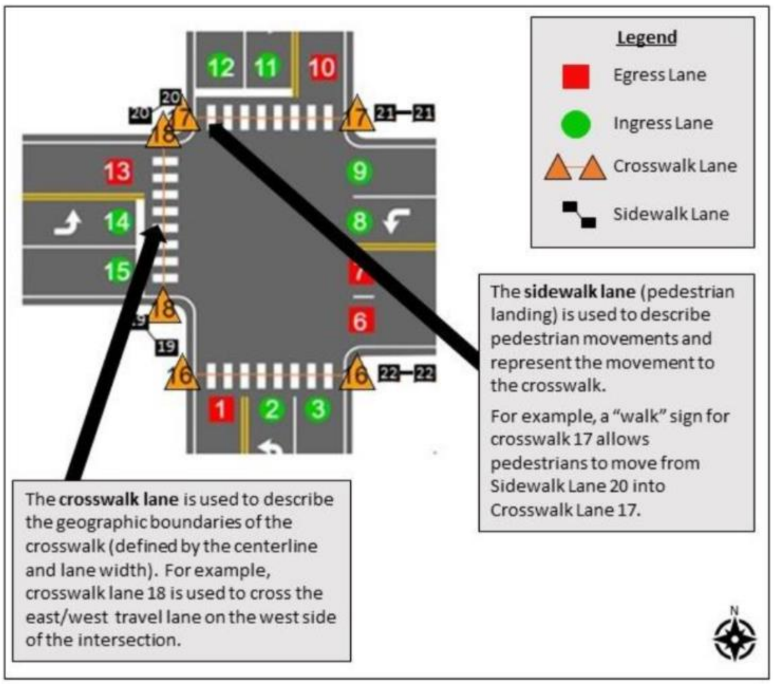


Figure 42: How to Place Sidewalk and Crosswalk Lanes

When making connections, the sidewalk lane always serves as a type of ingress lane and the crosswalk lane as an egress lane for defining pedestrian movements. Connections are made from sidewalk nodes to respective, co-located crosswalk nodes (i.e., the connection does not go from the crosswalk node to the sidewalk node) to denote *maneuvers, which are always designated as "straight", allowed from the sidewalk lane (pedestrian landing) to the crosswalk by a "walk" sign in a signal group. Signal group information for pedestrian movements should be found in signal phase diagrams, such as the one found in Figure 38. For example, the connections from sidewalk lanes 19 and 20 to crosswalk lane 18 correspond to signal group ID 2. The full list of relationships for sidewalk and crosswalk lane connections, corresponding signal group ID, and allowed maneuvers for this representative intersection is shown in Table 4. Note that several ingress lanes have multiple connections to egress lanes, but each connection only is assigned to one phase.*

Table 4 is intended to be comprehensive in detail, however it should be noted that the information presented may not be entered in this manner, depending on what tool is used to create the MAP message. For example, the information for allowed maneuvers may not be entered with a linkage to the egress lane connection and may be entered as a single entry instead of multiple rows.

Table 4: Relationship of Pedestrian Lanes and Connections to Signal Groups for MAP Messages

Connection #	(Ingress) Lane	Connects To (Egress) Lane	Signal Group ID	Allowed Maneuver(s)
30	20	17	8	StraightAllowed
31	20	19	2	StraightAllowed
32	21	17	8	StraightAllowed
33	22	18	4	StraightAllowed
34	23	18	4	StraightAllowed
35	23	19	2	StraightAllowed

Note that the visual graphics of a MAP creation tool may be more limited for sidewalk and crosswalk lanes than for motor vehicle ingress and egress lanes, given the nature of connections between two nodes that have the same geographic coordinates. Additionally, some MAP creation tools may not yet have advanced capabilities to recognize a crosswalk lane as bi-directional and may visually display a connection from a sidewalk lane to a node at the opposite side of the intersection. In this case, the MAP creator should double check that the node locations have been entered correctly and disregard the visual inconsistencies.

Scenario #5: Description of updating a MAP message

There are many reasons that a MAP message may need to be revised. For each of these situations, the MAP message contents should be examined for accuracy and revised, as needed. This scenario attempts to provide some principles and considerations for a MAP creator to follow when revising the MAP message for any reason, such as the following:

- *Errors may be identified in the current version of the MAP message. This may be something that is obviously incorrect (e.g., a mis-assigned connection between two nodes), or something less obvious (e.g., improved accuracy of node points).*
- *Addition or removal of signal phases or signal groups.*
- *Reassignment of connections to different signal phases or signal groups.*
- *New applications may be desired that require additional or more precise information in the MAP message.*
- *Restriping may change the configuration of ingress or egress lanes, location of stop lines, permitted*

movements (e.g., restrict or allow different turn movements), or add new features that were not present before (e.g., new crosswalks).

- *Reconstruction may similarly change the location and presence of features, as well as associated movements that are permitted.*
- *The earth's plate movements may periodically require adjustments to the node point locations.*

The nature of any reconstruction or re-striping effort will vary, which makes it difficult for a MAP creator to follow any one process for revising the MAP message.

This guidance document recommends revising the MAP message as soon as is practical in order to minimize adverse impacts to travelers. For maintenance or construction activities, it is impractical for agencies to develop interim MAP messages such that no MAP message may be available for hours or even weeks while the work zone and closures are active. Although the timing for removing and revising a MAP message is left to the judgement of the practitioner, three key principles for practitioners to bear in mind are:

1. *A broadcast message containing incorrect information has the risk of doing greater harm than if no message were broadcast at all. Any broadcast message should always contain correct information.*

2. *A MAP message containing information that does not match physical conditions and traffic control in the field should no longer be broadcast, even though this will disrupt the functionality of applications at a connected intersection.*

3. *A revised MAP message containing updated and correct information should be created and broadcast as soon as is practical to restore application functionality (i.e., this is preferred in lieu of broadcasting outdated or incorrect information).*

Removing an incorrect MAP message. *Ideally, a MAP message with incorrect or outdated information would be replaced with a revised MAP message as soon as an error is discovered or removed before a work zone is initiated. In rare instances, the practitioner may determine that the nature of an identified error is not significant enough to immediately remove the MAP message from being broadcast before a revised MAP message can be developed, thereby allowing applications like transit signal priority to continue operating. However, for safety-critical applications, it more likely that broadcast of a MAP message containing any errors should be immediately stopped. This will prevent applications from functioning until a revised MAP message is available for broadcast.*

During maintenance activities, it is recommended that practitioners cease broadcast of MAP messages as soon as traffic control is changed to minimize errors. As such, a MAP message should stop being broadcast as soon as a re-striping or reconstruction project begins as these activities will temporarily restrict and change allowable movements, including lanes that are available for use as ingress lanes or egress lanes, or potentially allowing use of an egress lane as an ingress lane instead or vice versa.

A nationally consistent change management process establishing minimum requirements and expectations for MAP messages during work zones and other "temporary" events, if available, should be used by agencies and practitioners to help streamline and standardize this process.

Creating and broadcasting a revised MAP message. *Depending on the nature of identified errors or changes at the intersection, a practitioner may choose to either revise the existing MAP message or create an entirely new MAP message. In either instance, practitioners should ensure that the latest MAP message used at the intersection has been identified and take care to increase both the MAP revision number and intersection geometry counter by one from the previously broadcast MAP message. Practitioners may use the design plans to create a new MAP message before the traffic control changes have been fully implemented in the field via re-striping or reconstruction, for example. Again, however, the recommendation is to not begin broadcasting the revised MAP message until the reconstruction is fully completed. For example, even after major elements of reconstruction are complete, the MAP message may still not fully or accurately represent all features on the roadway until signage and striping have been installed. As an example, a stop line or crosswalk in the MAP message that has not been painted might result in message from an application that could be confusing to a driver.*

Validate updated MAP message. *In addition to making updates or changes in the new MAP message, the MAP creator must ensure that the MAP revision number and intersection geometry counter have each been increased by one from the previously broadcast MAP message. The MAP creator should also verify that the re-striped or reconstructed roadway in the field matches what is in the generated MAP message, particularly if design drawings were used to generate the MAP message. Finally, after the MAP message has been validated, the MAP creator should store, document, and/or archive the files and information about the current MAP message per agency processes and policies to access as future updates are needed.*

References

- Florida Department of Transportation (FDOT) – District Five, “ITSIQA Intersection Movement Count Naming Convention”
- Society of Automotive Engineers (SAE), “J2735: Dedicated Short Range Communications (DSRC) Message Set Dictionary,” Revised July 23, 2020.
- TrafficCast, “User Guide BlueTOAD Spectra RSU,” Revision 04 – August 2020
- University of Virginia Center for Transportation Studies, “Guidance Document for MAP Message Preparation,” Revision 02 – June 2023

Appendix A: Connected Vehicle MAP Form

Connected Vehicle MAP Form

FDOT District Five

EXAMPLE

The intent of this document is to provide documentation to assist in the development and future revision(s) of Connected Vehicle (CV) MapData (MAP) at signalized intersections. This form shall be required for each location within a project in which CV roadside units (RSU) are proposed.

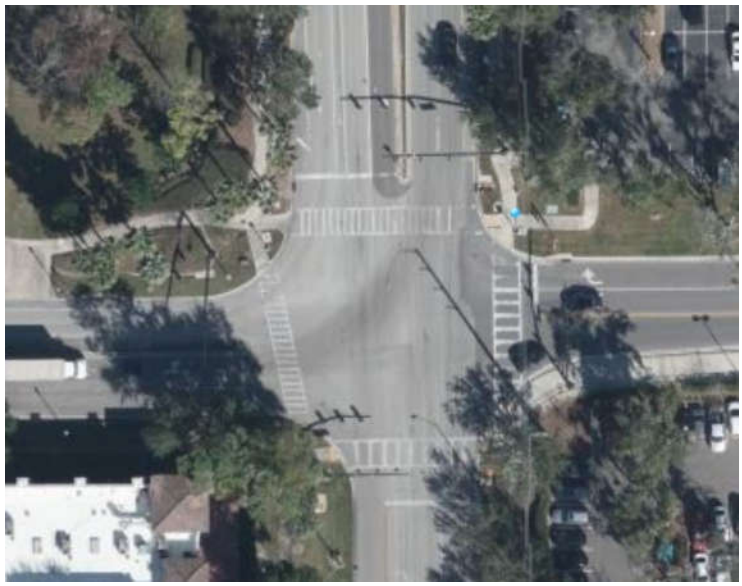
FPID No.	123456-1-32-01
Project Name	Connected Vehicle Gotham City Deployment
Consultant Firm	Wayne Enterprises, Inc.
Engineer of Record	Bruce T. Wayne (PE No. 99999)

Please complete all fields in the following form. Refer to https://noemi.cflsmartroads.com/data/ to determine the six-digit Intersection Global ID No., located in the top left corner of the intersection property display. Field Reference Points shall be permanent infrastructure components located outside of the immediate intersection and shall be clearly defined and easily located in the field. Good examples include right-angle sidewalk junctions and curb corners. Avoid infrastructure subject to vehicle knockdowns, such as traffic signal controller cabinets and pedestrian poles, as well as non-descript locations that are difficult to replicate (e.g., center of traffic signal foundation). Provide an on-site field photo depicting the Field Reference Point. All field collected Latitude and Longitude points shall be provided in decimal degrees and obtained using a differential GPS (D-GPS) unit with recent calibration results.

FIELD COLLECTION INFORMATION:	
Intersection / Location	Orlando Avenue (US 17/92) at SR 423 (Lee Road)
Intersection Global ID No.	750203
Description of Field Reference Point	Northeast corner of the intersection; right-angle corner of raised curb on pedestrian curb ramp.
On-Site Photo of Field Reference Point	
Latitude (D-GPS)	28.6276161°
Longitude (D-GPS)	-81.3983143°

The following fields shall be completed based upon data points derived from the Parent Map of the *USDOT Connected Vehicle ISD Message Creator* tool. Provide a screenshot clearly depicting the Verified Reference Marker in the location of the Field Reference Point and record the initial Latitude and Longitude in decimal degrees.

Using the field collected latitude and longitude datum determined from the D-GPS unit at the Field Reference Point, manually update the Verified Latitude and Verified Longitude fields within the Parent Map.

USDOT ISD MAP CREATOR TOOL INFORMATION:	
Snapshot of Verified Reference Marker (ISD Message Creator)	
Latitude (initial, ISD)	28.627602597244618°
Longitude (initial, ISD)	-81.39831781670485°

I certify that the information provided in this form is accurate and based on field collection efforts utilizing Differential Global Positioning System (D-GPS) technology. Furthermore, I certify that the Verified Latitude and Verified Longitude points entered within the Parent Map of the *USDOT Connected Vehicle ISD Message Creator* tool match the information determined via field collection efforts with the D-GPS unit.

Engineer of Record: ______________________________

Signature: ______________________________ Date: ____________________

Ref No. 1 - Global Intersection ID values obtained from NOEMI