CONNECTED INTERSECTIONS PROGRAM
TECHNICAL SUPPORT

Utah Department of Transportation Test Results – FINAL

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Prepared by

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Contents

1. Introduction

The primary purpose of the SAE J2735 V2X Communications Message Set Dictionary, most recently updated in July 2020, is to provide the precise structure of the messages used in C-V2X communications. The abstract syntax notation (ASN) provided in J2735 defines the precise structural details of the data concept, such as precision and range of valid values, which frames and elements are mandatory and which are optional. In some cases, the standard also provides information that is useful in understanding how to apply the message set to V2X applications. However, the description of data elements is not specific enough to eliminate the potential for ambiguity, resulting in variances in the data contained in messages broadcast between different implementations.

To date, there have been many state and local-led efforts toward deploying CV equipment on the roadside. Many of these deployments include the broadcast of Signal Phase and Timing (SPaT) and MapData (MAP) messages, typically supporting applications such as Red Light Violation Warning (RLVW).

However, it is possible that a vehicle deployed specifically to leverage SPaT and MAP messages broadcast from a particular roadside deployment to support RLVW may not be able to leverage SPaT and MAP messages from another deployment, due to design and development differences between deployments. Differences in the data in message content between sites can take several forms:

- Inclusion of optional data elements
- Interpretation of data elements. How the data element is intended to be used
- Progression of data elements. Rules that specify how a given data elements should change (or not change) from one message to the next.

These inconsistencies are not a direct reflection on the capabilities of certain vendors, developers, consultants, and/or engineers who have collaborated on these various state and local deployment efforts to deploy an interoperable system (from a data standpoint). Rather, it points toward the ambiguities and gaps in the existing (J2735) messaging standard that allow for differences between deployments to exist while remaining technically compliant. ITE released CTI 4501, Connected Intersection Implementation Guidance, in November 2021, to provide IOOs guidance for implementing consistent SPaT, MAP, and RTCM messages. A minor revision to CTI 4501 was released in July 2022[1]. Practitioners have not had much time to implement changes in response to its release.

This document sets the requirements and provides guidance for nationally interoperable connected intersections across the United States that support interoperable applications for signalized intersections. It is seen as an important first step that has established an open dialogue between IOOs,

[1] https://www.ite.org/ITEORG/assets/File/Standards/CTI%204501v0101.pdf

OEMs, and the traffic signal controller industry that provides an explanation on what data and connected vehicle messages are being provided from an interoperable connected intersection so safety applications can be developed for production vehicles, with an initial focus on the Red Light Violation Warning (RLVW) application. There is, however, growing concern that the existing capabilities of traffic signal controllers and other roadside technologies are not sufficient for allowing CTI 4501 requirements to be readily met.

CTI 4501 provides an important first step towards developing interoperable connected intersections and supporting connected signalized intersection safety applications. Understanding what functionality is needed to realize the benefits provided by compliance with these requirements is also an important next step for practitioners who must implement this functionality.

1.1 PURPOSE

The purpose of this test report is to document the test results of the multi-site connected vehicle (CV) message verification activities in support of the goals and objective of the Connected Vehicle Pooled Fund Study (CV PFS) as stated in the CV-PFS Connected Intersection Program Test Plan. To this end the Test Plan identified test cases that directly correspond to message requirements defined in CTI 4501. By assessing each requirement in this fashion, a better understanding of how sites align with the requirements and where development is needed can be obtained. The results include discussion regarding barriers to implementing CTI 4501-compliant messages and identifies design details that provide information about how requirements can be met.

Three pooled funds study representatives allowed data collection to be performed at multiple intersections so that CTI 4501 data requirements could be assessed.

	Marysville, Ohio	**West Point, Georgia**	**Park City, UT**
Number of Intersections	6	3	6
Communications	DSRC	DSRC	C-V2X
RSU	Danlaw, Kapsch	Kapsch Dual Mode	Kapsch Dual Mode
Traffic Signal Controller	Econolite Cobalt	Intelight	Intelight X3
Message Handler	Connect:ITS, Virtual CCU, Kapsch CVCP	Intelight (software application)	Helix Signal Command Module (SCM)
Position Correction	Ohio CORS	-	AGRC NTRIP Caster

Note: The results provided in this report are specific to data collected from intersections in Park City.

2. Activities Performed

2.1 DEVELOP TEST METHODOLOGY

CTI 4501 contains 128 unique message requirements. Most of these requirements have an associated design detail, which add context around the requirement, provide clarifying details, and to provide relevant examples as necessary. Based on the details provided in CTI 4501, a test methodology was developed for each requirement to understand what data needed to be collected and how that data would be processed to assess a site's compliance with the requirement. The detailed results in Appendix A provide the objective, method, and pass criteria for each requirement.

2.2 TEST EQUIPMENT

DSRC Data Capture Tool. An OBU that captures messages being sent via DSRC as well as BSMs broadcast by the device. This tool is only used on sites where DSRC is the primary communications medium. It produces pcap files, json format (accepted by CAMP online tool), and system log files, which are recoded to memory the OBU and can be extracted by the user.

C-V2X Data Capture Tool. An OBU that captures messages being sent via C-V2X as well as BSMs broadcast by the device This tool is only used on sites where C-V2X is the primary communications medium. It produces the same output files as the DSRC Data Capture tool.

Real-Time CV Data Visualization. A Bluetooth connection between an android tablet and the DSRC or C-V2X capture tool allows CV data received on the capture tool to be utilized by the Kapsch Insight application running on the tablet. The application displays a live visualization of MAP, SPaT, and BSM data overlayed on satellite imagery, and provides a live running count of message types received.

High framerate camera. A high framerate camera is needed to precisely capture short time differences between events captured in the recorded video. The camera used to record video was a GoPro Hero9 Black which records video to a micro SD card, and has settings for a user to adjust the frame rate, resolution, zoom level, brightness, etc.

Survey Equipment. Survey-grade GPS equipment was used to measure the locations of roadway features with millimeter precision. A Trimble R12 GNSS receiver and TSC 3 controller were identified as having sufficient accuracy to provide the level of accuracy (8 mm H/15 mm V) required for ground truth data. This equipment can connect to a local continuously operating reference station (CORS) network to take advantage of virtual reference station (VRS) position corrections. Survey equipment was used to collect data from the DriveOhio site only.

2.3 DATA COLLECTION

The equipment described above was used to collect data from each site. Prior to arriving in the field, a data collection plan for each site was developed to ensure the time spent collecting data could be spent as judiciously as possible and to essentially form a checklist of data activities that needed to be completed. An agenda was also included in the data collection plan to keep site leads aware of when and where data collection activities were occurring. The descriptions below describe how this equipment was used to collect data from each site.

Static Data Collection. The DSRC or C-V2X Data Collection Tool is set up in a vehicle parked in close proximity to an intersection for an extended duration (typically 15-20 minutes), and captures messages broadcast from the intersection. This process is repeated at each intersection. The data collected during static data collection is used for assessing requirements that involve message content and long-term broadcast rates.

Driving Data Collection. The DSRC or C-V2X Data Collection Tool is set up in a vehicle that drives along a pre-defined route (to cover all approaches at all intersections) while capturing messages broadcast from the intersections along the route. BSMs broadcast from the Data Collection Tool are included in the stream of received messages. The data collected during driving data collection is used for assessing requirements that involve reception rates and ranges along each approach

Test Tool Video Capture. The high frame rate camera is used to simultaneously record the data visualization from Kapsch Insight and the live signal head in the field. Tablet accessibility features were used to magnify certain aspects of the visualization, so they were easier to perceive on the video. Data collection occurred during daylight hours, so the tablet brightness setting was increased to the maximum level to improve the ability to see both the tablet screen and the signal head in the video. Exposure settings on the camera were configured in some cases to provide an optimal balance of brightness between the tablet display and the signal head. The setup is moved to provide an optimal vantage point from which to observe each set of signal heads at each intersection.

Since the tablet (running Kapsch Insight) requires a Bluetooth connection with the DSRC or C-V2X data capture tool, it is important that the tablet stays close enough to the data capture tool so that connectivity issues did not result in a delayed output (which would impact the ability to perform the latency assessment). The data collected during the test tool video capture is used for assessing requirements the involve latency and ensuring data in CV messages is representative of actual field conditions.

Survey. A survey was performed to measure the location of features in the field. These features include the location of stop lines, edge lines, and other transition points such as crosswalks and pedestrian landings. Measurements were taken more frequently around curves. The data collected during the survey is used for assessing requirements that involve the accuracy of location-based data in the MAP message. The survey was only performed only at the DriveOhio site.

2.4 PROCESS DATA TO ASSESS CONFORMANCE TO REQUIREMENTS

Once the data collection activities were complete, the collected data was processed using tools to assess each specific requirement. An overview of the tools used to process the collected data are described in the list below

Wireshark. A network traffic analysis tool that reads and decodes packet capture (individual message) data captured from data collection tool while in the field. Wireshark allows messages to be filtered and sorted based on data element content, and exported to text-based formats so that the data can be used by other tools used to assess requirements.

CAMP Online Tool. The CAMP online tool provides an automated assessment of data content in SPaT and MAP messages (content conformance to SAE J2735 and CTI 4501) and provides a visualization of SPaT and MAP data overlaid on a satellite image. The visualization shows the intersection centerpoint, ingress and egress lanes, lane ID, and connections. A text-based display of intersection-level MAP data, lane-level attribute and maneuver data, and SPaT data are provided alongside the visualization. The text display of SPaT movement state and time change details can be 'replayed' so that the user can watch how the data progresses.

Excel. Table-based tool that allows the user to perform simple data manipulations using built-in functions and user-defined functions, use conditional formatting to visualize results, or to generate graphs to assess requirements. In most cases, data used in Excel was exported from Wireshark in a comma-separated value format.

Mapping Tools. – Mapping tools such as ArcGIS and R studio are helpful for visualizing data that the CAMP tool does not yet support. Data is typically exported from Wireshark and processed and/or transformed in Excel before being imported. Mapping tools are generally used to visualize reception rates and ranges and to compare surveyed data against geographical data in MAP messages.

Video Processing Software. - Video processing software was used to overlay video timestamp information on captured video. This is necessary as most media players will not show sub-second time details in a status bar.

2.5 INTERPRET RESULTS

The results from each site are used to determine on an intersection-by-intersection level which requirements are being met and which are not. The assessment of each requirement provides an explanation of results as necessary to provide additional detail as to why a requirement, passes, did not pass, or could not be tested. Aggregating results across all sites provides an indication of which requirements are capable of being met and which will require more development to be met.

3. Results Summary and Discussion

The content in this section is intended for practitioners who manage, oversee, and make executive decisions about connected vehicle deployments. The results summary provides a high-level understanding of areas of compliance and non-compliance with CTI 4501 requirements for each message type: SPaT, MAP, and RTCM. In CTI 4501, message requirements are separated into five different sub-requirements: ① Message Performance Requirements, ② Generic Message Requirements, ③ Signal Timing Data Requirements, ④ Roadway Geometry Data Requirements, and ⑤ Positioning Messages. The requirements as organized in CTI 4501 map to each message type as follows:

- SPaT
  - SPaT-related ① message performance requirements and ② generic requirements
  - ③ signal timing data requirements that were met
  - ③ signal timing data requirements that were not met
  - ③ signal timing data requirements that were not tested or not applicable
- MAP
  - MAP-related ① message performance requirements and ② generic requirements
  - ④ roadway geometry data requirements that were met
  - ④ roadway geometry data requirements that were not met
  - ④ roadway geometry data requirements that were not tested or not applicable
- RTCM
  - RTCM-related ① message performance requirements and ② generic requirements
  - All ⑤ positioning message requirements.

Results where requirements were not met will also indicate if test sites from other state experienced similar results. A discussion following the summary of results is provided to identify barriers to compliance and propose how those barriers could be overcome. Detailed test results for each requirement (that the content in this section is derived from) are provided in Appendix A and provides more insight for developers, engineers, and consultants involved with day-to-day activities of CV systems.

Since the collection of data used to perform the CTI 4501 requirements assessment, practitioners in Utah have begun to make modifications to the existing system in an effort to improve compliance with requirements. While this is not reflected in the results presented in this document, it demonstrates that practitioners recognize value in the requirements and are motivated to make the improvements necessary to realize the benefits of interoperable SPaT, MAP, and RTCM data.

3.1 SPAT

3.1.1 Performance and General Requirements

SPaT messages were observed at all intersections in Utah. All SPaT messages are J2735-compliant, but do not contain all required elements per CTI 4501, which is similar to SPaT messages from other test sites.

The roadRegulatorId and the maxEndTime data elements are required by CI 4501, however, they were not present in the SPaT messages. These omissions were expected; the roadRegulatorId is not fully defined yet by SAE and existing signal controllers do not necessarily provide the maxEndTime in all instances.

SPaT periodicity and latency requirements were only met when RTCM messages were disabled at test intersections with older Kapsch RSUs. This issue was not observed at other intersections with Commsignia RSUs and is therefore considered to be a result of older Kapsch hardware.

The sequence of revision counter values always increased from one SPaT message to the next, regardless of whether values in the message changed or not. When all of the data (except timestamp data) in the message remains the same, the revision counter should not increment, but remain the same between the two messages (CTI 4501 3.3.3.2.2.1 and 3.3.3.2.2.2).

3.1.2 Message Requirements – things that worked well

The items in the list below provide a summary of observations and test results that indicate compliance with certain CTI 4501 signal timing data requirements. For more detailed results, see Appendix A, requirements 3.3.3.3.X.

- ✓ **MAP-SPaT Alignment.**
    - The list of signal group values in SPaT messages align with the list of signal group values in MAP messages for all intersection.
    - The visualized signal event data from the test tool closely aligns with the expected event state (as would be expected based on indications from the actual signal head) for each movement. This is an indication that the SPaT messages are generally consistent/compatible with MAP messages (there was one exception where a signal group was incorrectly specified for a connection at SR-224/Kearns). This does not imply the movement state data is always correctly specified for each connection. See discussion regarding movements controlled by more than one phase in section 3.1.3.
- ✓ **Current movement event.** A movement event was always included for the current movement.
- ✓ **Inclusion of Movement state.** A movement state was always included for a movement event.

- ✓ **Movement State.** A movement state was included for the current movement for every signal group. Controller phases 1-8 are currently represented in movement states at Utah intersections.

- ✓ **Event State - Protected and permissive clearance.** An event state of permissive-clearance always followed an event state of permissive-movement-allowed. An event state of protected-clearance is expected to follow an event state of protected-movement-allowed, but this event state was not present in the SPaT data.

- ✓ **No past state.** A movement state was never specified for a movement event that had passed.

- ✓ **Inclusion of time change details.** The time change details data frame was always provided for a movement event.

- ✓ **Inclusion of minimum end time.** The minimum end time value was always included in the time change details data frame.

- ✓ **Yellow interval time change details.** The minimum end time was always found to be equal to the maximum end time, which is expected operation, since the yellow interval is fixed.

- ✓ **Not including the start time.** The start time value is not included in the time change details data frame for the current movement state.

3.1.3 Message Requirements – areas for improvement

The items in the list below provide a summary of observations and test results that indicate areas that need improvement to better align with certain CTI 4501 signal timing data requirements. Potential remedies and/or development efforts that may need to be undertaken are provided with each listed observation. For more detailed results, see Appendix A, requirements 3.3.3.3.X.

- ↳ **Movement State.** Currently, SPaT messages in Utah only specify movement states that directly correspond to traffic signal controller phases 1-8. Movements that are not directly controlled by typical phases 1-8 are not being properly reflected in movement state data. Examples are provided below:

    - When present, pedestrian movements are required by CTI 4501 to be included in the SPaT message. All intersections tested had pedestrian movements, however, they were not included in the SPaT message. Data from the traffic signal controller (TSCBM or otherwise) should be checked to see if pedestrian movement data is present (so that it can be included in SPaT) or work with the traffic signal controller manufacturer to add pedestrian movement data to outputs.

    - Movement state data that corresponds to overlap phases were not observed in SPaT data. There is one intersection (SR-224 and Kearns Blvd) where the westbound right turn movement is at least partially controlled by an overlap movement (overlap phase controls the right turn arrow signal indication). Similar to pedestrian movements above, the TSCBM should be checked to see if overlap movement data is present.

- Movement state data for movements controlled by more than one phase (as defined in the controller) were not observed in SPaT messages. For instance, protected-permissive left turns: the protected portion of the movement is controlled by arrow indications on the signal head which are controlled by one phase in the controller. There are at least two intersections that are known to have this operation (SR-224 at Sun Peak / Old Ranch and SR-224 at Payday / Holiday Ranch Loop). One other site currently accommodates protected-permissive turning movements in the SPaT message, however, this is generally considered an area where more development is needed. Roadside equipment could provide the functionality needed to combine information from two phases (configured by the user) to create the new movement state. Alternatively, development on the traffic signal controller could allow the traffic signal controller to produce this new movement state. The signal group for the new movement state (configured by the user) would need to be reflected in the corresponding left turn in the MAP message. See discussion in section 3.1.5 for more detail.

- **Subsequent Movement Event.** Movement event data was never included for a future (subsequent) movement. This was a limitation experienced by all sites. Information about the next movement event should always be included, even if the event state and timing is unknown. Development efforts for the provision of next movement state data is primarily focused on the traffic signal controller.

- **Event State - Specification of protected vs. permissive.** Currently, SPaT messages in Utah only specify movement states with permissive event events. Both other sites had made at least some progress in correctly differentiating between protected and permissive movement event states, though some work is still needed for overall compliance. This can currently be accomplished by applying functionality on the roadside that allows a user to specify (through a configurable setting) which SPaT data are for protected movements. When building the MAP message, the roadside equipment would then modify the event state for those movements to indicate a protected event state. Alternatively, this could be accomplished through development on the traffic signal controller – the controller has knowledge of which movements are protected, and can use this to modify the event state of SPaT data accordingly.

- **Time Change Details.**

  - **Inclusion of maximum end time.** The max end time value was not always provided for the current movement event. Per CTI 4501, the maximum end time should always be provided for the current movement event. A value of unknown should be indicated if there is uncertainty regarding the actual maximum end time. Development efforts for the provision of maximum end time data is primarily focused on the traffic signal controller.

- **Progression of minimum end time and maximum end time values.** Captured data had instances where the minimum end time decreased, and the maximum end time increased. The minimum end time, once specified for an event state should never decrease, and the maximum end time once specified should never increase. The minimum end time should always be less than or equal to the maximum end time. When the minimum end time is equal to the maximum end time, this indicates (with certainty) that a transition to the next signal state is going to occur at the time value dually indicated in the minimum end time and maximum end time elements. When this occurs, subsequent movement event information should be included. Development efforts relating to the progression of minimum end time and maximum end time values is focused on the traffic signal controller. See discussion in section 3.1.5 for more detail.

3.1.4 Could not be tested or not applicable

- **Intersection Status.** The intersection status data element is comprised of 14 requirements that could not be tested as there was no data collected to understand when each bit should be asserted. However, it is anticipated that all sites would currently not be able to successfully meet any of these requirements if ground truth data were available to perform the assessment.

- **Subsequent Movement Event State and Time Change Details.** Event state and time change details requirements could not be assessed as subsequent movement events were not included in SPaT messages. There are requirements that specifically describe how the event state and time change details data elements should be populated for subsequent movement events. As subseqnent movement events are included in the SPaT message, further testing should be performed to check compliance with these requirements.

- SPaT requirements relating to the use of **flashing yellow arrows** and **enabled lanes** were not applicable to any test intersections in Utah. As intersections with these features are equipped, further testing should be performed to check compliance with these requirements.

3.1.5 SPaT Discussion

Between SPaT, MAP, and RTCM, SPaT messages are arguably the most dynamic. Data in the SPaT message often varies from one message to the next. CTI 4501 requirements not only specify the inclusion of certain data elements, but also specifies design details regarding how the values of these elements are to be interpreted and how they are supposed to progress from one message to the next. This level of detail is necessary, as the consistency in SPaT data produced is known to vary widely from one site to the next, which is reflected in data collected from the three test sites. For example, each site experienced unique issues relating to data elements in the time change details data frame. Some sites included certain time change details elements while others did not, and the method by which each given time change detail value progressed varied from one deployment to the next. This example provides an indication of multiple potential issues:

1. Data produced by traffic signal controllers is not consistent across sites, likely due to ambiguity in the J2735 standard.

2. Data provided by traffic signal controllers is not provided in a fashion that allows CTI 4501 time change details requirements to be met

3. There is variance in how roadside processing equipment processes data from traffic signal controllers to generate CTI 4501-compliant time change details data elements across sites. However, this cannot be discussed in detail until there is more consistency in the data produced by traffic signal controllers.

The availability of data to populate the SPaT message is largely dependent on the traffic signal controller. The intent is for traffic signal controllers to produce NTCIP 1202-compliant data which is used by other processing equipment on the roadside to generate and encode the SPaT message. Generally, today's deployments are highly dependent on a traffic signal controller's ability to produce the traffic signal controller broadcast message (TSCBM) and/or other data made available by the traffic signal controller. This data is processed and used by roadside equipment to populate the SPaT message. Given the number of signal controller manufacturers, models, and softwares/firmwares that are presently available, is it likely that the TSCBM and/or other traffic signal control data are being implemented differently across different controllers and software/firmware versions. This fact lends itself to site-specific implementation of roadside processing equipment functionality to take traffic signal controller data to generate and broadcast the SPaT message. Roadside processing equipment cannot simply be moved one site to another (with a different controller) and expect to produce SPaT in the same fashion.

One of the first steps in fostering the generation of CTI 4501-compliant SPaT message using today's traffic signal controller data production capabilities is to provide some amount of consistency in the data produced by different traffic signal controllers. This is then followed by consistency in how signal controller data is handled and processed by roadside processing equipment to generate the SPaT message. Of particular note, it is important to acknowledge that the TSCBM was not designed to readily meet the complexity of requirements in CTI 4501. To implement functionality that allows SPaT messages to be CTI 4501 compliant, more information is needed – NTCIP 1202 data from the controller and/or user provided information about certain signal operations, and the processing capability of roadside equipment to transform data from all these sources to produce the NTCIP 1202-compliant payload.

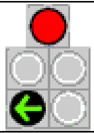
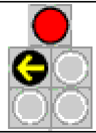
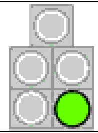
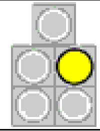
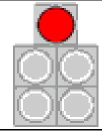
The bulleted list below begins to describe some of the steps that practitioners could take today to begin to address problems using the current capabilities of traffic signal controller technologies.

- CTI 4501 Appendix A.3 proposes how the traffic signal controller should generate data used to populate data elements in the time change details data frame. This is written in an attempt to provide some level of consistency in the data produced by traffic signal controllers. It uses language and concepts that should be familiar to developers of traffic signal controllers. A significant development effort needs to be undertaken by traffic signal controller manufacturers to provide the desired consistency. Given the importance of the time change details data elements in enabling the full RLVW application in an interoperable fashion, these development efforts should be accompanied by rigorous testing to ensure robust and accurate operations.

- Information about the next movement state should always be provided, even if unknown. Data from the traffic signal controller, if available, could be used to populate information about subsequent movement states. CTI 4501 4.3.3.3.4.1, 4.3.3.3.4.2, 4.3.3.3.5.7, and 4.3.3.3.5.8 provide additional design detail regarding the population of data elements for the next movement state. Furthermore, the TSCBM provides a field specifically for the duration of a yellow signal phase (yellow time) that could be used to populate the next movement state time change details when the current movement state is green. The yellow duration for a phase is also likely available through other outputs from the signal controller. Details regarding the next movement state can only be populated once there is absolutely certainty that the transition will occur (during an assured green period – i.e. when the minimum end time equal to maximum end time during a green indication) and when it is known that the green indication will transition to a yellow indication (which is not always a certainty – e.g., lagging protected-permissive left turn). However, for most three-state signals (or for leading protected-permissive left turns), the transition from green to yellow is certain. That is, it is possible to leverage the *yellow time* element of the TSCBM or from other signal controller outputs if available to enable the specification of a yellow future movement state (during a green movement state) for a number of commonly utilized signal plans. If not available, the traffic signal controller developer should implement changes to include this information so it can be used to populate the next movement state when the current movement state is green. However, it is important to recognize to be in alignment with CTI 4501, the next signal state should be provided in all cases, regardless if the current signal state is green, yellow, or red.

- CTI 4501 4.3.2.2 provides design detail detailing how several of the bits related to the controller status should be populated. Most of the data necessary to apply the logic and properly populate these bits are made available from the traffic signal controller. Roadside equipment could utilize data from the traffic signal controller to provide some level of compliance with requirements, or traffic signal controller developments could be made to make the intersection status data element available to the roadside. Other bits (regarding the status of SPaT and MAP messages) will likely require logic to be implemented on the roadside. Implementing changes to address the intersection status data elements is anticipated to be a more substantial development effort.

- New movement states should be generated to accurately reflect the signal state for movements which essentially require combined information from two controller phases (such as protected-permissive left turns). Since the signal groups in the SPaT message are related to connections, and not phases as defined by the controller, this means that data from multiple controller phases need to be combined to generate a resultant signal group (event state and time change details) specifically for the left turn movement.

Signal Indication example					
Permissive phase (solid indicator)	*any*	*any*	Green*	Yellow*	Red*
Protected phase (arrow indicator)	Green*	Yellow*	Red (not visible)	Red (not visible)	Red* (not visible)
Resultant event state	protected-Movement-Allowed	protected-Clearance	permissive-Movement-Allowed	permissive-Clearance	stop-And-Remain

**Note: the appropriate timing data from the controlling phase should be used to populate the time change details data frame.*

- The event state and time change details need to be obtained from the traffic signal controller and included as a new signal group in the SPaT message for each pedestrian movement or overlap movement. As pedestrian data is included, care should be taken to ensure that CTI 4501 SPaT requirements related to pedestrian movements are met, as these requirements could not be tested due to the lack of pedestrian movement data in SPaT messages observed in the data collected

Due to the inherent fundamental relationship between data currently used by traffic signal controllers for typical operations and the data needed to populate a CTI 4501-compliant SPaT message, it is reasonable to expect that traffic signal controllers will eventually generate the entire SPaT payload (including user inputs for any other information needed). If this functionality is realized, other roadside processing equipment would simply need to sign and broadcast the encoded message. However, there is currently uncertainty regarding the timeline for this development.

3.2 MAP

3.2.1 Performance and General Requirements

MAP messages were observed at all intersections in Utah. All MAP messages are J2735-compliant, but do not contain all required elements per CTI 4501, which is similar to MAP messages from other test sites. Specifically, the road regulator id, reference speed limit, and reference elevation elements are needed in the MAP messages to be compliant. Once these reference values are provided in the MAP message, it is important to consider speed limit changes and elevation changes along each approach lane so that these changes can be properly reflected in nodes that comprise each vehicle lane.

MAP periodicity requirements were only met when RTCM messages were disabled at test intersections. This was not the case at several other intersections (not tested) in the region, and is thus partially considered to be a result of the particular combination of roadside equipment used at test intersections.

The sequence of revision counter values never increased from one MAP message to the next, which is expected given that the MAP message did not change during data collection. If the MAP message is updated, the revision counter should increment per CTI 4501 3.3.3.2.2.3 through 3.3.3.2.2.6.

3.2.2 Message Requirements – things that worked well

The items in the list below provide a summary of observations and test results that indicate compliance with certain CTI 4501 roadway geometry data requirements. For more detailed results, see Appendix A, requirements 3.3.3.4.X.

- ✓ **Roadway Geometry.** All intersections contained at least one roadway geometry.
- ✓ **Reference Information.** All MAP messages exhibited values for the intersection id, latitude/longitude reference point, and default lane width.
- ✓ **Driving Lanes and Crosswalk Lanes.** Per satellite imagery and ground observation, all driving lanes and crosswalk lanes were provided in the MAP messages (one exception, specified in the detailed results, should be resolved with a simple MAP modification),
- ✓ **Unique Lane ID.** All lanes in all MAP Message exhibited unique lane identifiers.
- ✓ **Lane node offset type.** The correct offset types were used for each lane node. Compliance with this requirement is important for keeping the MAP message as concise as possible.
- ✓ **Connections.** Lane connections were properly defined (with one exception, specified in the detailed results, should be resolved with a simple MAP modification) and all connections have a signal group value specified.
- ✓ **Lane Direction and Direction of Travel** All vehicle lane node points were defined in the correct direction and the direction of travel (ingress/egress) were properly specified in all MAP messages.
- ✓ **Lane Attributes (vehicle lanes).** Lane attributes requirement for vehicle lanes are met. Of particular note was the correct application of the lane attributes for the transit-only left turn lane at SR-224/Canyon's Resort intersection.
- ✓ **Maneuvers Allowed.** The maneuvers allowed at the lane level and the connection level were mostly specified properly. Some additional aspects to consider are provided in the detailed results.

3.2.3 Message Requirements – areas for improvement

The items in the list below provide a summary of observations and test results that indicate partial or non-compliance with certain CTI 4501 roadway geometry data requirements. For more detailed results, see Appendix A, requirements 3.3.3.4.X.

Note: The ability to remedy any issues with MAP messages is largely dependent on the ability of the MAP generation tool to allow the user to specify these elements, and effectively handle user inputs to generate the correct MAP payload. If the MAP generation tool used does not allow a user to specify a particular input needed to populate the MAP message with a required data element, then development efforts on the MAP generation tool will be necessary. Otherwise, the remedy is simplified to data collection and input of the requisite data into the MAP generation tool.

- **Reference Information.** MAP messages should provide a reference elevation and reference speed limit value, as required by CTI 4501.
- **Changes in elevation, speed limit, and lane width.** As the elevation, speed limit, and lane width change along ingress and egress lanes, respective values should be specified for lane nodes where these changes occur, as required by CTI 4501.
- **Sidewalk Lanes.** Sidewalk lanes were not observed in MAP messages. CTI 4501 requires sidewalk lanes to be specified on pedestrian landings on both ends of crosswalks. Once sidewalk lanes are added, connections from the sidewalk lane to the crosswalk lane should be specified. Similar results on the whole were observed at other sites.
- **Lane Sharing**. The lane sharing bitstring is currently populated with all zeros, which indicates that the lane is not shared with any other modes. However, motorized vehicles, buses, and bicycles are allowed to use most of the vehicle lanes in MAP messages. This data element should be revisited to determine which shared modes are applicable for each lane, to ensure compliance with CTI 4501.
- **Lane Attributes (crosswalk lanes).** Lane attributes for sidewalk lanes should be revisited determine if any attributes are applicable..
- **Ingress Lane Length.** Ingress lanes at some intersections need to be extended further upstream from the stop line (based on speed limit) to align with advanced notification requirements.

3.2.4 Could not be tested or not applicable

- Since a ground survey was not performed, requirements associated with **geometry accuracy** (latitude, longitude, elevation, lane width) could not be tested. However, care should be taken to ensure points around curves are provided frequently enough to be compliant.
- MAP requirements relating to **revocable lanes, bicycle lanes, tracked vehicle lanes, and parking lanes** were not applicable to any test intersections in Utah. As intersections with these features are equipped, further testing should be performed to check compliance with these requirements.

3.2.5 MAP Discussion

Generally speaking, the amount of development effort needed to generate CTI 4501-compliant MAP messages is expected to be far less strenuous compared to efforts required to generate CTI 4501-compliant SPaT. There are a few aspects of MAP message generation that lead to this assertion.

First, MAP message payloads are generated using a single tool, and once generated, this payload is simply stored and repeated by roadside equipment. The primary development effort would be limited to this single tool to produce a CTI-compliant MAP message. The USDOT has developed a public tool to generate MAP messages called the CV ISD Message Creator[2] that can be used to generate MAP message for CV deployments. However, this tool has some limitations in terms of the types of data elements that can be specified and included the MAP messages that it generates. It currently does not support the inclusion of all types of data required by CTI 4501. System developers may also have created their own tools to generate MAP messages for deployments. It is recommended that changes to the ISD Message Creator or system developer MAP generation tools are made so that MAP messages with CTI-4501 mandatory data elements can be generated. Furthermore, many popular online mapping tools (e.g. google maps, open street map, etc.) are not spatially accurate enough to be used to extract data used to define lane geometry, especially when 'eyeballing' centerlines – a common method used by MAP generation tools. It is recommended that survey-grade data be used. This is either by performing a ground survey, or using aerial imagery that is known to be accurately projected in the WGS 84 coordinate system.

Second, the data used to populate the MAP message is readily assessable. It is a relatively straightforward effort to perform a field survey or use trusted aerial imagery to collect all of the information needed to populate the MAP Message. This will require some level of effort, however, since intersection geometry generally changes infrequently, once the data to generate a MAP message has been collected, this will not be a frequent exercise. The CV Pooled Fund Study has produced a MAP Guidance Document[3] based on the CTI 4501 guidance that provides guidance regarding seven steps involved in generating MAP messages (Step 1: Assemble Data, Step 2: Determine Verified Point Marker, Step 3: Place Nodes and Create MAP Content, Step 4: Visual Validation, Step 5: Convert to SAE J2375 Format, Step 6: Load to RSU, Step 7: Field Validation). This guidance provides additional detail and examples to supplement the CTI 4501 message requirements that MAP developers will find beneficial.

One other aspect of MAP messages to consider is the maximum payload size that can be accommodated for a single MAP message. As more data elements are added to the MAP message to become compliant with the precise and detailed requirements in CTI 4501, the MAP message payload may exceed payload size limitations for a message broadcast via C-V2X. Thus at some point, it may be important to consider how an intersection geometry is divided into multiple MAP messages to accommodate all of the required data elements.

[2] https://webapp.connectedvcs.com/isd/

[3] https://engineering.virginia.edu/sites/default/files/common/Centers/CTS/CVPFS/resources/MAP%20Guidance%20Document%20-%20Revision%20%231%20%28June%202022%29.pdf

3.3 RTCM

3.3.1 RTCM Message Requirements

RTCM messages were observed at all intersections in Utah. All RTCM messages broadcast contain data elements required by both J2735 and CTI 4501. This is unique compared to other test sites where RTCM was not observed. It is expected that the experience gained from developing the functionality to enable RTCM in Utah could be valuable for other practitioners.

Requirements related to the progression of the message count data element and the RTCM message types and broadcast frequency are only partially met. Two separate message counts appear to be maintained for RTCM messages, and RTCM message types are currently not combined into a single RTCM message as specified in the requirements. One of the required RTCM message types (1013) was not observed.

Detail regarding the requirements discussed above can be found in CTI 4501:

- Message count: 3.3.3.2.2.7 and 3.3.3.2.2.8,
- Message Types: 3.3.3.5.1
- Broadcast frequency: 3.3.3.5.2.2

3.3.2 RTCM Discussion

The observed RTCM message data demonstrates the technical capabilities of roadside equipment that are necessary to combine the specified RTCM message types into the same RTCM message, broadcast at a specified rate, and to increment the message count variable. It is expected that through refinement of processes on the roadside equipment that handles the generation and broadcast of RTCM messages, that full compliance with these requirements is within the current capability of developers to successfully implement. The inclusion of RTCM message type 1013 is also dependent on external reference station systems to support the availability of this message type.

4. Concluding Remarks

The test results based on data captured from the three sites assessed as part of this project provide a reflection of hard work and progress made by deployers over the course of several years. The spread of test results between the three test sites is relatively small – This is an indication that there is some level of consistency in the systems deployed at all three sites, and that all sites stand to benefit from knowledge sharing that will result from development efforts that will need to be undertaken to become compliant with requirements that are currently not being met. Sites have had relatively little time to react to and implement system changes to align with the latest guidance requirements provided in CTI 4501. With this in mind, some of the changes required are relatively simple, while others are going to require more substantial development efforts. There is still progress left to be made.

First, the development of functionality on devices to generate CTI 4501-compliant SPaT, MAP and RTCM messages is expected to require multi-disciplinary approach. With some exception, to date signal controller manufacturers as well as roadside processing equipment developers have been primarily responsible for much of the progress that has been made with respect to the roadside functionality that exists today. Experts from other disciplines, described below, can complement the expertise of developers to deliver a robust system that is capable of meeting the CTI 4501 requirements.

- Traffic engineers are familiar with traffic control plans (i.e. signal controller inputs), how the traffic signal can affect operations, and how traffic operates at the intersection. Ultimately, traffic engineers provide the background necessary to understand if the data in the SPaT message is reflective of actual operations. A traffic engineer is also going to provide a level of knowledge about if the data included in a MAP message properly reflects lane geometry and traffic control markings/signage. Furthermore, traffic engineers often work with surveyors, another valuable background for collecting data needed to gather accurate intersection geometry data for MAP messages.

- CV Systems engineer. The suggestion of a systems engineer does not necessarily imply a traditional systems engineering approach should be taken. However, a systems engineer could foster collaboration between developers of multiple systems, document any changes, and perform testing as changes are made. The systems engineer documents system operations for the knowledge of the deploying IOO, and so that developments and lessons learned can be passed along to other agencies with CV deployments and agencies considering CV deployments.

- A CV standards and guidance expert possesses a depth of knowledge of SAE J2735 and CTI 4501. This is particularly useful for testing if the content in SPaT, MAP, and RTCM messages is compliant with these requirements.

These disciplines work together to identify issues in CV message(s), tracing the data back through the system to find the source of the issue, propose modifications, making changes to system design/operation, and performing validation tests to ensure that the issue has been remedied and that no other issues were inadvertently created. Some individuals may possess knowledge of multiple disciplines, but there is no single person who can provide expertise from all. That is why it is important for this interdisciplinary approach to also a collaborative one.

Next, there needs to be a greater emphasis on the testing of messages against requirements. Prior to the effort undertaken as part of this project, sites were not completely aware of how their deployment aligned with the latest CTI 4501 guidance. Testing is especially crucial in instances where new combinations of controllers and other roadside equipment are being used or are being used in new situations/scenarios that have not been previously experienced. Testing is also important to detect issues that arise due to changes in roadway geometry and traffic signal controller operations without making requisite changes to SPaT and MAP messages to reflect these changes. However, currently, the amount of effort required to perform these assessments is quite high, especially on a continuous basis. To the extent possible, these assessments should be automated, so that SPaT, MAP, and RTCM messages can be assessed for compliance on a more frequent basis to more readily detect when issues are present.

To this end, the CV Pooled Fund Study is in the process of designing a Connected Intersection Message Monitoring System (CIMMS). The primary concept of the CIMMS is to provide constant near-real-time automated monitoring of messages to determine if SPaT, MAP, and RTCM messages are compliant with the requirements defined in CTI 4501 (e.g., messages contain all CTI 4501-required data, correctly reflect operations, and data progresses in a proper fashion from one message to the next). It ingests data from sources that provide an indication of ground truth operations. If the system detects that ground truth operations are not properly reflected in SPaT, MAP, or RTCM, or are otherwise showing signs of non-compliance, a warning is issued to provide an alert to the IOO (or managing entity) so that the potential issue can be identified and remedied.

The initial development of the CIMMS will be a proof-of-concept system. It will only assess a handful of message requirements (those considered of most value to stakeholders, identified during outreach efforts), and the determination of ground truth operations is limited to being inferred through driver behavior as evidenced in BSMs collected from vehicle traveling through the intersection. The CIMMS is designed in an open-source fashion so that functionality can be improved and expanded upon to assess other requirements and ingest other sources of ground truth data that can be used to verify message compliance with requirements.

Finally, sites may have deployed (or be interested in deploying) OBUs equipped with the RLVW application in fleet and/or private vehicles. It is important to consider that current implementations of RLVW on an OBU may rely on system designs that cannot produce CTI 4501-compliant messages. As system updates are made to generate CTI 4501-compliant SPaT, MAP, and RTCM, it will be important for OBU vendors to consider changes that need to be made to the RLVW application (on their respective devices) to ensure that the RLVW application functions as intended using CTI 4501-compliant data.

Appendix A. Detailed Results

This appendix contains a summary of results followed by detailed results for each individual requirement.

Results Summary Key	Requirement Met	Partially Met	Not Met	Not Applicable	Indeterminate / Could not be tested
	✓	**O**	×	N/A	?

CTI 4501 Req ID	Requirement Title	Utah Results by Intersection ID						Utah Intersections Summary (6)				All Intersections Summary (15)			
		7706	7707	7708	7709	7710	7720	Met	Partial	Not tested	Not Met	Met	Partial	Not tested	Not Met
3.3.3.1.1.1	SPaT Message - SAE J2735	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.1.1.2	SPaT Message - Mandatory Data Elements	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.1.1.3	SPaT Message - CI Mandatory Data Elements	**O**	**O**	**O**	**O**	**O**	**O**	0	6	0	0	0	15	0	0
3.3.3.1.1.4	SPaT Message PSID	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.1.1.5	MAP Message - SAE J2735	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.1.1.6	MAP Message - Mandatory Data Elements	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.1.1.7	MAP Message - Required Data Elements	**O**	**O**	**O**	**O**	**O**	**O**	0	6	0	0	0	15	0	0
3.3.3.1.1.8	MAP Message PSID	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.1.1.9	RTCMcorrections Message - SAE J2735	✓	✓	✓	✓	✓	✓	6	0	0	0	6	0	0	9
3.3.3.1.1.10	RTCMcorrections Message - Mandatory Data Elements	✓	✓	✓	✓	✓	✓	6	0	0	0	6	0	9	0
3.3.3.1.1.11	RTCMcorrections Message - Required Data Elements	✓	✓	✓	✓	✓	✓	6	0	0	0	6	0	9	0
3.3.3.1.1.12	RTCMcorrections Message PSID	✓	✓	✓	✓	✓	✓	6	0	0	0	6	0	9	0
3.3.3.1.2.1	Broadcast SPaT Message	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.1.3.1	Transport Message Size - WAVE	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.1.3.2.1	Nodes by Offsets	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.1.3.2.2.1	Computed Lane - Lane Identifier	N/A	N/A	N/A	N/A	N/A	N/A	*not applicable*				*not applicable*			
3.3.3.1.3.2.2.2	Computed Lane - X-Offset	N/A	N/A	N/A	N/A	N/A	N/A	*not applicable*				*not applicable*			
3.3.3.1.3.2.2.3	Computed Lane - Y-Offset	N/A	N/A	N/A	N/A	N/A	N/A	*not applicable*				*not applicable*			
3.3.3.1.3.2.2.4	Angle	N/A	N/A	N/A	N/A	N/A	N/A	*not applicable*				*not applicable*			
3.3.3.1.4.1	Data Coverage - Every Lane	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.1.4.2	Advanced Notification - Time	**O**	**O**	✓	✓	✓	**O**	3	3	0	0	11	4	0	0
3.3.3.1.5.1	SPaT Message - Broadcast Periodicity	**O**	**O**	**O**	**O**	**O**	**O**	0	6	0	0	9	6	0	0
3.3.3.1.5.2	SPaT Message - Broadcast Latency	✓	✓	✓	✓	✓	✓	6	0	0	0	12	3	0	0
3.3.3.1.5.3	MAP Message - Broadcast Periodicity	**O**	**O**	**O**	**O**	**O**	**O**	0	6	0	0	8	7	0	0

CTI 4501 Req ID	Requirement Title	Utah Results by Intersection ID						Utah Intersections Summary (6)				All Intersections Summary (15)			
		7706	7707	7708	7709	7710	7720	Met	Partial	Not tested	Not Met	Met	Partial	Not tested	Not Met
3.3.3.1.6.1	Completeness - SPaT Message	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.1.6.2	Completeness - MAP Message	O	O	O	O	O	O	0	6	0	0	0	15	0	0
3.3.3.2.1	Time Accuracy	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.2.2.1	SPaT Message - Revision Counter Increment	✓	✓	✓	✓	✓	✓	6	0	0	0	9	6	0	0
3.3.3.2.2.2	SPaT Message - Revision Counter Not Increment	?	×	?	×	×	×	0	0	2	4	6	3	2	4
3.3.3.2.2.3	MAP Message - Revision Counter Increment	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.2.2.4	MAP Message - Revision Counter Not Increment	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.2.2.5	MAP Message - Intersection Revision Counter Increment	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.2.2.6	MAP Message - Intersection Revision Counter Not Increment	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.2.2.7	RTCMcorrections Message - Sequence Number Increment	O	O	O	O	O	O	0	6	0	0	0	6	9	0
3.3.3.2.2.8	RTCMcorrections Message - Sequence Number Not Increment	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.2.3.1	SPaT Message - Message Time Stamp	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.2.3.2	SPaT Message - Intersection Time Stamp	✓	✓	✓	✓	✓	✓	6	0	0	0	9	0	0	6
3.3.3.3.1.1	Intersection Signal Timing Information	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.3.1.2	Road Regulator Identifier	×	×	×	×	×	×	0	0	0	6	0	6	0	9
3.3.3.3.1.3	Intersection Reference Identifier	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.3.2.1	Manual Control	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.2	Stop Time	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.3	Failure Flash	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.4	Preemption	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.5	Priority	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.6	Fixed Time	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.7	Traffic Dependent Mode	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.8	Standby Mode	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.9	Failure Mode	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.10	Controller Off	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.11	Recent MAP Update	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.12	New Lane IDs	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.13	No MAP Available	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.2.14	No SPaT Available	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.3.1	Current Movement State for a Signal Group	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.3.3.2	Unknown Current Movement State for a Signal Group	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.3.3	Flashing Yellow Arrow Permissive Movement	N/A	N/A	N/A	N/A	N/A	N/A	*not applicable*				*not applicable*			
3.3.3.3.3.4	Protected and Permissive Clearance	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0

Utah Department of Transportation Test Results – FINAL

CTI 4501 Req ID	Requirement Title	Utah Results by Intersection ID						Utah Intersections Summary (6)				All Intersections Summary (15)			
		7706	7707	7708	7709	7710	7720	Met	Partial	Not tested	Not Met	Met	Partial	Not tested	Not Met
3.3.3.3.3.5	Resolve Protected Versus Permissive Movement	×	N/A	×	N/A	×	N/A	0	0	3	3	5	0	4	6
3.3.3.3.3.6	Conflict Causes Permissive	✓	✓	✓	✓	✓	✓	6	0	0	0	9	0	0	6
3.3.3.3.3.7	No Conflict Causes Protected	?	×	×	N/A	×	N/A	0	0	3	3	9	0	3	3
3.3.3.3.3.8	WALK State Enumeration (No Conflict)	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.3.9	WALK State Enumeration (Potential Conflict)	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.3.10	Flashing DON'T WALK State Enumeration	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.3.11	Steady DON'T WALK State Enumeration	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.3.12	Movement State for Signal Groups Identified	✓	✓	✓	✓	✓	✓	6	0	0	0	14	0	0	1
3.3.3.3.4.1	Next Movement State	×	×	×	×	×	×	0	0	0	6	0	0	0	15
3.3.3.3.4.2	Unknown Next Movement State	×	×	×	×	×	×	0	0	0	6	0	0	0	15
3.3.3.3.4.3	No Past State	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.3.5.1	Time Change Details	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.3.5.2	Unknown Time Change Detail	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.3.5.3	Minimum End Time	○	○	○	○	○	○	0	6	0	0	0	15	0	0
3.3.3.3.5.4	Maximum End Time	×	×	×	×	×	×	0	0	0	6	0	9	0	6
3.3.3.3.5.5	Unknown Maximum End Time	×	×	×	×	×	×	0	0	0	6	0	0	9	6
3.3.3.3.5.6	No Current Movement State Start Time	✓	✓	✓	✓	✓	✓	6	0	0	0	12	0	0	3
3.3.3.3.5.7	Next Movement State Start Time	×	×	×	×	×	×	0	0	0	6	0	0	0	15
3.3.3.3.5.8	Next State Start Time Equals Current State Minimum End Time	×	×	×	×	×	×	0	0	0	6	0	0	0	15
3.3.3.3.6.1	Time of Next Allowed Movement	×	×	×	×	×	×	0	0	0	6	0	0	0	15
3.3.3.3.7	Enabled Lanes Indication	N/A	N/A	N/A	N/A	N/A	N/A	*not applicable*				*not applicable*			
3.3.3.3.8	SPaT Message - Accuracy	○	○	○	○	○	○	0	6	0	0	4	11	0	0
3.3.3.4.1.1	Intersection Geometry Information	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.1.2	Intersection Geometry - Road Regulator Identifier	×	×	×	×	×	×	0	0	0	6	0	6	0	9
3.3.3.4.1.3	Intersection Geometry - Intersection Identifier	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.1.4.1	Intersection Reference Point - Position	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.1.4.2	Intersection Reference Point - Description	○	○	○	○	○	○	0	6	0	0	3	12	0	0
3.3.3.4.1.4.3	Intersection Reference Point Accuracy	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.1.5	Default Lane Width	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.1.6	Lane Identifier	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.1.7	Center of Vehicle Lane Geometry	✓	✓	✓	✓	✓	✓	6	0	0	0	13	2	0	0
3.3.3.4.1.8	Center of Crosswalk Lane Geometry	✓	✓	✓	✓	✓	✓	6	0	0	0	8	0	1	6

CTI 4501 Req ID	Requirement Title	Utah Results by Intersection ID						Utah Intersections Summary (6)				All Intersections Summary (15)			
		7706	7707	7708	7709	7710	7720	Met	Partial	Not tested	Not Met	Met	Partial	Not tested	Not Met
3.3.3.4.1.9	Center of Pedestrian Landings Geometry	×	×	×	×	×	×	0	0	0	6	0	0	1	14
3.3.3.4.1.10	Lane Description	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.1.11	First Node Point - Ingress Vehicle Lane	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.1.12	First Node Point - Egress Vehicle Lane	✓	✓	✓	✓	✓	✓	6	0	0	0	8	7	0	0
3.3.3.4.1.13	Node Offset from Intersection Reference Point	✓	✓	✓	✓	✓	✓	6	0	0	0	8	0	0	7
3.3.3.4.1.14	Node Elevation Offset from Intersection Reference Point	?	?	?	?	?	?	0	0	6	0	0	2	13	0
3.3.3.4.1.15	Offset from Previous Node	✓	✓	✓	✓	✓	✓	6	0	0	0	8	1	0	6
3.3.3.4.1.16	Elevation Offset from Previous Node	?	?	?	?	?	?	0	0	6	0	0	2	13	0
3.3.3.4.1.17	Advanced Notification - Ingress Vehicle Lane	O	O	O	O	O	O	0	6	0	0	3	12	0	0
3.3.3.4.1.18	End Nodes - Crosswalk Lane	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.4.1.19	End Nodes - Pedestrian Landing	?	?	?	?	?	?	0	0	6	0	0	0	15	0
3.3.3.4.1.20	Maximum Distance between Nodes	?	?	?	?	?	?	0	0	6	0	0	6	9	0
3.3.3.4.1.21	Maximum Number of Nodes	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.1.22	Node Lane Width	?	?	?	?	?	?	0	0	6	0	0	6	9	0
3.3.3.4.1.23	Node Accuracy	?	?	?	?	?	?	0	0	6	0	0	6	9	0
3.3.3.4.2.1	Direction of Travel	✓	✓	✓	✓	✓	✓	6	0	0	0	13	2	0	0
3.3.3.4.2.2	Lane Sharing	×	×	×	×	×	×	0	0	0	6	3	0	0	12
3.3.3.4.2.3	Lane Type Attributes	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.2.4	Lane Attributes - Vehicle	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.2.5	Lane Attributes - Crosswalk	O	O	O	O	O	O	0	6	0	0	0	8	7	0
3.3.3.4.2.6	Lane Attributes - Bicycle	N/A	N/A	N/A	N/A	N/A	N/A	*not applicable*				*not applicable*			
3.3.3.4.2.7	Lane Attributes - Tracked Vehicles	N/A	N/A	N/A	N/A	N/A	N/A	*not applicable*				*not applicable*			
3.3.3.4.2.8	Lane Attributes - Parking	N/A	N/A	N/A	N/A	N/A	N/A	*not applicable*				*not applicable*			
3.3.3.4.3	Lane Maneuvers	O	O	O	O	O	O	0	6	0	0	0	15	0	0
3.3.3.4.4.1	Lane Connections	✓	O	✓	✓	✓	✓	5	1	0	0	8	7	0	0
3.3.3.4.4.2	Connection Egress Lane	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.4.3	Connection Maneuvers	O	O	O	O	O	O	0	6	0	0	0	9	0	6
3.3.3.4.4.4	Connection Signal Group	✓	✓	✓	✓	✓	✓	6	0	0	0	14	1	0	0
3.3.3.4.4.5	Include Only Permitted Connections	✓	✓	✓	✓	✓	✓	6	0	0	0	13	1	0	1
3.3.3.4.5.1	Default Speed Limit	×	×	×	×	×	×	0	0	0	6	3	0	0	12
3.3.3.4.5.2	Change in Lane Speed Limit	×	×	×	×	×	×	0	0	0	6	0	0	0	15
3.3.3.4.6	Revocable Lanes	N/A	N/A	N/A	N/A	N/A	N/A	*not applicable*				*not applicable*			
3.3.3.4.7	MAP Message - Accuracy	✓	✓	✓	✓	✓	✓	6	0	0	0	13	2	0	0
3.3.3.4.8.1	Matching Intersection Reference Identifier	✓	✓	✓	✓	✓	✓	6	0	0	0	15	0	0	0
3.3.3.4.8.2	Matching SPaT and MAP Version	✓	✓	✓	✓	O	✓	5	1	0	0	14	1	0	0
3.3.3.5.1	Positioning Corrections	O	O	O	O	O	O	0	6	0	0	0	6	9	0
3.3.3.5.2.1	RSU Proximity	✓	✓	✓	✓	✓	✓	6	0	0	0	6	3	6	0
3.3.3.5.2.2	Minimum RTCM Corrections Broadcast Frequency	O	O	O	O	O	O	0	6	0	0	0	6	9	0

TOTALS	**7706**	**7707**	**7708**	**7709**	**7710**	**7720**

Utah Department of Transportation Test Results – FINAL

CTI 4501 Req ID	Requirement Title	Utah Results by Intersection ID						Utah Intersections Summary (6)				All Intersections Summary (15)			
		7706	7707	7708	7709	7710	7720	Met	Partial	Not tested	Not Met	Met	Partial	Not tested	Not Met
Requirement Met	✓	55	54	56	56	55	55								
Partially Met	**O**	16	17	15	15	16	16								
Could not be tested	**?**	33	31	32	31	31	31								
Not Met	✘	14	15	15	14	16	14								
Not Applicable	**N/A**	10	11	10	12	10	12								

For brevity, intersections are referenced by their Intersection ID (as specified in SPaT and MAP messages)
7706 7707 7708 7709 7710 7720

Requirement	3.3.3.1.1.1 SPaT Message - SAE J2735
Objective	Verify SPaT messageId
Method	Use Wireshark to view pcap files and check the value of the messageId.
Pass Criteria	MessageId of signalPhaseAndTimingMessage (19) shall be present in messages received from the roadside device.
Results and Explanation	This requirement is considered to be **met** for all intersections. The following query was applied as a filter in Wireshark for data coming from each intersection. *j2735_2016.messageId == 19* The result of this query contained data from all intersections, and thus, all intersections are considered to be broadcasting SPaT Messages.

Requirement	3.3.3.1.1.2 SPaT Message - Mandatory Data Elements
Objective	Verify SAE J2735 required data elements
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. Note: The CAMP online tool accepts a comma-separated value file containing a list of messages received. Each row includes a timestamp, message id, message payload (json), and a signature indicator. The tool produces a report indicating which data elements are included in SPaT messages for each intersection along with if the element is mandatory, optional, or conditional, and if the message is in compliance with SAE J2735.
Pass Criteria	All SAE J2735-required data elements must be present in the message.
Results and Explanation	This requirement is considered to be **met** for all intersections. The CAMP online tool was used to analyze the inclusion of data elements in SPaT messages. The analysis indicates all J2735-mandatory data elements are included in SPaT messages for all intersections. This was confirmed through a manual assessment of SPaT messages. CAMP Online Tool results are provided in Appendix B.

Requirement	3.3.3.1.1.3 SPaT Message - CI Mandatory Data Elements
Objective	Verify CI required data elements
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement.
Pass Criteria	All CI-mandatory data elements must be present in the message.
Results and Explanation	This requirement is considered to be **partially met** for all intersections. The CAMP online tool was used to analyze the inclusion of data elements in SPaT messages. The analysis indicates all CI Implementation Guide-required data elements are included in SPaT messages for all intersections except for the roadRegulatorId and the maxEndTime. This was confirmed through a manual assessment of SPaT messages. CAMP Online Tool results are provided in Appendix B.

Requirement	3.3.3.1.1.4 SPaT Message PSID
Objective	Verify SPaT PSID
Method	Use Wireshark to view pcap files. The PSID (in 1609.3 header) is displayed as a column. All PSID values are checked to make sure they match the pass criteria.
Pass Criteria	A PCAP value of 0x00008002 shall be present in the 1609.3 header.

Results and Explanation	This requirement is considered to be **met** for all intersections. The following query was applied as a filter in Wireshark for data coming from each intersection. *j2735_2016.messageId == 19* The value for the PSID element (under IEEE 1609.3) was displayed as a column. The PSID for all SPaT messages was observed to be *0x00008002* at all intersections.

Requirement	3.3.3.1.1.5 MAP Message - SAE J2735
Objective	Verify MAP messageId
Method	Use Wireshark to view pcap files and check the value of the messageId.
Pass Criteria	A messageId of mapData (18) shall be present in messages received from the roadside device
Results and Explanation	This requirement is considered to be **met** for all intersections. The following query was applied as a filter in Wireshark for data coming from each intersection. *j2735_2016.messageId == 18* The result of this query contained data from all intersections, and thus, all intersections are considered to be broadcasting MAP Messages.

Requirement	3.3.3.1.1.6 MAP Message - Mandatory Data Elements
Objective	Verify SAE J2735 required data elements
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement.
Pass Criteria	All SAE J2735-required data elements must be present in the message.
Results and Explanation	This requirement is considered to be **met** for all intersections. The CAMP online tool was used to analyze the inclusion of data elements in MAP messages. The analysis indicates all J2735-mandatory data elements are included in MAP messages for all intersections. This was confirmed through a manual assessment of MAP messages. CAMP Online Tool results are provided in Appendix B.

Requirement	3.3.3.1.1.7 MAP Message - Required Data Elements
Objective	Verify CI required data elements
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement.
Pass Criteria	All CI-mandatory data elements must be present in the message.
Results and Explanation	This requirement is considered to be **partially met** for all intersections. The CAMP online tool was used to analyze the inclusion of data elements in MAP messages. The analysis indicates all CI Implementation Guide-required data elements are included in MAP messages for all intersections except for the roadRegulatorId and data associated with the reference speed limit. CAMP Online Tool results are provided in Appendix B.

Requirement	3.3.3.1.1.8 MAP Message PSID
Objective	Verify MAP PSID
Method	Use Wireshark to view pcap files. The PSID (in 1609.3 header) is displayed as a column. All PSID values are checked to make sure they match the pass criteria.
Pass Criteria	A PCAP value of 0xe0000017 shall be present in the 1609.3 header.
Results and Explanation	This requirement is considered to be **met** for all intersections.

	The following query was applied as a filter in Wireshark for data coming from each intersection. *j2735_2016.messageId == 18* The value for the PSID element (under IEEE 1609.3) was displayed as a column. The PSID for all MAP messages was observed to be *0xe0000018* at all intersections.

Requirement	**3.3.3.1.1.9 RTCMcorrections Message - SAE J2735**
Objective	Verify RTCM messageId
Method	Use Wireshark to view pcap files and check the value of the messageId.
Pass Criteria	A messageId of rtcmCorrections (28) shall be present in messages received from the roadside device.
Results and Explanation	This requirement is considered to be **met** for all intersections. The following query was applied as a filter in Wireshark for data coming from each intersection. *j2735_2016.messageId == 28.* The result of this query contained data from all intersections, and thus, all intersections are considered to be broadcasting RTCM Messages. The RTCM Message List contains at least one RTCM message payload for all RTCM messages from all intersections. *Note: This requirement and other certain requirements (also identified in this document) cannot be met simultaneously. At the time data was collected, a non-negligible added latency between the time a message (of any type) is generated on the roadside and received by the OBU was experienced when RTCM messages were actively being broadcast.* ***The broadcast of RTCM messages was enabled*** *for the purposes of assessing this requirement but disabled when collecting data for assessment of different requirements.*

Requirement	**3.3.3.1.1.10 RTCMcorrections Message - Mandatory Data Elements**
Objective	Verify SAE J2735 required data elements
Method	Use Wireshark to view pcap files. The presence of all SAE J2735-mandatory data elements are checked to determine if they are included in the RTCM message.
Pass Criteria	All J2735-required data elements (contained in the required data frames) for the latest approved standard shall be present in the message.
Results and Explanation	This requirement is considered to be **met** for all intersections. By virtue of being received, decoded, and translated by Wireshark, RTCM messages received from all intersections contain the minimum required data elements as specified in SAE J2735.

Requirement	**3.3.3.1.1.11 RTCMcorrections Message - Required Data Elements**
Objective	Verify CI required data elements
Method	Use Wireshark to view pcap files. In addition to checking the presence of all SAE J2735-mandatory data elements, the lat and long of the anchorPoint data frame are displayed as a column to determine if they are included in the RTCM message.
Pass Criteria	All J2735-required data elements (contained in the required data frames) for the latest approved standard shall be present in the message, along with the lat, long, and elevation data elements in the anchorPoint data frame. Other data elements in the anchorPoint data frame are optional.
Results and Explanation	This requirement is considered to be **met** for all intersections. In addition to all mandatory data elements, the lat, long, and elevation data elements in the anchor point data frame are populated for every RTCM message at all intersections

Requirement	3.3.3.1.1.12 RTCMcorrections Message PSID
Objective	Verify RTCM PSID
Method	Use Wireshark to view pcap files. The PSID (in 1609.3 header) is displayed as a column. All PSID values are checked to make sure they match the pass criteria.
Pass Criteria	A PCAP value of 0x00008000 shall be present in the 1609.3 header.
Results and Explanation	This requirement is considered to be **met** for all intersections. The following query was applied as a filter in Wireshark for data coming from each intersection. *j2735_2016.messageId == 28* The value for the PSID element (under IEEE 1609.3) was displayed as a column. The PSID for all MAP messages was observed to be *0x00008000* at all intersections.

Requirement	3.3.3.1.2.1 Broadcast SPaT Message
Objective	Verify SPaT broadcast. Note: Analysis of communication between the traffic signal controller, roadside processing hardware, and the RSU is not performed.
Method	Use Wireshark to view pcap files. Message type of SPaT shall be present in the pcap data stream.
Pass Criteria	This requirement is considered satisfied if SPaT Messages are being broadcast from the intersection
Results and Explanation	This requirement is considered to be **met** for all intersections. SPaT messages are included in the pcap data from all intersections.

Requirement	3.3.3.1.3.1 Transport Message Size - WAVE
Objective	Verify message size is within limit
Method	Use Wireshark to view pcap files. The message length is displayed as a column. The message length is checked for all messages to determine if the framelength meets the pass criteria
Pass Criteria	Wireshark framelength variable of all messages less than 1400 bits in size
Results and Explanation	This requirement is considered to be **met** for all intersections. The Frame length variable was applied as a column. SPaT message sizes ranged from 246 to 411 bytes. MAP messages ranged from 814 to 961 bytes. RTCM messages ranged from 349 to 570 bytes. As changes are made to messages, the requirement should be re-evaluated for compliance.

Requirement	3.3.3.1.3.2.1 Nodes by Offsets
Objective	Verify use of offsets for defining lane nodes
Method	Use Wireshark to view pcap file. Presence of the x and y offset values are checked when offsets are used to define nodes.
Pass Criteria	Requirement is considered to be met if x-offset and y-offset are both present (only for offset specification of nodes)
Results and Explanation	This requirement is considered to be **met** for all intersections. All nodes specified in the MAP message contain an x offset and a y offset to describe its position.

Requirement	3.3.3.1.3.2.2.1 Computed Lane - Lane Identifier
Objective	Verify use of lane id element for computed lane
Method	Use Wireshark to view pcap files. Presence of the lane ID is checked when a computed lane is used to define nodes.
Pass Criteria	Requirement is considered to be met if lane identifier is present (only for computed lane specification)
Results and Explanation	This requirement is considered **not applicable** for all intersections. None of the MAP messages utilize computed lanes.

Requirement	3.3.3.1.3.2.2.2 Computed Lane - X-Offset
Objective	Verify use of x offset element for computed lane
Method	Use Wireshark to view pcap files. Presence of the x offset is checked when a computed lane is used to define nodes.
Pass Criteria	Requirement is considered to be met if x-offset is present (only for computed lane specification)
Results and Explanation	This requirement is considered **not applicable** for all intersections. None of the MAP messages utilize computed lanes.

Requirement	3.3.3.1.3.2.2.3 Computed Lane - Y-Offset
Objective	Verify use of y offset element for computed lane
Method	Use Wireshark to view pcap files. Presence of the y offset is checked when a computed lane is used to define nodes.
Pass Criteria	Requirement is considered to be met if y-offset is present (only for computed lane specification)
Results and Explanation	This requirement is considered **not applicable** for all intersections. None of the MAP messages utilize computed lanes.

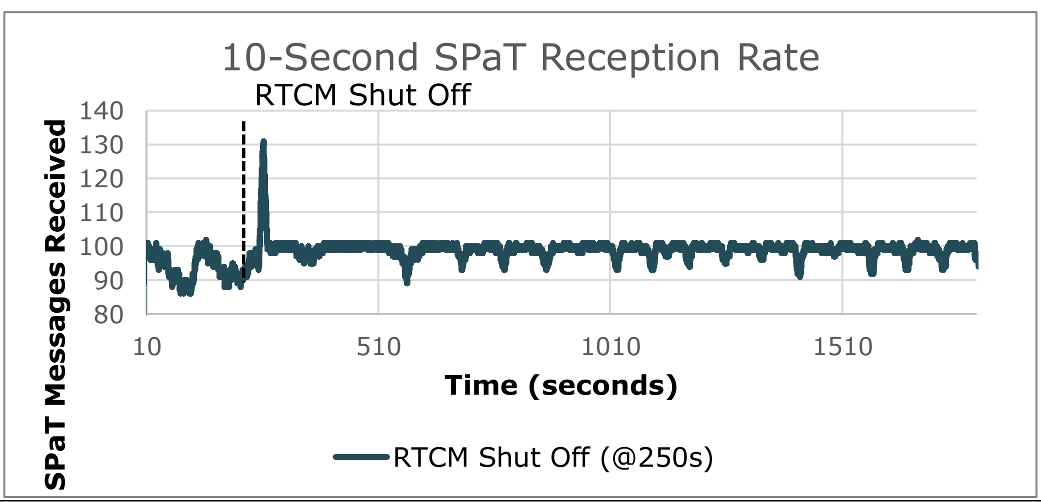
Requirement	3.3.3.1.3.2.2.4 Angle
Objective	Verify use of angle element for computed lane
Method	Use Wireshark to view pcap files. Presence of the angle is checked when a computed lane is used to define nodes.
Pass Criteria	Requirement is considered to be met if angle is present (only for computed lane specification)
Results and Explanation	This requirement is considered **not applicable** for all intersections. None of the MAP messages utilize computed lanes.

Requirement	3.3.3.1.4.1 Data Coverage - Every Lane
Objective	Verify SPaT and MAP can be received on all approaches
Method	Wireshark is used to export lat/lon data from the BSM and SPaT and MAP messages from each intersection. External data processing tools are used to relate SPaT and MAP messages to each BSM using timestamps. A +-500ms window around each BSM is used to search for the number received SPaT messages from each intersection, and a +-1000ms window is used to search for the number of MAP messages received from each intersection. The BSM lat/long is used to display the number of SPaT and MAP messages received on a MAP. A SPaT and MAP reception

	map is generated for each intersection using all of the BSMs generated during the driving data capture. The areas of reception are compared against the geometry of ingress lanes
Pass Criteria	Requirement is considered to be met if both SPaT and MAP messages are received for all locations between the stop line and the upstream-most (final) point defined for each approach lane.
Results and Explanation	This requirement is considered to be **met** for all intersections. SPaT and MAP messages are received on all ingress lanes for all intersections. Maps that show detailed SPaT and MAP reception rates for a test vehicle as it approaches the intersection from each ingress lane are provided in Appendix C.

Requirement	**3.3.3.1.4.2 Advanced Notification - Time**
Objective	Verify SPaT and MAP reception range
Method	Wireshark is used to export lat/lon data from the BSM and SPaT and MAP messages from each intersection. External data processing tools are used to relate SPaT and MAP messages to each BSM using timestamps. A +-500ms window around each BSM is used to search for the number received SPaT messages from each intersection, and a +-1000ms window is used to search for the number of MAP messages received from each intersection. The BSM lat/long is used to display the number of SPaT and MAP messages received on a MAP. A SPaT and MAP reception map is generated for each intersection using all of the BSMs generated during the driving data capture. The areas of reception are compared against minimum advance notification distance.
Pass Criteria	Requirement is considered to be met if both SPaT and MAP messages are received for all locations between the stop line and the minimum data coverage distance (a function of speed limit, upstream of each stop line) for each approach lane.
Results and Explanation	This requirement is considered to be **met** for intersections 7708, 7709, and 7710 This requirement is considered to be **partially met** for intersections 7706, 7707, and 7720 *Note: At the time data for assessing this requirement was collected, t**he broadcast of RTCM messages was enabled.** When RTCM messages are enabled, non-negligible impact to latency and periodicity is experienced which has a minor impact on the results of this analysis. This is because SPaT and MAP reception rates are used to generate reception range visualizations to assess compliance with this requirement. It is expected that reception rates would vary more consistently if RTCM were not broadcast, which would make it a bit easier to visualize the result.* SPaT and MAP messages are received within the minimum advanced notification distance (in meters = (observed speed limit [mph] + 7)*4.469) for all approaches with the following exceptions: • 7706 eastbound approach – actual reception range for both SPaT and MAP did not exceed the minimum required reception range though it was very close. This is likely the result of the location of the RSU combined with attenuation from trees in the median of the eastbound approach. • 7707 westbound approach - actual reception range from both SPaT and MAP did not exceed the minimum required reception range. This is likely the result of the location of the RSU combined with a curve in the westbound approach and attenuation from trees on the southeast corner of the intersection. • 7720 eastbound approach – actual reception range for MAP only did not exceed the minimum required reception range. However, SPaT performed well on this approach. This is likely due to broadcast periodicity issues experienced when RTCM messages are simultaneously broadcast. It is expected that this requirement would be met if RTCM messages were not simultaneously broadcast.

	Maps that show detailed SPaT and MAP reception rates for a test vehicle as it approaches the intersection from each ingress lane are provided in Appendix C.

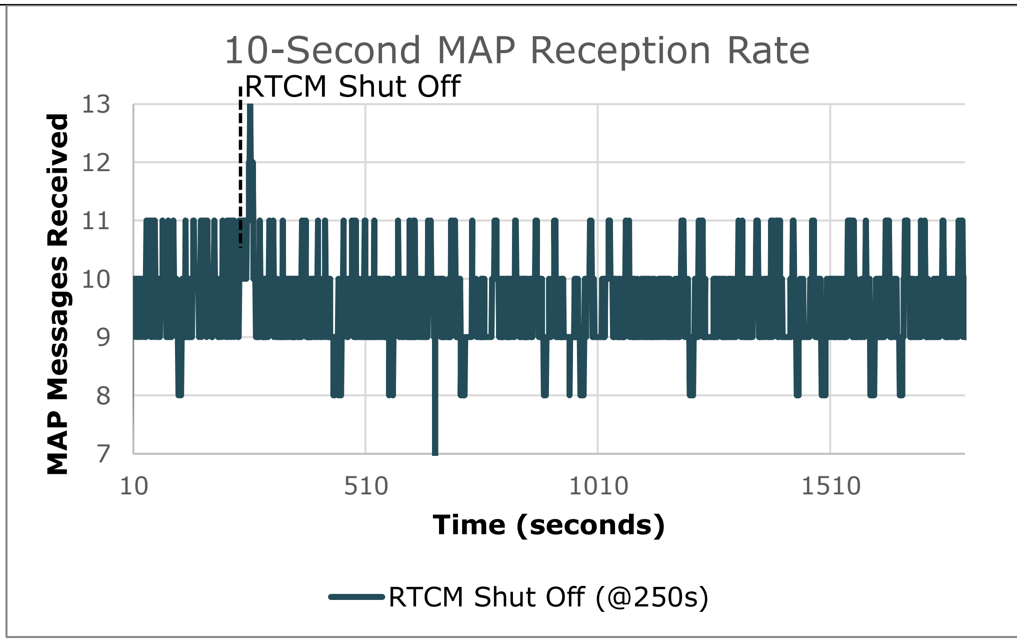
Requirement	**3.3.3.1.5.1 SPaT Message - Broadcast Periodicity**
Objective	Verify SPaT broadcast frequency
Method	Wireshark is used to export SPaT message reception timestamps from each intersection. External data processing tools are used to perform a rolling 10-second count of MAP messages is performed every 1 second.
Pass Criteria	Requirement is considered met if between 90 and 110 SPaT messages are received for every rolling average period
Results and Explanation	This requirement is considered to be **partially met** for all intersections. *Note: At the time data for assessing this requirement was collected, t**he broadcast of RTCM messages was enabled.** When RTCM messages are enabled, non-negligible impact to latency and periodicity is experienced which affects the results of this analysis. A secondary data capture at intersection 7709 was also performed when the broadcast of RTCM messages was disabled which provided for much more ideal operation. While this provides an indication the system is capable of meeting this requirement, it cannot be met simultaneously with other requirements that specify the broadcast of RTCM messages.* This requirement is assessed by counting the number of SPaT messages received over a rolling 10-second period over the duration of the stationary data capture. All intersections provided lower than expected reception rates for the entire duration of the data capture. The 10-second SPaT reception rate typically oscillated from 85 to 102 messages, and in a few instances the bottom of the oscillation reached around 80 messages at some intersections. At intersection 7708, there was a single instance where 2 SPaT messages were broadcast over a 12-second period. A secondary data collection from intersection 7709 (when RTCM was shut off 250 seconds into the data collection period) revealed more desirable operation. Before RTCM messages were shut off, similar operations as those captured in the initial data set were observed. Once RTCM messages were shut off, the number of SPaT messages briefly increased to around 130 over a 10-second period before resuming a typical broadcast rate, oscillating from 92 to 100 messages throughout the remainder of the duration. A comparison of the reception rate over time for intersection 7709 is provided in the chart below with RTCM and when RTCM was shut off. 

	Furthermore, a count of SPaT messages received by the vehicle during the stationary data capture were analyzed. The number of messages received is divided by the duration of the data capture at each intersection to determine the average SPaT broadcast frequency. Results in the table below indicate that all average SPaT broadcast frequencies fall in the 9.1-9.4 Hz range when RTCM is broadcast. When RTCM was turned off, the average SPaT broadcast rate at intersection 7709 increased from 9.12 to 9.91.

intersection	timespan (s)	# SPaT	SPaT avg rate (Hz)
7706	991	9237	9.32
7707	1075	10105	9.40
7720	1078	10042	9.31
7708	1134	10332	9.10
7709	950	8671	9.12
7709 (no RTCM)	1599	15852	9.91
7710	1141	10172	9.38

Requirement	3.3.3.1.5.2 SPaT Message - Broadcast Latency
Objective	Verify SPaT latency.
Method	Video data is reviewed to determine the time (relative to the start of the video) that the actual signal head changes and the time that the corresponding event state changes on the test tool. Broadcast latency is considered to be smaller than this value (since this also includes other sources of latency). Note that the process used to verify this requirement cannot be used as evidence that the requirement is not being met, as there are other sources of latency captured using this method (e.g., test tool Bluetooth connectivity) that cannot be precisely accounted for.
Pass Criteria	Requirement is considered met if the calculated time difference is less than 300 ms.
Results and Explanation	This requirement is considered to be **met** for all intersections under certain conditions. Simultaneous video capture of the test tool and the actual signal indicate varying amounts of latency between signal groups at all intersections. The average latency observation for each signal groups ranges from 84 to 241 milliseconds, which is within the defined latency tolerance of 300 milliseconds. The average latency of all observations across all intersections is 149 milliseconds. Detailed latency results are provided in Appendix E. It is important to note that some of the latency captured using this method includes latency that is attributable to the data capture/display process (which is not included in the scope of this requirement). The relative consistency of most individual signal state transition latencies (~150±50ms) suggests that larger measured latency values disproportionately consist of data capture/display latency. If this portion the latency was known and could be accounted for, it is anticipated the average latency would be lower than the measured values, resulting in all signal groups at all intersections being in compliance with this requirement. *Note: At the time data for assessing this requirement was collected, t**he broadcast of RTCM messages was disabled.** When RTCM messages are enabled, non-negligible impact to latency and periodicity is experienced. This means that this requirement cannot be met simultaneously with other requirements where RTCM messages must be enabled.*

Requirement	**3.3.3.1.5.3 MAP Message - Broadcast Periodicity**
Objective	Verify MAP broadcast frequency
Method	Wireshark is used to export MAP message reception timestamps from each intersection. External data processing tools are used to perform a rolling 10-second count of MAP messages is performed every 1 second.
Pass Criteria	Requirement is considered met if between 9 and 11 MAP messages are received for every rolling average period
Results and Explanation	This requirement is considered to be **partially met** for all intersections. *Note: At the time data for assessing this requirement was collected, t**he broadcast of RTCM messages was enabled.** When RTCM messages are enabled, non-negligible impact to latency and periodicity is experienced which affects the results of this analysis. A secondary data capture at intersection 7709 was also performed when the broadcast of RTCM messages was disabled which provided for much more ideal operation. While this provides an indication the system is capable of meeting this requirement, it cannot be met simultaneously with other requirements that specify the broadcast of RTCM messages.* This requirement is assessed by counting the number of MAP messages received over a rolling 10-second period over the duration of the stationary data capture. All intersections provided lower than expected reception rates for the entire duration of the data capture. The 10-second MAP reception rate typically ranged between 9, 10, or 11 messages, intermittently decreasing to 8 messages, at even lower in certain instances at all intersections. At intersection 7708, there was a single instance where 1 MAP message was broadcast over a 20-second period. A secondary data collection from intersection 7709 (when RTCM was shut off 250 seconds into the data collection period) revealed more desirable operation. Before RTCM messages were shut off, similar operations as those captured in the initial data set were observed. Once RTCM messages were shut off, the number of MAP messages briefly increased to around 13 over a 10-second period before resuming a typical broadcast rate, oscillating from 9 to 10 messages throughout the remainder of the duration, less frequently 8 or 11. A comparison of the reception rate over time for intersection 7709 is provided in the chart below with RTCM and when RTCM was shut off.



Furthermore, a count of MAP messages received by the vehicle during the stationary data capture were analyzed. The number of messages received is divided by the duration of the data capture at each intersection to determine the average MAP broadcast frequency. Results in the table below indicate that all average MAP broadcast frequencies fall around 1Hz.

Furthermore, a count of MAP messages received by the vehicle during the stationary data capture were analyzed. The number of messages received is divided by the duration of the data capture at each intersection to determine the average MAP broadcast frequency. Results in the table below indicate that all average MAP broadcast frequencies for intersections 7706, 7707, 7720, and 7708 remained below expected operations, while intersection 7709 and 7710 exhibited normal average broadcast rates when RTCM is also broadcast. When RTCM was turned off, the average SPaT broadcast rate at intersection 7709 remained the same at 0.99.

intersection	timespan (s)	# MAP	MAP avg rate (Hz)
7706	991	806	0.81
7707	1075	929	0.86
7720	1078	890	0.83
7708	1134	1043	0.92
7709	950	938	0.99
7709 (no RTCM)	1599	1585	0.99
7710	1141	1137	1.00

Requirement	3.3.3.1.6.1 Completeness - SPaT Message
Objective	Verify movement state information is in SPaT
Method	SPaT and MAP data are inspected to determine if every allowed movement in every ingress lane into the intersection is controlled and may have one or more movement state, as represented by DE_MovementPhaseState.
Pass Criteria	Requirement is considered to be met if every ingress lane connection has a signal group specified, and the signal group in the SPaT message has at least one movement state specified.

Results and Explanation	This requirement is considered to be **met** for all intersections. Every ingress lane in the MAP message has a signal group and every signal group has a corresponding signal group in the SPaT Message that includes a movement state at all intersections. A following requirement (3.3.3.4.4.1) however indicates that not all required connections and sidewalks are present in the MAP message. Care should be taken once these connections are added that this requirement continues to be met.

Requirement	3.3.3.1.6.2 Completeness - MAP Message
Objective	Verify all lane information is in MAP
Method	MAP message lane centerline geometry data is overlayed on up-to-date satellite imagery. The CAMP Online Tool (https://camp-llc.org/) is used to generate this visualization. Note: The CAMP online tool accepts a comma-separated value file containing a list of messages received. Each row includes a timestamp, message id, message payload (json), and a signature indicator. The tool produces a report indicating which data elements are included in SPaT messages for each intersection along with if the element is mandatory, optional, or conditional, and if the message is in compliance with the SAE J2735.
Pass Criteria	Requirement is considered to be met if all lanes in the MAP message roughly reflects all approach lanes in the field (note: accuracy of lane points are verified in a different requirement)
Results and Explanation	This requirement is considered to be **partially met** for all intersections. MAP data is inspected to ensure all lanes of travel (including vehicle lanes, bike lanes, tracked vehicle lanes, and crosswalks) are present. All vehicle travel lanes and crosswalks are represented in all MAP messages at all intersections. None of the sidewalks (landings) at the intersection are represented in the MAP messages, which is an issue at all intersections. There are no bike lanes or tracked vehicle lanes.

Requirement	3.3.3.2.1 Time Accuracy
Method	**A method for assessing this requirement has not yet been determined**
Results and Explanation	This requirement **could not be tested** as time data from the traffic signal controller was not collected as part of this effort.
Requirement	3.3.3.2.2.1 SPaT Message - Revision Counter Increment
Objective	Verify ability to increment revision counter
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display eventState, startTime, minEndTime, maxEndTime, likelyTime, and nextTime as columns. The data is exported for evaluation in external data processing tool to assess changes in the values in these data elements from message to message and determining if this also corresponds to a change in the msgCount.
Pass Criteria	msgCount increments when any of the following message data elements have changed for any signalGroup: eventState, startTime, minEndTime, maxEndTime, likelyTime, nextTime
Results and Explanation	This requirement is considered to be **met** for all intersections. SPaT messages were displayed sequentially and the event state, minEndTime, and maxEndTime values were assessed for changes between messages (about 100ms apart). When a change was observed between two messages, the messageCount (revision) data element was assessed to determine if its value increments. All intersections had instances of the message count incrementing properly, as shown in the example below. There were no

<table>
<tr><td></td><td>instances found where an event state, minEndTime, and maxEndTime did not change, but the message count continued to increase.

Example of messageCount (revision) incrementing properly (note changes in the eventState, minEndTime, and maxEndTime variables) – startTime and nextTime omitted for brevity

<table>
<tr><th>No.</th><th>Epoch Time</th><th>revision</th><th>id</th><th>eventState</th><th>minEndTime</th><th>maxEndTime</th></tr>
<tr><td>118146</td><td>2022-08-17 18:00:10.822155</td><td>81</td><td>7720</td><td>permissive-Movement-Allowed,stop-And-Remain,permissive-Movement-Allowed,stop-And-Remain</td><td>123,71,123,152</td><td>123,123,152</td></tr>
<tr><td>118147</td><td>2022-08-17 18:00:10.881765</td><td>82</td><td>7720</td><td>permissive-Movement-Allowed,stop-And-Remain,permissive-Movement-Allowed,stop-And-Remain</td><td>124,72,124,152</td><td>124,124,152</td></tr>
<tr><td>118151</td><td>2022-08-17 18:00:10.981442</td><td>84</td><td>7720</td><td>permissive-Movement-Allowed,stop-And-Remain,permissive-Movement-Allowed,stop-And-Remain</td><td>126,74,126,152</td><td>126,126,152</td></tr>
<tr><td>118154</td><td>2022-08-17 18:00:11.078217</td><td>85</td><td>7720</td><td>permissive-Movement-Allowed,stop-And-Remain,permissive-Movement-Allowed,stop-And-Remain</td><td>127,75,127,152</td><td>127,127,152</td></tr>
<tr><td>118159</td><td>2022-08-17 18:00:11.212105</td><td>86</td><td>7720</td><td>permissive-Movement-Allowed,stop-And-Remain,permissive-Movement-Allowed,stop-And-Remain</td><td>128,76,128,152</td><td>128,128,152</td></tr>
<tr><td>118161</td><td>2022-08-17 18:00:11.251216</td><td>87</td><td>7720</td><td>permissive-Movement-Allowed,stop-And-Remain,permissive-Movement-Allowed,stop-And-Remain</td><td>129,77,129,152</td><td>129,129,152</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td>Requirement</td><td>3.3.3.2.2.2 SPaT Message - Revision Counter Not Increment</td></tr>
<tr><td>Objective</td><td>Verify ability to not increment revision counter</td></tr>
<tr><td>Method</td><td>Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display eventState, startTime, minEndTime, maxEndTime, likelyTime, and nextTime as columns. The data is exported for evaluation in external data processing tool to assess changes in the values in these data elements from message to message and determining if this also corresponds to a change in the msgCount.</td></tr>
<tr><td>Pass Criteria</td><td>msgCount does not increment when all of the following message data elements have not changed for all signalGroups: eventState, startTime, minEndTime, maxEndTime, likelyTime, nextTime</td></tr>
<tr><td>Results and Explanation</td><td>This requirement is considered to be not met intersections 7707, 7720, 7709, and 7710.

This requirement could not be tested for intersection 7706 and 7708 as the signal timing information never remained the same from one SPaT message to the next at these intersections.

SPaT messages were displayed sequentially and the event state, minEndTime, and maxEndTime values were assessed for sameness between messages (about 100ms apart). When the same data was observed between two messages, the messageCount (revision) data element was assessed to determine if its value does not increment. The messageCount at intersections 7707, 7720, 7709, and 7710 always increases from one SPaT message to the next. However, there were instances of the message count incrementing when the signal timing information in the SPaT message did not change. Examples provided below.

Intersection 7720 example of messageCount (revision) incrementing when it should not be (note eventState, minEndTime, and maxEndTime variables do not change).

<table>
<tr><th>No.</th><th>Epoch Time</th><th>revision</th><th>id</th><th>eventState</th><th>minEndTime</th><th>maxEndTime</th></tr>
<tr><td>118172</td><td>2022-08-17 18:00:11.877666</td><td>91</td><td>7720</td><td>permissive-clearance,stop-And-Remain,permissive-clearance,stop-And-Remain</td><td>131,152,131,152</td><td>131,152,131,152</td></tr>
<tr><td>118174</td><td>2022-08-17 18:00:11.929456</td><td>92</td><td>7720</td><td>permissive-clearance,stop-And-Remain,permissive-clearance,stop-And-Remain</td><td>131,152,131,152</td><td>131,152,131,152</td></tr>
<tr><td>118176</td><td>2022-08-17 18:00:11.949012</td><td>93</td><td>7720</td><td>permissive-clearance,stop-And-Remain,permissive-clearance,stop-And-Remain</td><td>131,152,131,152</td><td>131,152,131,152</td></tr>
<tr><td>118180</td><td>2022-08-17 18:00:12.056506</td><td>94</td><td>7720</td><td>permissive-clearance,stop-And-Remain,permissive-clearance,stop-And-Remain</td><td>131,152,131,152</td><td>131,152,131,152</td></tr>
<tr><td>118181</td><td>2022-08-17 18:00:12.080944</td><td>95</td><td>7720</td><td>permissive-clearance,stop-And-Remain,permissive-clearance,stop-And-Remain</td><td>131,152,131,152</td><td>131,152,131,152</td></tr>
</table>
</td></tr>
</table>

Requirement	3.3.3.2.2.3 MAP Message - Revision Counter Increment
Objective	Verify ability to increment revision counter
Method	Use Wireshark to view pcap files. Apply filter to only look at MAP messages (j2735_2016.messageId == 18). The msgCount in the MAP message header is compared against the msgCount in each intersection data frame.
Pass Criteria	msgCount (MAP message frame) increments when the value of any intersection msgCount increases.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (MAP message did not change)

Requirement	3.3.3.2.2.4 MAP Message - Revision Counter Not Increment
Objective	Verify ability to not increment revision counter
Method	Use Wireshark to view pcap files. Apply filter to only look at MAP messages (j2735_2016.messageId == 18). The msgCount in the MAP message header is compared against the msgCount in each intersection data frame.
Pass Criteria	msgCount (MAP message frame) does not increment when the value of all intersection msgCounts remain the same.
Results and Explanation	This requirement is considered to be **met** for all intersections. MAP messages do not change, and the msgIssueRevision remained the same for MAP messages at all intersections throughout the data collection period.

Requirement	3.3.3.2.2.5 MAP Message - Intersection Revision Counter Increment
Objective	Verify ability to increment revision counter
Method	Use Wireshark to view pcap file. The first and last MAP payloads from each intersection are assessed. The first and last MAP payloads are compared, as well as a change in the value msgCount to assess for corresponding changes.
Pass Criteria	msgCount (each IntersectionGeometry data frame) increments when the value of any element in the intersection geometry changes other than a timestamp value
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (MAP message did not change)

Requirement	3.3.3.2.2.6 MAP Message - Intersection Revision Counter Not Increment
Objective	Verify ability to not increment revision counter
Method	Use Wireshark to view pcap file. The first and last MAP payloads from each intersection are identified. The first and last MAP payloads are compared, as well as a change in the value msgCount to assess for corresponding changes.
Pass Criteria	msgCount (each IntersectionGeometry data frame) does not increment when the value of all elements in an intersection geometry have not changed, except for timestamp values.
Results and Explanation	This requirement is considered to be **met** for all intersections. Intersection geometries at each intersection remained the same and, and the intersection geometry revision number remained the same at all intersections throughout the data collection period. *Note: The value of the intersection revision counter and the MAP message revision counter are different for intersection 7710. While this does not violate any requirements, it could be considered unusual for these values to differ when there is only a single intersection geometry in a MAP message.*

Requirement	3.3.3.2.2.7 RTCMcorrections Message - Sequence Number Increment
Objective	Verify ability to increment sequence number
Method	The RTCM payloads and msgCount data element are extracted. The RTCM payloads are compared from one message to the next, as well as a change in the value msgCount to assess for corresponding changes.
Pass Criteria	msgCount RTCM message frame) increments when the value of any element changes other than a timestamp value
Results and Explanation	This requirement is considered to be **partially met** for all intersections. In most cases, the msgCount increases in a typical fashion, however, there are many instances where the increment does not occur in a normal fashion.

1. The msgCount appears to increment separately for two different groupings of RTCM messages
2. The msgCount appears to skip some values.

Example of pcap data from intersection 7709 shows the msgCnt data element apparently incrementing in two groups, highlighted in red and blue. The content of messages within the blue group appears to be unique, while the content of messages within the red group appears to repeat in a cyclical fashion. Within each group, the msgCount sometimes skips values. There are some instances where the messages in the blue group do not appear to broadcast for over a 30-second period.

Other messages, such as SPaT also tend to be missing around the same time the missing RTCM messages are expected to have been received. It is not known if this is a result of system issues with signing/broadcasting messages at such a high frequency, or if there were intermittent test equipment reception issues. However, during a separate data collection when RTCM messages were turned off, the pcap data indicates more typical SPaT reception, which suggests that there is something related to the broadcast of RTCM that is one potential source for this issue.

It should be considered if multiple RTCM payloads can be included in the same RTCM message to cut down on the total number of RTCM messages broadcast.

messageId	msgCnt	RTCMmessage
rtcmCorrections	89	d300c34322934d8d070000200425a1240000000020204000...
rtcmCorrections	67	d300153ee293037bdcfcef6535814c170949a01d83c70000...,d30048409293144144564e554c4c414e54454e4e4120204e...
rtcmCorrections	92	d300193ef293144144564e554c4c414e54454e4e4120204e...
rtcmCorrections	93	d3003f4064f6962930c91450000014001438000009000d15...
rtcmCorrections	94	d3002c407961a149863062400001f00040400000100028a8...
rtcmCorrections	95	d3001440829305103bdd2fbe5ed5fd379ba09a004005d09e...
rtcmCorrections	96	d300c34322934d8d16a000200425a1240000000020204000...
rtcmCorrections	99	d300193ef293144144564e554c4c414e54454e4e4120204e...
rtcmCorrections	100	d3003f4064f6962930c91450000014001438000009000d15...
rtcmCorrections	101	d3002c407961a149863062400001f00040400000100028a8...
rtcmCorrections	102	d3001440829305103bdd2fbe5ed5fd379ba09a004005d09e...
rtcmCorrections	103	d300c34322934d8d264000200425a1240000000020204000...
rtcmCorrections	69	d300153ee293037bdcfcef6535814c170949a01d83c70000...,d30048409293144144564e554c4c414e54454e4e4120204e...
rtcmCorrections	106	d300193ef293144144564e554c4c414e54454e4e4120204e...
rtcmCorrections	107	d3003f4064f6962930c91450000014001438000009000d15...
rtcmCorrections	108	d3002c407961a149863062400001f00040400000100028a8...
rtcmCorrections	109	d3001440829305103bdd2fbe5ed5fd379ba09a004005d09e...
rtcmCorrections	70	d300153ee293037bdcfcef6535814c170949a01d83c70000...,d30048409293144144564e554c4c414e54454e4e4120204e...
rtcmCorrections	113	d300193ef293144144564e554c4c414e54454e4e4120204e...
rtcmCorrections	114	d3003f4064f6962930c91450000014001438000009000d15...
rtcmCorrections	115	d3002c407961a149863062400001f00040400000100028a8...

Requirement	3.3.3.2.2.8 RTCMcorrections Message - Sequence Number Not Increment
Objective	Verify ability to not increment sequence number
Method	The RTCM payloads and msgCount data element are extracted. The RTCM payloads are compared from one message to the next, as well as a change in the value msgCount to assess for corresponding changes.
Pass Criteria	msgCount (RTCM message frame) does not increment when the value of all elements have not changed, except for timestamp values.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test: no two sequential RTCM messages had the same data. The CI Implementation Guide acknowledges that RTCM corrections information changes rapidly, and as a result, so does MsgCount. *Note: There were several instances where the same RTCM payloads were received in sequential messages where msgCnt incremented, however, there may be an explanation for this observation. In these instances, it appears that there was a large time difference between the receipt of sequential messages. Similar to assessment of the requirement above, this may have been the result of not broadcast some messages due to system*

	issues with signing/broadcasting messages at such a high frequency, or intermittent test equipment reception issues.

Requirement	3.3.3.2.3.1 SPaT Message - Message Time Stamp
Objective	Verify inclusion of minuteOfTheYear data element
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display timeStamp as a column
Pass Criteria	The timeStamp data element is included the SPaT message, and roughly matches the actual time the message is received. Note: Latency and/or differences between system clocks may result in the timeStamp changing up to several seconds before or after the message is received. For the purpose of evaluating this requirement, this is acceptable.
Results and Explanation	This requirement is considered to be **met** for all intersections. The SPaT message frame included the timeStamp data element at all intersections. The value of the timeStamp element correctly reflected the hour and minute. However, the value of timeStamp changed about 4 seconds after the capture tool (laptop) timestamp indicated a minute change. This was noted in the stationary pcap data when RTCM messages were simultaneously broadcast. However, a sample set of data collected from intersection 7709 when RTCM messages were disabled indicated the value of timestamp changed much more closely to the capture tool timestamp when the message was actually received.

Requirement	3.3.3.2.3.2 SPaT Message - Intersection Time Stamp
Objective	Verify inclusion of minuteOfTheYear data element
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display moy as a column
Pass Criteria	The moy data element in each intersectionState data frame in the SPaT message, and roughly matches the actual time the message is received. Note: Latency and/or differences between system clocks may result in moy changing up to several seconds before or after the message is received. For the purpose of evaluating this requirement, this is acceptable.
Results and Explanation	This requirement is considered to be **met** for all intersections. The SPaT message frame included the timeStamp data element at all intersections. The value of the timeStamp element correctly reflected the hour and minute. However, the value of timeStamp changed about 4 seconds after the capture tool (laptop) timestamp indicated a minute change. This was noted in the stationary pcap data when RTCM messages were simultaneously broadcast. However, a sample set of data collected from intersection 7709 when RTCM messages were disabled indicated the value of timestamp changed much more closely to the capture tool timestamp when the message was actually received.

Requirement	3.3.3.3.1.1 Intersection Signal Timing Information
Objective	Verify inclusion of intersectionState data frame
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersections' as a column (provides a count of intersection state data frames in the intersection state list).
Pass Criteria	The SPaT Message contains a minimum of one intersectionState data frame in the intersectionStateList.
Results and Explanation	This requirement is considered to be **met** for all intersections. SPaT messages at all intersections contain one intersectionState in the intersectionStateList

Requirement	3.3.3.3.1.2 Road Regulator Identifier
Objective	Verify inclusion and accuracy of roadRegulator identifier
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'region' as a column.
Pass Criteria	The roadRegulatorId data element is present in SPaT and MAP messages, and it is the same between all intersections within each test site (unless multiple jurisdictions are involved, where the roadRegulator Id is expected to be the same at intersection with each jurisdiction).
Results and Explanation	This requirement is considered to be **not met** for all intersections. The roadRegulatorId is not included in SPaT or MAP messages at any intersection.

Requirement	3.3.3.3.1.3 Intersection Reference Identifier
Objective	Verify inclusion and accuracy of intersection id
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'id' as a column.
Pass Criteria	The intersectionId data element is present in the SPaT and MAP messages, and its value is different between all intersections within each test site (unless multiple jurisdictions are involved, where the intersectionId is expected to be different at intersections with each jurisdiction.). Furthermore, the intersectionId should be the same at each intersection at each jurisdiction for both SPaT and MAP messages.
Results and Explanation	This requirement is considered to be **met** for all intersections. All intersections contained an intersection identifier in both SPaT and MAP messages that was unique to the intersection.

Requirement	3.3.3.3.2.1 Manual Control
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The Manual Control flag is correctly specified in the intersectionStatus data element (bit 0) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (manual control never enabled). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.2 Stop Time
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The Stop Time flag is correctly specified in the intersectionStatus data element (bit 1) - as event noted during data collection.

Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (stop time never enabled). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.3 Failure Flash
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The Failure Flash flag is correctly specified in the intersectionStatus data element (bit 2) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (failure flash not observed). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.4 Preemption
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The Preemption flag is correctly specified in the intersectionStatus data element (bit 3) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (preemption not observed). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.5 Priority
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The Priority flag is correctly specified in the intersectionStatus data element (bit 4) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (priority not observed). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.6 Fixed Time
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.

Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The Fixed Time flag is correctly specified in the intersectionStatus data element (bit 5) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (fixed time not observed). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.7 Traffic Dependent Mode
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The Traffic Dependent Mode flag is correctly specified in the intersectionStatus data element (bit 6) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was no data to verify if the intersection was operating in traffic dependent mode. However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.8 Standby Mode
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The Standby Mode flag is correctly specified in the intersectionStatus data element (bit 7) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (standby conditions not observed). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.9 Failure Mode
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The Failure Mode flag is correctly specified in the intersectionStatus data element (bit 8) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (failure not observed). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.10 Controller Off

Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The Controller Off is correctly specified in the intersectionStatus data element (bit 9) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (controllers always on). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.11 Recent MAP Update
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The Recent MAP Update flag is correctly specified in the intersectionStatus data element (bit 10) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (MAP messages remained the same throughout). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.12 New Lane IDs
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The New Lane ID flag is correctly specified in the intersectionStatus data element (bit 11) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (lane identifiers remained the same throughout). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.13 No MAP Available
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The No MAP Available flag is correctly specified in the intersectionStatus data element (bit 12) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (MAP always broadcast). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.2.14 No SPaT Available
Objective	Verify correct use of the specified bit in the intersectionStatus element Note: Triggering a condition that should cause this bit to change is not performed during data collection.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'intersectionStatus' as a column.
Pass Criteria	The No SPaT Available flag is correctly specified in the intersectionStatus data element (bit 13) - as event noted during data collection.
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (SPaT data not being available was not observed). However, it is anticipated that this requirement would not be met if the condition were to be observed.

Requirement	3.3.3.3.3.1 Current Movement State for a Signal Group
Objective	Verify actual signal state properly reflected in SPaT/MAP data
Method	Use Wireshark to view pcap files. Look at a list of signal groups in the MAP and SPaT messages, and a list of event states in the SPaT message.
Pass Criteria	Signal groups defined in the MAP message can be matched to a signal group in the SPaT message. The signal group in the SPaT message has an event state associated with it.
Results and Explanation	This requirement is considered to be **met** for all intersections A list of all signal groups included in a MAP message are initially determined. A corresponding SPaT message (same region and intersection id) is then assessed to determine if every signalGroup identified from MAP is included in SPaT, and that a valid eventState is provided for each signal group. All SPaT messages contain signal group information that corresponds to all signal groups in the corresponding MAP message for all intersections. An example from intersection 7709 is provided in the image below. Note that signal groups are repeated in the MAP message since the same signal group controls more than one movement (i.e., connection).

No.	Epoch Time	messageId	id	signalGroup	eventState
123693	2022-08-17 18:07:55.807911	mapData	7709	8,8,8,2,2,2,2,4,4,4,6,6,6,6	
123695	2022-08-17 18:07:55.880214	signalPhaseAndTimingMessage	7709	2,4,6,8	permissive-Movement-Allowed,stop-And-Remain,permissive-Movement-Allowed,stop-And-Remain

Requirement	3.3.3.3.3.2 Unknown Current Movement State for a Signal Group
Objective	Verify use of the unknown value for the movement state
Method	Cannot be tested - it is not known when a signal controller does not know the current movement state.
Pass Criteria	N/A
Results and Explanation	This requirement **could not be tested** as there was a condition not observed in order to perform the test (conditions for an unknown movement state are never observed)

Requirement	3.3.3.3.3.3 Flashing Yellow Arrow Permissive Movement
Objective	Verify use of the permissive movement allowed value for the movement state
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' and 'eventState' as a column.

Pass Criteria	The event state is 'permissive-movement-allowed' for the flashing yellow arrow signal group when the flashing yellow arrow indicator is active. This is also confirmed though review of the video capture - the test tool provides a green signal indication for the corresponding signal group when the flashing yellow signal head is active.
Results and Explanation	This requirement is considered **not applicable** for all intersections. None of the signalized intersections tested use the flashing yellow arrow.

Requirement	**3.3.3.3.3.4 Protected and Permissive Clearance**
Objective	Verify the progression of the value of the movement state
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' and 'eventState' as a column. An external data processing tool is used to evaluate the progression of eventState values for each signal group.
Pass Criteria	The state of a vehicular movement is permissive-clearance when proceeding a permissive-movement-allowed signal state OR if the state of a vehicular movement is protected-clearance when proceeding a protected-movement-allowed signal state.
Results and Explanation	This requirement is considered to be **met** for all intersections. When transitioning from green to yellow, all permissive greens transition to a permissive yellow. A transition from protected green to protected yellow was not observed.

Requirement	**3.3.3.3.3.5 Resolve Protected Versus Permissive Movement**
Objective	Verify that movements that are protected during some portion of the cycle and permissive during other portions of a cycle are properly indicated (e.g., a protected-permissive left turn).
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' and 'eventState' as a column. An external data processing tool is used to evaluate the eventState values of signal groups for movements that are known to be protected or permissive (such as a left or right turn) to ensure the correct eventStates are provided during the correct parts of the cycle.
Pass Criteria	The state of a vehicular movement is permissive-movement-allowed when a green indication is provided when there are potential conflicting movements AND if the state of a vehicular movement is protected-movement-allowed when an arrow indication is provided when there are no conflicting movements.
Results and Explanation	This requirement is considered to be **not met** for intersections 7706, 7708, and 7710. This requirement is considered **not applicable** for intersections 7707, 7709 and 7720 (no signal groups are protected for a portion of the cycle and permissive during other portions of the cycle). Signal groups assigned to left turn movements at intersections 7707 and 7710 only ever indicates a permissive event state during the protected portion of the phase but remains red for the permissive portion of the phase. The signal group assigned to left turn movements at intersection 7709 was never observed as indicating protected, but similar to 7707 and 7710, remained red during the permissive portion of the phase. This is likely because the signal group assigned to these left turn movements is directly associated with the controller phase that controls the protected portion of the left turn movement – the permissive portion of these left turn movements needs to be incorporated with this protected part of the phase.

An example of the signal state progression for intersection 7708 is provided below. The left turn controlled by signal group 1 is controlled by a 5-section head and progresses in this example according to the indications below.

The table starts with the SB left turn and through movements indicating a permissive green followed by a permissive yellow. In reality the left turn is protected, and a protected green and protected yellow should be indicated. The left turn signal group transitions to red for the remainder of the cycle while the opposing NB through movement (signal group 2) transitions to permissive green. However, after the protected part of the left turn movement ends (end of protected yellow), signal groups 1 should transition to a permissive green, matching the event state of the SB through movement (signal group 6). A green border is drawn in signal group 1, where the event state should have transitioned to permissive green.

SB Signal	SG 1 (SB left)	SG 2 (NB through)	SG 6 (SB through)
	permissive-Movement-Allowed	stop-And-Remain	permissive-Movement-Allowed
	permissive-Movement-Allowed	stop-And-Remain	permissive-Movement-Allowed
	permissive-Movement-Allowed	stop-And-Remain	permissive-Movement-Allowed
	permissive-Movement-Allowed	stop-And-Remain	permissive-Movement-Allowed
	permissive-Movement-Allowed	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
↓	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
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	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	permissive-clearance	stop-And-Remain	permissive-Movement-Allowed
	stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
	stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed

		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
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		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
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		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
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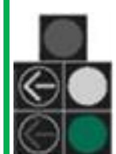
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	stop-And-Remain	permissive-Movement-Allowed
		stop-And-Remain	permissive-Movement-Allowed	permissive-Movement-Allowed
		stop-And-Remain	permissive-Movement-Allowed	permissive-Movement-Allowed
		stop-And-Remain	permissive-Movement-Allowed	permissive-Movement-Allowed
		stop-And-Remain	permissive-Movement-Allowed	permissive-Movement-Allowed
		stop-And-Remain	permissive-Movement-Allowed	permissive-Movement-Allowed

Requirement	3.3.3.3.3.6 Conflict Causes Permissive
Objective	Verify use of permissive states when a conflicting movement is also active or per signal head indication (solid)
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' and 'eventState' as a column. An external data processing tool is used to evaluate the eventState values of conflicting signal groups when a given signal state for a signal group is protected (permissive-movement-allowed OR permissive-clearance)
Pass Criteria	The state of a vehicular movement is permissive-movement-allowed when a solid green or yellow indication is provided when there are potential conflicting movements.
Results and Explanation	This requirement is considered to be **met** for all intersections. Visualization of SPaT data indicates that permissive event states are always provided for movements – this is regardless of whether the movement is actually permissive or protected. Though this is not ideal operations, it allows this requirement to always pass.

Requirement	3.3.3.3.3.7 No Conflict Causes Protected
Objective	Verify use of protected state when conflicting movements are not active or per signal head indication (arrow)
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' and 'eventState' as a column. An external data processing tool is used to evaluate the eventState values of conflicting signal groups

	when a given signal state for a signal group is protected (protected-movement-allowed OR protected-clearance)
Pass Criteria	The state of a vehicular movement is protected-movement-allowed when a green or yellow arrow indication is provided when there are no conflicting movements.
Results and Explanation	This requirement is considered to be **not met** for intersections 7707, 7708, and 7710. This requirement could **not be tested** for intersection 7706 (protected left turn state was not observed). This requirement is considered to be **not applicable** for intersection 7709 and 7720 (protected left turns not provided at these intersections). From the example provided in the explanation of 3.3.3.3.3.5, intersection 7707 signal group 1 should be protected to match the signal head indication – however, the event state indicates this is a permissive movement. All other protected movements at intersections 7707, 7708, and 7710 are indicated as permissive when the protected left turn phase is green or yellow.

Requirement	3.3.3.3.3.8 WALK State Enumeration (No Conflict)
Objective	Verify use of protected green state when conflicting movements are not active.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' and 'eventState' as a column. An external data processing tool is used to evaluate the eventState values of signal groups that conflict with a pedestrian signal group when the signal state for a pedestrian signal group is protected (protected-movement-allowed OR protected-clearance)
Pass Criteria	The state of a pedestrian movement is protected-movement-allowed when a WALK indication is provided when there are no conflicting movements.
Results and Explanation	This requirement **could not be tested** for all intersections as there was a condition not observed in order to perform the test (crosswalk signal groups not present).

Requirement	3.3.3.3.3.9 WALK State Enumeration (Potential Conflict)
Objective	Verify use of protected green state when conflicting movements are not active.
Method	Use Wireshark to view pcap files. Apply filter to only look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' and 'eventState' as a column. An external data processing tool is used to evaluate the eventState values of signal groups that conflict with a pedestrian signal group when the signal state for a pedestrian signal group is protected (permissive-movement-allowed OR permissive-clearance)
Pass Criteria	The state of a pedestrian movement is permissive-movement-allowed when a WALK indication is provided concurrent with a permissive indication for a conflicting traffic movement.
Results and Explanation	This requirement **could not be tested** for all intersections as there was a condition not observed in order to perform the test (crosswalk signal groups not present).

Requirement	3.3.3.3.3.10 Flashing DON'T WALK State Enumeration
Objective	Verify use of protected clearance state when conflicting movements are not active.
Method	Video capture of the test tool and pedestrian signal head is reviewed. The pedestrian signal is compared against the test tool event state visualization when the pedestrian signal provides a flashing DON'T WALK indication.

Pass Criteria	The state of a pedestrian movement is permissive-clearance when a steady DON'T WALK indication is provided.
Results and Explanation	This requirement **could not be tested** for all intersections as there was a condition not observed in order to perform the test (crosswalk signal groups not present).

Requirement	**3.3.3.3.3.11 Steady DON'T WALK State Enumeration**
Objective	Verify use of stop and remain state
Method	Video capture of the test tool and pedestrian signal head is reviewed. The pedestrian signal is compared against the test tool event state visualization when the pedestrian signal provides a steady DON'T WALK indication.
Pass Criteria	The state of a pedestrian movement is stop-and-remain when a steady DON'T WALK indication is provided.
Results and Explanation	This requirement **could not be tested** for all intersections as there was a condition not observed in order to perform the test (crosswalk signal groups not present).

Requirement	**3.3.3.3.3.12 Movement State for Signal Groups Identified**
Objective	Verify that signal group values match between SPaT and MAP messages.
Method	Use Wireshark to view pcap files. Apply filter to look at MAP and SPaT messages (j2735_2016.messageId == 18 || j2735_2016.messageId == 19). Display 'signalGroup' as a column. The list of unique signal groups in MAP messages is compared against the unique list of signal groups in SPaT messages broadcast from the same intersection.
Pass Criteria	Each signalGroup in the SPaT message is directly related to a signalGroup in the MAP message. There are no signalGroups in the SPaT message that do not have a corresponding signal group in the MAP message, and there are no signal groups in the MAP message that have a corresponding signal group in the SPaT message.
Results and Explanation	This requirement is considered to be **met** for all intersections. All signal group values in each MAP message have an accompanying signalGroup value in each respective SPaT message. messageId | id | signalGroup mapData | 7706 | 8,8,8,2,2,2,5,4,4,4,6,6,1,6 signalPhaseAndTimingMessage | 7706 | 1,2,4,5,6,8

Requirement	**3.3.3.3.4.1 Next Movement State**
Objective	Verify inclusion of subsequent movement data
Method	Use Wireshark to view pcap files. Apply filter to look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' 'startTime' 'minEndTime' and 'maxEndTime' as a column. The time change details of the second (subsequent) movement event (in the movement event list) may be specified as unknown, of if specific values are listed, compared against the time change details of the first movement event to determine if they properly correspond to the current movement event.
Pass Criteria	StartTime of the next signal state is specified when the minEndTime is equal to the maxEndTime for the current phase. The minEndTime of the next signalState must be greater than the startTime, and the maxEndTime must be greater than or equal to the minEndTime.

Results and Explanation	This requirement is considered to be **not met** for all intersections. *Note: This requirement cannot be met without further development of the traffic signal controller to produce the required data.* Movement events beyond the current movement event are not provided in any SPaT messages at all intersections.

Requirement	3.3.3.3.4.2 Unknown Next Movement State
Objective	Verify inclusion of subsequent movement data
Method	Use Wireshark to view pcap files. Apply filter to look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' 'startTime' 'minEndTime' and 'maxEndTime' as a column. The time change details of the second (subsequent) movement event (in the movement event list) may be specified as unknown, of if specific values are listed, compared against the time change details of the first movement event to determine if they properly correspond to the current movement event.
Pass Criteria	The next movement state is specified for a signalGroup and all required data elements in the timeChangeDetails data frame may be specified as 36111 for unknown.
Results and Explanation	This requirement is considered to be **not met** for all intersections. *Note: This requirement cannot be met without further development of the traffic signal controller to produce the required data.* Movement events beyond the current movement event are not provided in any SPaT messages at all intersections.

Requirement	3.3.3.3.4.3 No Past State
Objective	Verify that time information is not from the past.
Method	Use Wireshark to view pcap files. Apply filter to look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' 'startTime' 'minEndTime' and 'maxEndTime' as a column. The time change details of the first (current) movement event (in the movement event list) are compared against the timestamp in the message.
Pass Criteria	None of the timemarks in the timeChangeDetails should indicate a time that is prior to the current message time (if available).
Results and Explanation	This requirement is considered to be **met** for all intersections. The timeStamp data (moy and dSecond) is compared against all timeChangeDetails data elements to ensure the time change details after the current timestamp. All timeChangeDetails were determined to be in compliance with this requirement.

Requirement	3.3.3.3.5.1 Time Change Details
Objective	Verify that the timeChangeDetails data frame is specified for each movement event
Method	Use Wireshark to view pcap files. Apply filter to look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' 'startTime' 'minEndTime' 'maxEndTime' 'likelyTime' and 'nextTime' as a column. The presence of any of these values is checked.
Pass Criteria	Any of the data elements within the timeChangeDetails data frame are included for every movement event in a SPaT message.
Results and Explanation	This requirement is considered to be **met** for all intersections. Time change details are provided for every signalGroup in the SPaT message at all intersections.

Requirement	3.3.3.3.5.2 Unknown Time Change Detail
Objective	Verify that all required timeChangeDetails are included Note: Analysis of communication between the traffic signal controller, roadside processing hardware, and the RSU is not performed.
Method	Cannot be tested - it is not known when a signal controller does not know the value of a time change detail.
Pass Criteria	N/A
Results and Explanation	This requirement **could not be tested** at all intersections. It is not known when the connected intersection cannot determine a time change detail.

Requirement	3.3.3.3.5.3 Minimum End Time
Objective	Verify correct progression of the minEndTime data element
Method	Use Wireshark to view pcap files. Apply filter to look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' and 'minEndTime' as a column. An external data processing tool is used to determine if the minEndTime properly progresses for each signal group.
Pass Criteria	In the absence of operational interruptions, the minEndTime for the current phase shall not decrease in a given cycle. Yellow Intervals should be constant in length (i.e., minEndTime should not change during the yellow interval) and should be consistent in overall duration within a signal group from one cycle to the next.
Results and Explanation	This requirement is considered to be **partially met** for all intersections. The minEndTime is always specified for each signal group. The minEndTime for each signalGroup were ordered sequentially and the values of the indicated timestamps were assessed to determine if they are always increasing. On the whole, the progression of the minEndTime data element was mostly in line with observed signal operations – steady during the initial part of a green phase, increasing in 100ms intervals during the 'rest in green' and again remaining steady prior to the transition to yellow. This is in line with how the signal is expected to operate. However, there were instances where the minEndTime was found to occasionally decrease – it is uncertain if this is a result of interruption of the typical progression (e.g., priority or preemption). However, in the absence of these interruptions, the minEndTime should only ever increase while an eventState remains the same. If there is uncertainty in knowing the actual earliest time the movement state might end (i.e., it could decrease), the value for 'unknown' should be specified.

Requirement	3.3.3.3.5.4 Maximum End Time
Objective	Verify correct progression of the maxEndTime data element
Method	Use Wireshark to view pcap files. Apply filter to look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' and 'maxEndTime' as a column. An external data processing tool is used to determine if the maxEndTime properly progresses for each signal group.
Pass Criteria	In the absence of operational interruptions, the maxEndTime for the current phase shall not increase in a given cycle. Yellow Intervals should be constant in length (i.e., maxEndTime should not change during the yellow interval) and should be consistent in overall duration within a signal group from one cycle to the next.
Results and Explanation	This requirement is considered to be **not met** for all intersections. The maxEndTime is not always specified for each signal group. To be compliant, the maxEndTime should always be specified. It is uncertain what events trigger the presence/absence of the maxEndTime data element for each signal group.

	The maxEndTime for each signalGroup were ordered sequentially and the values of the indicated timestamps were assessed to determine if they are always decreasing (except immediately after signal state change). The maxEndTime was found to increase for a signal group from one SPaT message to the next in multiple instances, which is not expected behavior. In some instances, the increase in the maxEndTime occurs abruptly, exhibiting expected behavior before and after the abrupt increase. In other instances, the maxEndTime constantly increased by 0.1s from one SPaT message to the next and exhibited the same value as the minEndTime when a signal remained in a 'rest in green' state. Typically, once the minEndTime is equal to the maxEndTime, these values shouldn't change and the time until the signal state transition is fixed. However, the maxEndTime continuously increases, which is not expected behavior. While there is no specific guidance for how the maxEndTime value should behave when a phase is in a 'rest in green' state, it is not expected to decrease – in this circumstance, it is recommended that the maxEndTime be set to a value of 'unknown'. During yellow intervals, the minEndTime was always found to be equal to the maxEndTime, which is expected operation, since the yellow interval is fixed.

Requirement	3.3.3.3.5.5 Unknown Maximum End Time
Objective	Verify correct use of the unknown value for maxEndTime
Method	Cannot be tested - it is not known when a signal controller does not know the max end time.
Pass Criteria	N/A
Results and Explanation	This requirement is considered to be **not met** for all intersections. A value of 'unknown' was never specified for the maxEndTime. However, given the behavior of the maxEndTime values that are specified (described above in the explanation for 3.3.3.3.5.4), there are instances where the maxEndTime should have been specified as 'unknown' for certain signal groups.

Requirement	3.3.3.3.5.6 No Current Movement State Start Time
Objective	Verify not using startTime
Method	Use Wireshark to view pcap files. Apply filter to look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' and 'startTime' as a column. An external data processing tool is used to determine if the startTime is not specified for each signal group associated with the first (current) movement event.
Pass Criteria	The startTime data element is not specified for the current phase for each signal group.
Results and Explanation	This requirement is considered to be **met** for all intersections. The startTime is never specified in the timeChangeDetails for the first (current) movement event for each signal group.

Requirement	3.3.3.3.5.7 Next Movement State Start Time
Objective	Verify use of startTime
Method	Use Wireshark to view pcap files. Apply filter to look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' 'startTime' 'minEndTime' and 'maxEndTime' as a column. The time change details of the second (subsequent) movement event (in the movement event list) may be specified as unknown, of if specific values are listed, compared against the time change details of the first movement event to determine if they properly correspond to the current movement event.
Pass Criteria	The startTime data element is specified for any subsequent phases for each signal group.

Results and Explanation	This requirement is considered to be **not met** for all intersections. *Note: This requirement cannot be met without further development of the traffic signal controller to produce the required data.* Movement events beyond the current movement event are not provided in any SPaT messages at all intersections.

Requirement	3.3.3.3.5.8 Next State Start Time Equals Current State Minimum End Time
Objective	Verify correct value for startTime
Method	Use Wireshark to view pcap files. Apply filter to look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' 'startTime' 'minEndTime' and 'maxEndTime' as a column. The time change details of the second (subsequent) movement event (in the movement event list) may be specified as unknown, of if specific values are listed, compared against the time change details of the first movement event to determine if they properly correspond to the current movement event.
Pass Criteria	The startTime data element for a subsequent phase is equal to the minEndTime for the current phase for all signal Group
Results and Explanation	This requirement is considered to be **not met** for all intersections. *Note: This requirement cannot be met without further development of the traffic signal controller to produce the required data.* Movement events beyond the current movement event are not provided in any SPaT messages at all intersections.

Requirement	3.3.3.3.6.1 Time of Next Allowed Movement
Objective	Verify correct values of minEndTime and maxEndTime when signal state changes.
Method	Use Wireshark to view pcap files. Apply filter to look at SPaT messages (j2735_2016.messageId == 19). Display 'signalGroup' 'startTime' 'minEndTime' and 'maxEndTime' as a column. The time change details of the first (current) and second (subsequent) movement events are assessed to determine if time change details are properly populated.
Pass Criteria	The nextTime data element is present when a value for the startTime is provided for a second (subsequent) movement event for the same signal group. In this case, the nextTime of the first movement event shall be greater than the startTime of the subsequent movementEvent. If the startTime for the second (subsequent) movement is unknown, then the nextTime is not included for the first (current) movementEvent.
Results and Explanation	This requirement is considered to be **not met** for all intersections. *Note: This requirement cannot be met without further development of the traffic signal controller to produce the required data.* Movement events beyond the current movement event are not provided in any SPaT messages at all intersections.

Requirement	3.3.3.3.7 Enabled Lanes Indication
Objective	Verify use of enabled lanes when intersection conditions change.
Method	Use Wireshark to view pcap files. Apply filter to look at MAP messages (j2735_2016.messageId == 18). For each lane, the Lane Attributes-Vehicle data element is identified. If the first bit of this data element is asserted, then the lane is considered revocable. The lane ID for these revocable lanes are determined.

	Apply filter to look at SPaT messages (j2735_2016.messageId == 19). The list of lane IDs in the enabled lane list is displayed as a column.
Pass Criteria	If the MAP message for the intersection defines a revocable lane for the intersection AND a revocable lane is currently active ('enabled'), then this requirement is met if the data frame DF_EnabledList is included in the SPaT message for the intersection. This test is only applicable for intersections where enabled lanes are used and are active. The lanes in the MAP message represented by the lane IDs in the enabled lane list should reflect the ground truth at the time of data collection.
Results and Explanation	This requirement is considered **not applicable** for all intersections. None of the intersections tested require the use of revocable/enabled lanes.

Requirement	**3.3.3.3.8 SPaT Message - Accuracy**
Objective	Verify all signal phase information is included in SPaT
Method	Video capture of the test tool and signal heads is reviewed. The signal indication is compared against the test tool event state visualization.
Pass Criteria	Requirement is considered to be met if all phases are being accurately shown in the test tool, and this reflects the actual signal indication of each approach in the field
Results and Explanation	This requirement is considered to be **partially met** for all intersections. Simultaneous video capture of the test tool and the actual signal indicate that the information being broadcast in the SPaT message generally lined up with the phases as they are defined in the controller. However, controller phases do not necessarily directly correspond to the control of movements through the intersection – particularly protected-permissive turning movements. Most permissive-only and protected-only movements lined up well with the data in the SPaT messages. However, protected-permissive left turn movements were only properly indicating the protected portion of the phase, and was showing red during the permissive portion of the phase. These types of left turns are controlled by a 5-section head, the left turn arrows controlled by one phase and the solid indicators are controlled by another phase (when the left turn arrow is “red” i.e., off). These phases need to be ‘combined’ to properly indicate the event state for a protected-permissive left turn movement. At intersection 7710, the right turn from Kearns Blvd is also controlled by a 5 section signal head. The right turn arrow (indicating protected) is controlled by an overlapping movement, and the solid indicator (indicating permissive, when right turn overlap is not active) is controlled by phase 4. This situation is specifically being mentioned since overlapping phase information does not appear to be currently reflected in any of the signal groups in the SPaT messages broadcast from intersection 7710. Overlap phase information from the traffic signal controller will need to be accessed and used in the generation for certain movements in SPaT messages.

Requirement	**3.3.3.4.1.1 Intersection Geometry Information**
Objective	Verify inclusion of intersection geometry in MAP message
Method	Use Wireshark to view pcap files. Apply filter to only look at MAP messages (j2735_2016.messageId == 18). Display 'intersections' as a column (provides a count of intersection geometry data frames in the intersection geometry list).
Pass Criteria	At least one intersection geometry in each MAP message
Results and Explanation	This requirement is considered to be **met** for all intersections.

	The following query was applied as a filter in Wireshark for data coming from each intersection. *j2735_2016.messageId == 18* The number of intersections was displayed as a column. All MAP messages broadcast contained one intersection.

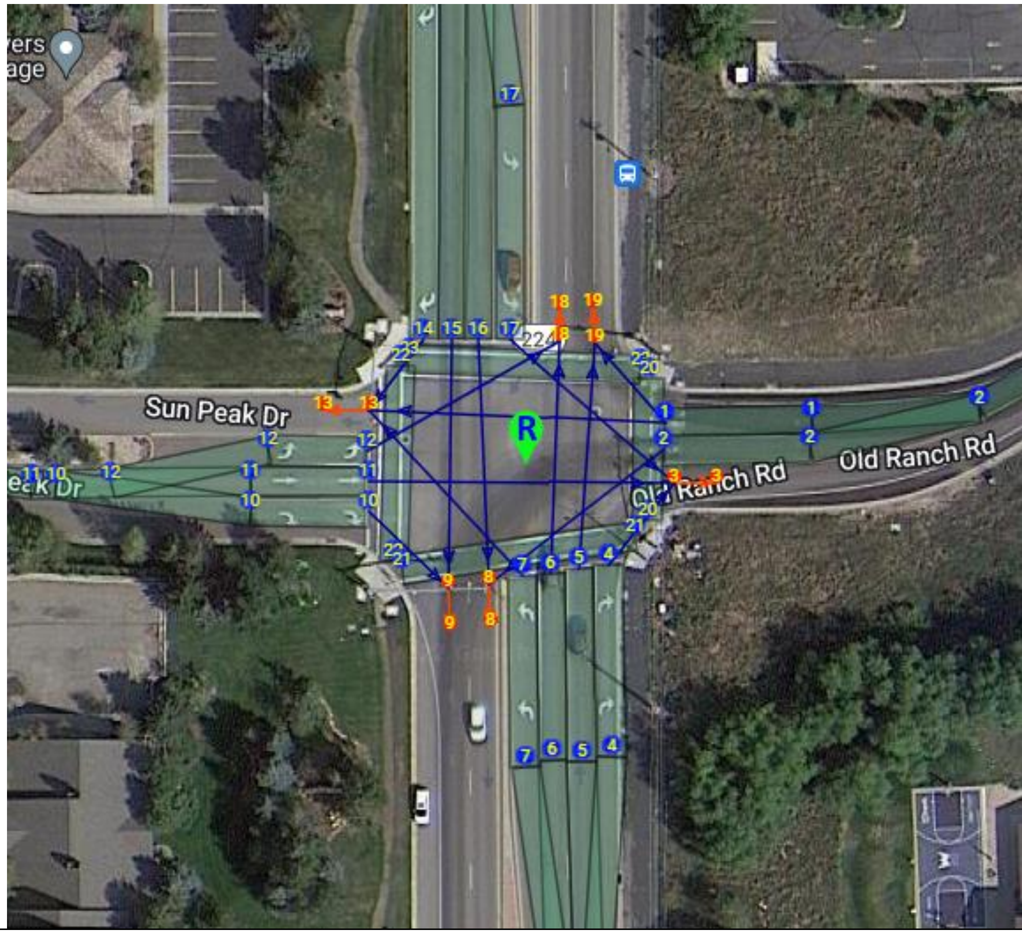
No.	Epoch Time	messageId	id	intersections
17	2022-08-17 16:25:20.374714	mapData	7706	1

Requirement	**3.3.3.4.1.2 Intersection Geometry - Road Regulator Identifier**
Objective	Verify inclusion and accuracy of roadRegulator identifier
Method	Use Wireshark to view pcap files. Apply filter to only look at MAP messages (j2735_2016.messageId == 18). Display 'region' as a column.
Pass Criteria	met given the presence of the roadRegulatorId data element in the SPaT and MAP messages, and it is the same between all intersections within each test site (unless multiple jurisdictions are involved, where the roadRegulator Id is expected to be the same at intersection with each jurisdiction).
Results and Explanation	This requirement is considered to be **not met** for all intersections. The roadRegulatorId is not included in SPaT or MAP messages at any intersection. CTI 4501 4.3.3.3.1.2 recommends road regulator id values of 31400-31699 for Utah (based on FIPS code 49).

Requirement	**3.3.3.4.1.3 Intersection Geometry - Intersection Identifier**
Objective	Verify inclusion and accuracy of intersection id
Method	Use Wireshark to view pcap files. Apply filter to only look at MAP messages (j2735_2016.messageId == 18). Display 'id' as a column.
Pass Criteria	This requirement is considered to be met given the presence of the intersectionId data element in the SPaT and MAP messages, and its value is different between all intersections within each test site (unless multiple jurisdictions are involved, where the intersectionId is expected to be different at intersections with each jurisdiction.). Furthermore, the intersectionId should be the same at each intersection at each jurisdiction for both SPaT and MAP messages. The intersection MAC address will need to be used to make sure SPaT and MAP (with the same IntersectionId) are being broadcast from the same intersection.
Results and Explanation	This requirement is considered to be **met** for all intersections. All intersections contained an intersection identifier in both SPaT and MAP messages that was unique to the intersection.

Requirement	**3.3.3.4.1.4.1 Intersection Reference Point - Position**
Objective	Verify location of reference point
Method	Extract the x offset value and the y offset value from each specified node point in the MAP message
Pass Criteria	The absolute value of the x-offset and y-offset shall be less than 32767
Results and Explanation	This requirement is considered to be **met** for all intersections. The centerpoint from each MAP message is placed on a satellite image along with a 327 meter buffer. It is then determined that the first (closest) point of every lane falls within the buffer for all intersections. A visual representation of this comparison is provided in the image below for intersection 7706.

	Note that the centerpoint should align to some measurable point (such as a pin or monument) within the intersection. However, a survey for known points near/within the intersection was not performed.



Requirement	**3.3.3.4.1.4.2 Intersection Reference Point - Description**
Objective	Verify inclusion of lat, long, elevation for reference point
Method	Use Wireshark to view pcap files. Apply filter to only look at MAP messages (j2735_2016.messageId == 18). Display 'lat' 'lon' and 'elevation' as a column.
Pass Criteria	The latitude, longitude, and elevation data elements are present in the refPoint data frame
Results and Explanation	This requirement is considered to be **partially met** for all intersections. The following query was applied as a filter in Wireshark for data coming from each intersection. *j2735_2016.messageId == 18* The reference lat, long, and elevation were displayed as columns. All intersections provided a reference lat and long in the MAP message. However, none of the intersections provided a reference elevation in the MAP message.

No.	Epoch Time	messageId	id	lat	long	elev
17	2022-08-17 16:25:20.374714	mapData	7706	406923573	-1115442230	

Requirement	**3.3.3.4.1.4.3 Intersection Reference Point Accuracy**

Objective	Verify location accuracy of reference point
Method	Extract the intersection reference latitude and longitude from the MAP message
Pass Criteria	The requirement is considered satisfied in the x and y offsets are represented using an offset of type Offset_B16 (or lower). Note: Unless the managing agency has defined where the intersection reference point is supposed to be and it is measurable, verification for this requirement will be contingent upon the verification of requirement of 3.3.3.4.1.4.1
Results and Explanation	This requirement is considered to be **met** for all intersections. The intersection reference point does not have a verifiable location. Considering the inclusion of lat and long reference points in MAP messages for all intersections, and compliance with 3.3.3.4.1.4.1 (Intersection Reference Point – Position), this requirement is considered to be met for all intersections.

Requirement	**3.3.3.4.1.5 Default Lane Width**
Objective	Verify inclusion of reference lane width
Method	Use Wireshark to view pcap files. Apply filter to only look at MAP messages (j2735_2016.messageId == 18). Display 'laneWidth' as a column.
Pass Criteria	The laneWidth data element is present in the intersection geometry data frame
Results and Explanation	This requirement is considered to be **met** for all intersections. The following query was applied as a filter in Wireshark for data coming from each intersection. *j2735_2016.messageId == 18* The reference laneWidth was displayed as a column. All intersections included a reference laneWidth of 366 in the MAP message.

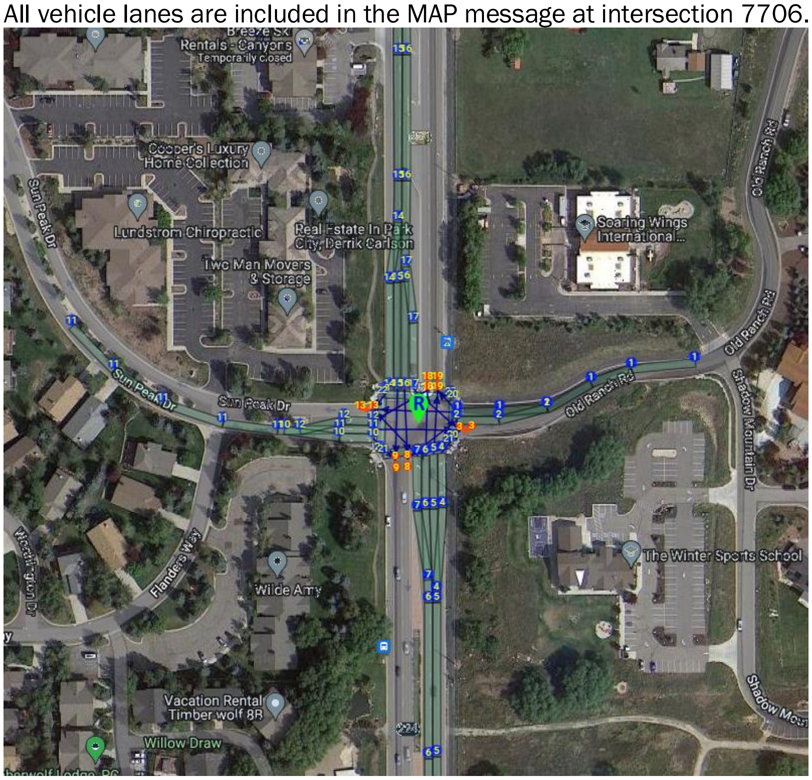
No.	Epoch Time	messageId	id	laneWidth
17	2022-08-17 16:25:20.374714	mapData	7706	366

Requirement	**3.3.3.4.1.6 Lane Identifier**
Objective	Verify lane id values are unique and in correct range
Method	Use Wireshark to view pcap files. Apply filter to only look at MAP messages (j2735_2016.messageId == 18). Display 'laneID' as a column.
Pass Criteria	All laneId values in the laneID list are unique.
Results and Explanation	This requirement is considered to be **met** for all intersections. The following query was applied as a filter in Wireshark for data coming from each intersection. *j2735_2016.messageId == 18* The laneID data element was displayed as a column (note that laneID elements from different lanes are separated by a comma). All intersections included unique laneID values in the correct range.

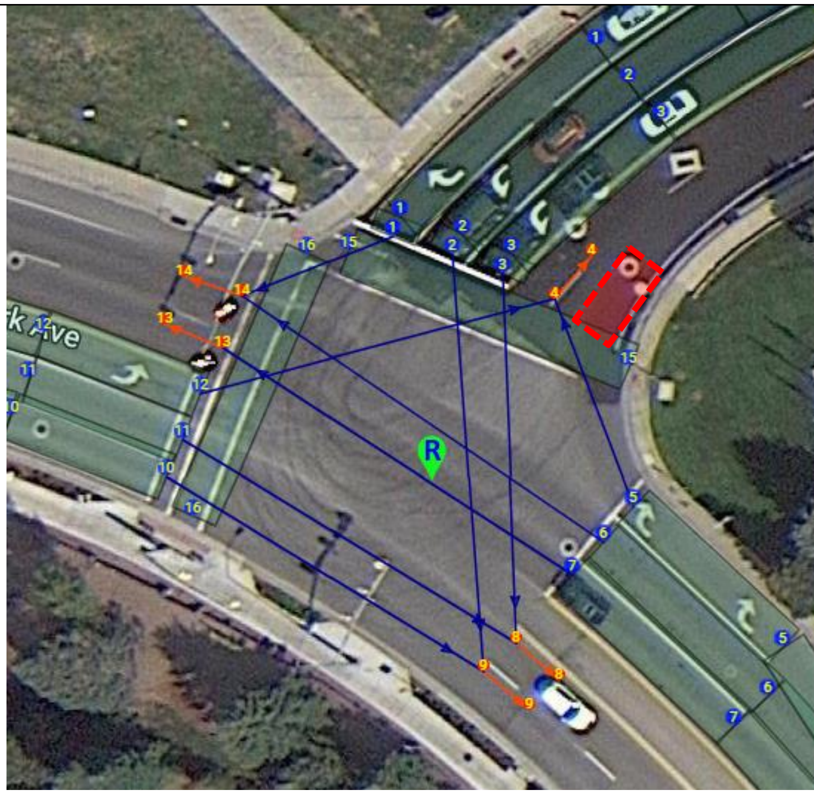
No.	Epoch Time	messageId	id	laneID
52691	2022-08-17 17:05:00.832784	mapData	7707	1,2,3,5,6,4,7,8,9,10,11,12,13,14,15,16,17,18,19,20,23,24,21,22
52722	2022-08-17 17:11:57.387741	mapData	7720	1,2,3,5,6,4,7,8,9,10,11,12,14,15,13,16,17,18,19,20

Requirement	**3.3.3.4.1.7 Center of Vehicle Lane Geometry**
Objective	Verify vehicle lane coverage
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The location of vehicle lanes is compared against satellite imagery.
Pass Criteria	The MAP message lane geometry data is visualized and compared against a visual ground survey or an up-to-date satellite image of vehicle lanes. All ingress and egress lanes should be

	present in the MAP message. (note: accuracy of lane points are verified in a different requirement)
Results and Explanation	This requirement is considered to be **met** for intersections 7706, 7707, 7708, 7709, and 7720. This requirement is considered to be **partially met** for intersection 7710. All vehicle travel lanes are represented in all MAP messages at all intersections. The only exception to this is Intersection 7710, where the MAP message indicates a single egress lane on Kearns Blvd, while satellite imagery indicates there should be two egress lanes. This is shown in the image below. Field observations support the relative correctness of the satellite imagery. All vehicle lanes are included in the MAP message at intersection 7706.



Egress lane missing in the MAP message at Intersection 7710 (red highlight):



One unique roadway operation feature that is not currently captured in the MAP message are the bus only lanes that extend beyond the beginning of the northbound and southbound right turn lanes at intersection 7706 and 7707. Signage along SR-224 indicates that the right lane is a bus only lane (though lane markings suggest operations may more closely resemble a bus-on-shoulder) where traffic is allowed to make right turns at locations where signage and lane markings suggest. One potential benefit of indicating the bus-only portion of the right lane in the MAP message would be for enabling CV applications such as RLVW and TSP for buses using the shoulder. An OBU will typically use lane geometry to know when to provide information to the driver or when to send a priority request in an SRM. The ability to place a vehicle in a lane further upstream of the stop line will likely enhance operations of these applications for equipped buses when using these lanes.

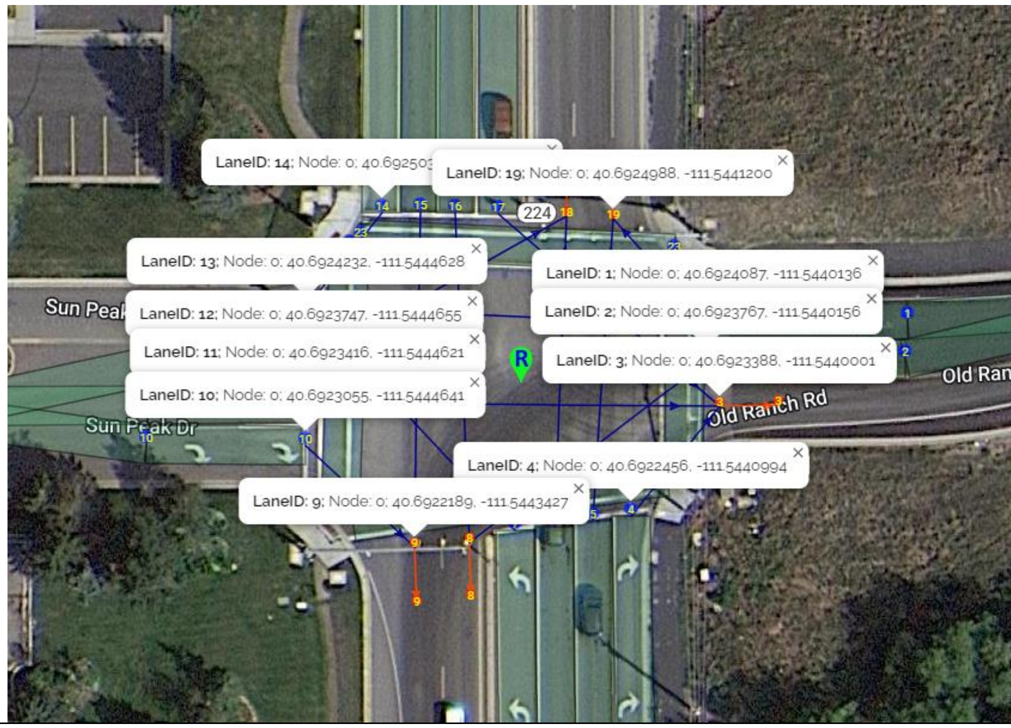
Requirement	3.3.3.4.1.8 Center of Crosswalk Lane Geometry
Objective	Verify crosswalk lane coverage
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The location of crosswalk lanes is compared against satellite imagery.
Pass Criteria	The MAP message crosswalk geometry data is visualized and compared against a visual ground survey or an up-to-date satellite image of crosswalks. All crosswalk lanes should be present in the MAP message. (note: accuracy of crosswalk points are verified in a different requirement)
Results and Explanation	This requirement is considered to be **met** for all intersections. All crosswalks are represented as crosswalk lanes in all MAP messages at all intersections.

Requirement	3.3.3.4.1.9 Center of Pedestrian Landings Geometry
Objective	Verify sidewalk lane coverage
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The location of sidewalk lanes is compared against satellite imagery.
Pass Criteria	The MAP message pedestrian landings (sidewalk) geometry data is visualized and compared against a visual ground survey or an up-to-date satellite image of pedestrian landings. All landings (sidewalk lanes) should be present in the MAP message. (note: accuracy of sidewalk points are verified in a different requirement)
Results and Explanation	This requirement is considered to be **not met** for all intersections. Landings (sidewalk lanes) are not included in MAP messages at any intersection. Satellite imagery indicates that all intersections have crosswalks (and landings) across most approaches.

Requirement	3.3.3.4.1.10 Lane Description
Objective	Verify minimum number of points required to define lane
Method	Use Wireshark to view pcap files. Apply filter to only look at MAP messages (j2735_2016.messageId == 18). Display 'nodes' as a column (displays the number of nodes in each lane).
Pass Criteria	This requirement is considered satisfied if there are two or more points defined for each lane.
Results and Explanation	This requirement is considered to be **met** for all intersections. The following query was applied as a filter in Wireshark for data coming from each intersection. *j2735_2016.messageId == 18* The number of nodes was displayed as a column (note that the number of nodes for different lanes are separated by a comma). All intersections included lanes with a number of nodes that range between 2 and 63 - the allowable range of values.

No.	Epoch Time	messageId	id	nodes
52691	2022-08-17 17:05:00.832784	mapData	7707	5,3,2,6,6,3,5,2,2,4,6,6,6,2,6,6,3,2,2,3,6,2,2,3
52722	2022-08-17 17:11:57.387741	mapData	7720	8,5,2,9,9,4,7,2,2,4,3,2,8,8,5,6,2,2,2,2

Requirement	3.3.3.4.1.11 First Node Point - Ingress Vehicle Lane
Objective	Verify first node point is close to intersection
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. Clicking on each node provides information regarding node order.
Pass Criteria	The first node point of an ingress vehicle lane is located at the upstream edge of the stop line. In the absence of a stop line, the first node point is located on the upstream edge of a crosswalk marking. In the absence of a stop line and crosswalk marking, the first node point is located using engineering judgement

Results and Explanation	This requirement is considered to be **met** for all intersections. The intersection centerpoint and a sequence of points for ingress and egress lanes is placed on a satellite image. It is then determined that the first point of every lane is the closest to the intersection centerpoint, and sequentially increases as each lane moves away from the center. The CAMP tool is used to perform this assessment. The lane centerline points can be clicked on to view an information bubble showing the point order. Egress lanes (red lines) have an arrow that indicates direction. The visual representation from the CAMP tool is provided in the image below fore intersection 7720. An information bubble is shown for the first point of several lanes in the image, each of which indicates "Node: 0". 

Requirement	**3.3.3.4.1.12 First Node Point - Egress Vehicle Lane**
Objective	Verify first node point is close to intersection
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. Clicking on each node provides information regarding node order.
Pass Criteria	The first node point of an egress vehicle lane is located at the downstream edge of the crosswalk marking. In the absence of crosswalk markings, the first node point is located with engineering judgement to represent the point immediately outside the intersection and any path that pedestrians might use to cross the intersection
Results and Explanation	This requirement is considered to be **met** for all intersections. See explanation for 3.3.3.4.1.11.

Requirement	**3.3.3.4.1.13 Node Offset from Intersection Reference Point**
Objective	Verify use of smallest offset type

<table>
<tr><td>Method</td><td>Use Wireshark to view pcap files. Extract the node offset point xy choice (node-XY-1 through node-XY-6), the x offset value and the y offset value from each specified node point in the MAP message</td></tr>
<tr><td>Pass Criteria</td><td>To be compliant with the requirement, the offset type that should be used is as follows:
<table>
<tr><th>Offset Type (choice value)</th><th>Offset Range</th><th>Size</th></tr>
<tr><td>node-xy1 (0)</td><td>< 5.11m</td><td>20 bits</td></tr>
<tr><td>node-xy2 (1)</td><td>5.12 – 10.23 m</td><td>22 bits</td></tr>
<tr><td>node-xy3 (2)</td><td>10.24 – 20.47m</td><td>24 bits</td></tr>
<tr><td>node-xy4 (3)</td><td>20.48 – 40.96m</td><td>26 bits</td></tr>
<tr><td>node-xy5 (4)</td><td>40.97 – 81.91m</td><td>28 bits</td></tr>
<tr><td>node-xy6 (5)</td><td>81.92 – 327.67m</td><td>32 bits</td></tr>
</table></td></tr>
<tr><td>Results and Explanation</td><td>This requirement is considered to be met for all intersection.

The offset type used is not larger than what is minimally required for the first node for all lanes at intersections.</td></tr>
</table>

<table>
<tr><td>Requirement</td><td>3.3.3.4.1.14 Node Elevation Offset from Intersection Reference Point</td></tr>
<tr><td>Objective</td><td>Verify use of elevation offset (if necessary)</td></tr>
<tr><td>Method</td><td>Use Wireshark to view pcap files. Extract the reference elevation and the elevation offset for the initial node point. This is compared to a surveyed elevation (if available) for accuracy.</td></tr>
<tr><td>Pass Criteria</td><td>An elevation offset (from the intersection reference point) shall be used to specify the first elevation point of each geometry. If the elevation does not change, this data element shall not be present.</td></tr>
<tr><td>Results and Explanation</td><td>This requirement could not be tested at all intersections, as a survey was not performed to obtain ground truth elevation data.

MAP messages for all intersections contained a reference elevation, but never contained elevation offset data (dElevation) for any nodes. While the elevation offset data is optional, this indicates that the elevation of the lanes should be the same as the reference elevation, which is not the case for a number of approaches. However, since a survey was not performed, the elevation data in the messages could not be compared to ground truth to confirm this notion.</td></tr>
</table>

<table>
<tr><td>Requirement</td><td>3.3.3.4.1.15 Offset from Previous Node</td></tr>
<tr><td>Objective</td><td>Verify use of elevation offset (if necessary)</td></tr>
<tr><td>Method</td><td>Use Wireshark to view pcap files. Extract the reference elevation and the elevation offset for the initial node point. This is compared to a surveyed elevation (if available) for accuracy.</td></tr>
<tr><td>Pass Criteria</td><td>To be compliant with the requirement, the offset type that should be used for each node is as follows:
<table>
<tr><th>Offset Type (choice value)</th><th>Offset Range</th><th>Size</th></tr>
<tr><td>node-xy1 (0)</td><td>< 5.11m</td><td>20 bits</td></tr>
<tr><td>node-xy2 (1)</td><td>5.12 – 10.23 m</td><td>22 bits</td></tr>
<tr><td>node-xy3 (2)</td><td>10.24 – 20.47m</td><td>24 bits</td></tr>
<tr><td>node-xy4 (3)</td><td>20.48 – 40.96m</td><td>26 bits</td></tr>
<tr><td>node-xy5 (4)</td><td>40.97 – 81.91m</td><td>28 bits</td></tr>
<tr><td>node-xy6 (5)</td><td>81.92 – 327.67m</td><td>32 bits</td></tr>
</table></td></tr>
<tr><td>Results and Explanation</td><td>This requirement is considered to be met for all intersections.

The offset type used is not larger than what is minimally required for all subsequent nodes for all lanes at all intersections.</td></tr>
</table>

Requirement	3.3.3.4.1.16 Elevation Offset from Previous Node
Objective	Verify use of elevation offset (if necessary)
Method	Use Wireshark to view pcap files. Extract the reference elevation and the elevation offset for subsequent nodes. This is compared to a surveyed elevation (if available) for accuracy.
Pass Criteria	An elevation offset (from a previously defined point) shall be used to specify the first elevation point of each geometry. If the elevation does not change, this data element shall not be present.
Results and Explanation	This requirement **could not be tested** at all intersections, as a survey was not performed to obtain ground truth elevation data. See explanation and discussion for 3.3.3.4.1.14.

Requirement	3.3.3.4.1.17 Advanced Notification - Ingress Vehicle Lane
Objective	Verify length of lane
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The overall length of each ingress lane is provided. This length is compared to the required length (a function of the speed limit on each approach).
Pass Criteria	The cumulative distance along the line generated by all points (in the correct order) is greater than the distance (as a function of the speed limit) specified in the requirement.
Results and Explanation	This requirement is considered to be **partially met** for all intersections. The CAMP tool was used to obtain the cumulative distance of all ingress lanes (from stop line to upstream-most point). This distance is compared to the minimum advanced notification distance (in meters = (observed speed limit [mph] + 7)*4.469) to determine if each lane is sufficiently long. An exception was given for lanes that could not be extended any further – either because they would spill back into the conflict zone of another signalized intersection, or it had reached the beginning of the lane (i.e., a turn lane). The results of this analysis are provided in Appendix D. There are instances at each intersection where lanes are of sufficient length or are not of sufficient length but cannot be extended any further. However, there are also instances at each intersection where a lane was not sufficiently long and could have been extended further. The list of lanes below should be extended to meet the lane length requirement: • Intersection 7706, Lane 1, 5, 6, 15, 16 • Intersection 7707, Lane 1, 5, 6, 11, 12, 13, 15, 16 • Intersection 7720, Lane 1, 10 • Intersection 7708, Lane 1 • Intersection 7709, Lane 2, 6, 7, 11 • Intersection 7710, Lane 1, 2, 6, 7, 10, 11

Requirement	3.3.3.4.1.18 End Nodes - Crosswalk Lane
Objective	Verify location of crosswalk endpoints
Method	Processed Survey data (crosswalk ground truth) are compared against MAP message crosswalk lane centerline using a geographic information systems tool.
Pass Criteria	The ends of the centerline of a crosswalk correspond with the location of a curb or landing. Order of crosswalk points can be defined in either direction. Note: It may be difficult to have the center of a crosswalk located along a curb while accurately defining the width of the crosswalk throughout its entire length
Results and Explanation	This requirement **could not be tested** at all intersections, as a survey was not performed to obtain ground truth crosswalk location data.

Requirement	3.3.3.4.1.19 End Nodes - Pedestrian Landing
Objective	Verify location of pedestrian landings
Method	Processed Survey data (sidewalk ground truth) are compared against MAP message sidewalk lane centerline using a geographic information systems tool.
Pass Criteria	The ends of the landing (sidewalk) correspond with the location of a crosswalk. Order of landing (sidewalk) points can be defined in either direction. Note: Center of pedestrian landing is not always at the center of the end of the crosswalk
Results and Explanation	This requirement **could not be tested** at all intersections, as a survey was not performed to obtain ground truth crosswalk location data, and sidewalks were not included in any MAP messages.

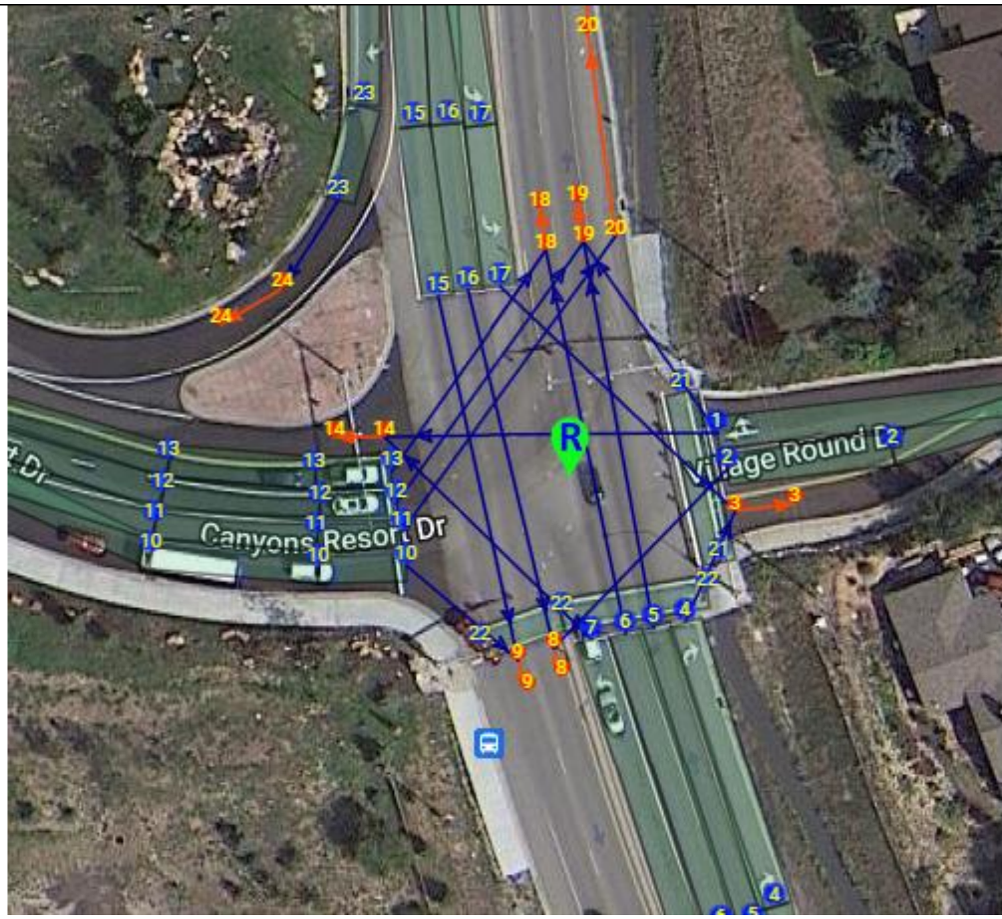
Requirement	3.3.3.4.1.20 Maximum Distance between Nodes
Objective	Verify location of lane centerline
Method	Processed Survey data (lane centerline ground truth) are compared against MAP message lane centerline using a geographic information systems tool.
Pass Criteria	Distance between the MAP lane centerline (line connecting subsequent nodes) and the actual surveyed centerline does not exceed 0.5 meters.
Results and Explanation	This requirement **could not be tested** at all intersections, as a survey was not performed to obtain ground truth lane centerline data Note that the chord distance (between successive lane geometry points) should not exceed a maximum value $2r\sqrt{1-\left(1-\frac{1.64}{r}\right)^2}$. Spacing lane points that are greater than this distance apart is an indication that the actual curve lane centerline will be greater than 0.5 meters away from the straight line that connects the two points (assuming the two points are exactly on the actual lane centerline.

Requirement	3.3.3.4.1.21 Maximum Number of Nodes
Objective	Verify maximum number of points required to define lane
Method	Use Wireshark to view pcap files. Apply filter to only look at MAP messages (j2735_2016.messageId == 18). Display 'nodes' as a column (displays the number of nodes in each lane).
Pass Criteria	This requirement is considered satisfied if there are 63 or fewer points defined for each lane.
Results and Explanation	This requirement is considered to be **met** for all intersections. See explanation for 3.3.3.4.1.10.

Requirement	3.3.3.4.1.22 Node Lane Width
Objective	Verify lane width matches actual lane width
Method	Processed Survey data (lane width) are compared against MAP message lane centerline widths using a geographic information systems tool.
Pass Criteria	Lane width at each node in MAP message roughly matches actual lane width. Note: Validating this requirement is difficult, as the requirement does not specify the acceptable tolerance for the value of the lane width at a given point.
Results and Explanation	This requirement **could not be tested** at all intersections, as a survey was not performed to obtain ground truth lane width data

Requirement	3.3.3.4.1.23 Node Accuracy
Objective	Verify location of lane centerline
Method	Processed Survey data (lane centerline ground truth) are compared against MAP message lane centerline using a geographic information systems tool.
Pass Criteria	Satisfied if the distance between each MAP lane node and the actual surveyed centerline does not exceed 0.2 meters.
Results and Explanation	This requirement **could not be tested** at all intersections, as a survey was not performed to obtain ground truth lane centerline data

Requirement	3.3.3.4.2.1 Direction of Travel
Objective	Verify direction of travel
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. Ingress and egress lanes are shown in different colors on the tool
Pass Criteria	Ingress lanes in the CAMP tool are colored green and should roughly correspond to lanes approaching the intersection in the satellite imagery. Egress lanes in the CAMP tool are colored red and should roughly correspond to lanes moving away from the intersection in the satellite imagery.
Results and Explanation	This requirement is considered to be **met** for all intersections A visualization of the order of points in the MAP message and the directional use data element are overlaid on a satellite image to determine if the lane direction is properly specified. The points should be ordered starting with the closest point to the intersection and moving away. A directional use hex value of 80 (binary 1000 0000) indicates an ingress lane, which means the direction of travel is the opposite of the order of points. A directional use hex value of 40 (binary 0100 0000) indicates an egress lane, which means the direction of travel is the same as the order of points. All lanes have the correct directional use specified. The image below shows intersection 7707, ingress lanes in green, and egress lanes in red. All vehicle lane directions of travel are properly specified.



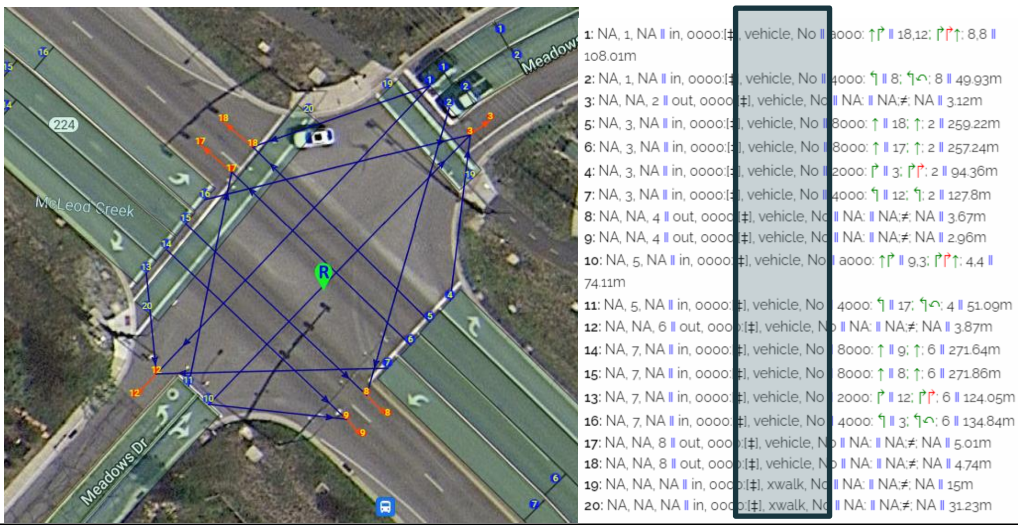
<table>
<tr><td>Requirement</td><td>3.3.3.4.2.2 Lane Sharing</td></tr>
<tr><td>Objective</td><td>Verify accuracy of laneSharing element</td></tr>
<tr><td>Method</td><td>The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool indicates the lane sharing values for each lane, and also provides an overlay of each lane geometry on satellite imagery. The lane sharing values for each lane are compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.</td></tr>
<tr><td>Pass Criteria</td><td>Modes are properly specified for each lane.</td></tr>
<tr><td>Results and Explanation</td><td>This requirement is considered to be not met for all intersections.

Every vehicle ingress lane has lane sharing specified. A summary of lane sharing values observed is shown below along with the interpretation:

<table>
<tr><th colspan="2">Lane Sharing</th><th rowspan="2">interpretation</th></tr>
<tr><th>hex</th><th>binary</th></tr>
<tr><td>0000</td><td>0000 0000 00.. ....</td><td>lane not shared</td></tr>
</table>

All vehicular travel lanes exhibit a sharedWith value of 0000, which indicates the lane is not shared. However, most lanes are shared by a number of modes: motorized vehicles, buses, and potentially bicyclists. The only exception to this is at intersection 7707, lane 11 and lane 20. These lanes are restricted to transit use only.</td></tr>
</table>

Requirement	3.3.3.4.2.3 Lane Type Attributes

Objective	Verify accuracy of LaneTypeAttributes element
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool indicates the lane type attributes values for each lane, and also provides an overlay of each lane geometry on satellite imagery. The lane type attributes values for each lane are compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.
Pass Criteria	The choice selected properly reflects the use of each lane.
Results and Explanation	This requirement is considered to be **met** for all intersections. All lanes specified have at least one associated laneType. Specifically, every lane in the MAP message at every intersection is specified either as a laneType of vehicle or crosswalk. MAP lanes that exhibit a laneType value of 'vehicle' match the travel lanes, and MAP lanes that exhibit a laneType value of 'crosswalk' match the location of crosswalks. Intersection 7720, shown in the example below indicates all vehicle travel lanes, except for lanes 19 and 20, which correspond to the crosswalks on the visualization. 

Requirement	**3.3.3.4.2.4 Lane Attributes - Vehicle**
Objective	Verify accuracy of LaneTypeAttributes element
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool indicates the lane type attributes values for each lane, and also provides an overlay of each lane geometry on satellite imagery. The lane type attributes values for each lane are compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.
Pass Criteria	Lane attributes are properly specified for each vehicle lane. (only for vehicle lane type)
Results and Explanation	This requirement is considered to be **met** for all intersections. Every vehicle laneType has lane attributes specified. A value of all zeros properly reflects ground conditions (not revocable, not a flyover lane, not HOV, not restricted to bus/taxi, not restricted from public use, does not have IR beacon coverage, and does not provide permission upon request). Two notable exceptions to this are noted at intersection 7707. Vehicle lane type attributes for ingress lane 11 indicate this is 'restricted to bus use' and is 'restricted from public use'. Vehicle lane type attributes for egress lane 20 indicate this is only 'restricted to bus use.' These lanes represent the transit only left turn ingress and egress lanes at Intersection

	7707. Given the presence of "Bus Only" type of signage for the left turn and for the rightmost lane on SR-224, it should be considered if the vehicle lane type attributes for lane 11 and lane 20 should be the same for consistency. Examples of signage present for ingress lane 11 (left) and egress lane 20 (right) are provided in the images below. 

Requirement	**3.3.3.4.2.5 Lane Attributes - Crosswalk**
Objective	Verify accuracy of LaneTypeAttributes element
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool indicates the lane type attributes values for each lane, and also provides an overlay of each lane geometry on satellite imagery. The lane type attributes values for each lane are compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.
Pass Criteria	Lane attributes are properly specified for each crosswalk lane. (only for crosswalk lane type)
Results and Explanation	This requirement is considered to be **partially met** for all intersections. Every crosswalk laneType has lane attributes specified. A value of all zeros does not properly reflect ground conditions. The crosswalk is not revocable, not bicycle use allowed, not a flyover, not a fixed cycle time, not bi-directional cycle times, no audio support, does not support RF push to walk technology, and there are no unsignalized segments present. However, since all specified crosswalks all have a push-to-walk button, bit 5 of the bit string should be asserted.

Requirement	**3.3.3.4.2.6 Lane Attributes - Bicycle**
Objective	Verify accuracy of LaneTypeAttributes element
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool indicates the lane type attributes values for each lane, and also provides an overlay of each lane geometry on satellite imagery. The lane type attributes values for each lane are compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.
Pass Criteria	Lane attributes are properly specified for each bicycle lane. (only for bicycle lane type)
Results and Explanation	This requirement is considered **not applicable** for all intersections. None of the intersections have bicycle lanes on any approaches.

Requirement	**3.3.3.4.2.7 Lane Attributes - Tracked Vehicles**
Objective	Verify accuracy of LaneTypeAttributes element
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool indicates the lane type attributes values for each lane, and also provides an overlay of each lane geometry on satellite imagery. The lane type attributes values for each lane are compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.
Pass Criteria	Lane attributes are properly specified for each tracked vehicle lane. (only for tracked vehicle lane type)
Results and Explanation	This requirement is considered **not applicable** for all intersections. None of the intersections have tracked vehicle lanes on any approaches.

Requirement	**3.3.3.4.2.8 Lane Attributes - Parking**
Objective	Verify accuracy of LaneTypeAttributes element
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool indicates the lane type attributes values for each lane, and also provides an overlay of each lane geometry on satellite imagery. The lane type attributes values for each lane are compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.
Pass Criteria	Lane attributes are properly specified for each parking lane. (only for parking lane type)
Results and Explanation	This requirement is considered **not applicable** for all intersections. None of the intersections have parking lanes on any approaches.

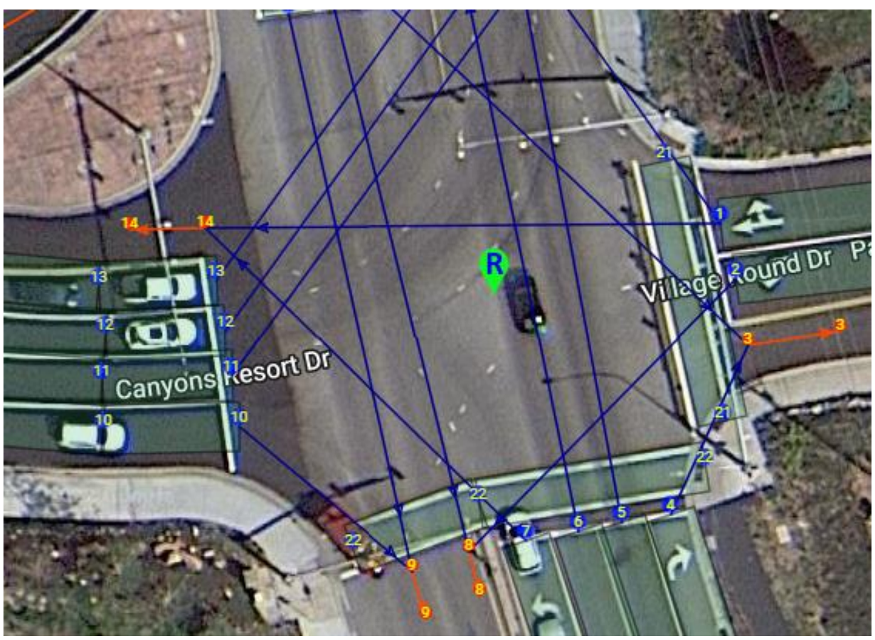
Requirement	**3.3.3.4.3 Lane Maneuvers**
Objective	Verify accuracy of allowedManeuvers element
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool indicates the lane maneuvers values for each lane, and also provides an overlay of each lane geometry on satellite imagery. The lane maneuvers values for each lane are compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.
Pass Criteria	The correct maneuvers and restrictions are present for each specified lane.
Results and Explanation	This requirement is considered to be **partially met** for all intersections. Every vehicle ingress lane has maneuvers specified. A summary of maneuvers values observed is shown below along with the interpretation:

Maneuvers		**Interpretation**
hex	**binary**	
2000	0010 0000 0000 0000	maneuverRightAllowed
4000	0100 0000 0000 0000	maneuverLeftAllowed
8000	1000 0000 0000 0000	maneuverStraightAllowed
a000	1010 0000 0000 0000	maneuverStraightAllowed, maneuverRightAllowed

All ingress lanes contain the allowed maneuvers data element. Most are specified correctly, exceptions provided in the bulleted list below.

- In general, the 'Right Turn on Red Allowed' flag should be asserted at the lane level for all right turn lanes at all intersections.

	• For each left turn, determine if U-turns are allowed. If so, assert 'U-turn allowed' bit. If a u-turn is allowed, then a connection corresponding to this movement should be added. State law, local law, and signage do not prohibit u turns at all intersections Once modifications have been made, each lane level allowed maneuvers element should be compared against associated connection level allowed maneuvers elements. The union of all connection level allowed maneuvers is the expected allowed maneuvers value for at the lane level. For example, if a lane has a connection where a right turn is allowed and a right turn on red is allowed, and another connection where a through movement is allowed, the lane level allowed maneuvers would indicate that a through movement is allowed, right turn movement is allowed, and a right turn on red is allowed.

Requirement	**3.3.3.4.4.1 Lane Connections**
Objective	Verify accuracy of Connections elements
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool provides an overlay of connections between lanes on satellite imagery. The connection (ingress-to-ingress or ingress-to-egress) is compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.
Pass Criteria	There are no travel paths represented as connections that are missing.
Results and Explanation	This requirement is considered to be **met** for intersections 7706, 7708, 7709, 7710, and 7720. This requirement is considered to be **partially met** for intersection 7707. Vehicle ingress lanes have connections specified to correct egress lanes. There is one instance where a connection is missing for intersection 35104. An inspection of intersection 7707 MAP message (overlaid on satellite imagery) shows that a connection should be added from lane 10 to lane 3 corresponding to the westbound through movement. The connection is missing in the image below. 

	For all intersections, if a u-turn is allowed, then a connection corresponding to this movement should be added. State law, local law, and signage do not prohibit u turns at all intersections. Note: Once an egress lane is added to intersection 7710, the connections for the right turn (from lane 5) and left turn (from lane 12) should be checked to ensure the correct egress lane is specified for each connection.

Requirement	**3.3.3.4.4.2 Connection Egress Lane**
Objective	Verify the specification of an egress lane for each connection
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool provides an overlay of connections between lanes on satellite imagery. The connection (ingress-to-ingress or ingress-to-egress) is compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.
Pass Criteria	Verify the specification of an egress lane for each connection
Results and Explanation	This requirement is considered to be **met** for all intersections. All connections in MAP messages at all intersections include the lane data element in the connecting lane data frame (which represents the lane that is being connected to). The image below provides an example at intersection 7706 lane 1 which has two connections – one that connects to lane 19 and the other that connects to lane 13.


```
v laneSet: 23 items
  v Item 0
    v GenericLane
        laneID: 1
        ingressApproach: 1
      > laneAttributes
        maneuvers: a000 [bit length 12, 4 LSB pad bits, 1010 0000  0000 .... decimal value 2560]
      > nodeList: nodes (0)
      v connectsTo: 2 items
        v Item 0
          v Connection
            v connectingLane
                lane: 19
                maneuver: 2400 [bit length 12, 4 LSB pad bits, 0010 0100  0000 .... decimal value 576]
              signalGroup: 8
        v Item 1
          v Connection
            v connectingLane
                lane: 13
                maneuver: 8000 [bit length 12, 4 LSB pad bits, 1000 0000  0000 .... decimal value 2048]
              signalGroup: 8
```


Requirement	**3.3.3.4.4.3 Connection Maneuvers**
Objective	Verify accuracy of allowedManeuvers element for each connection
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool indicates the lane maneuvers values for each connection, and also provides an overlay of each lane geometry on satellite imagery. The connection maneuvers values for each connection are compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.
Pass Criteria	The correct maneuvers and restrictions are present for each specified connection.
Results and Explanation	This requirement is considered to be **partially met** for all intersections. All connections have allowed maneuvers specified. A summary of maneuvers values observed is shown below along with the interpretation:

Maneuvers		Interpretation
hex	binary	

	2000	0010 0000 0000 0000	maneuverRightAllowed
	2400	0010 0100 0000 0000	maneuverRightAllowed, maneuverRightTurnOnRedAllowed
	4000	0100 0000 0000 0000	maneuverLeftAllowed
	5000	0101 0000 0000 0000	maneuverLeftAllowed, maneuverUTurnAllowed
	8000	1000 0000 0000 0000	maneuverStraightAllowed

If the assertion of the 'U-turn allowed' flag on left turn connections. If a U turn from this lane is permitted, then a new connection associated with the U turn movement needs to be added. The allowed maneuvers data element would assert the 'left turn allowed' bit for the left turn connection and the 'U turn allowed' bit for the U turn connection.

in many cases, the allowed maneuvers for a given connection is not properly reflected in the allowed maneuvers for the lane. If a given bit is asserted in a connection, then the same bit should also be asserted for the allowed maneuvers of the ingress lane associated with that connection.

Once modifications have been made, each lane level allowed maneuvers element should be compared against associated connection level allowed maneuvers elements. The union of all connection level allowed maneuvers is the expected allowed maneuvers value for at the lane level. For example, if a lane has a connection where a right turn is allowed and a right turn on red is allowed, and another connection where a through movement is allowed, the lane level allowed maneuvers would indicate that a through movement is allowed, right turn movement is allowed, and a right turn on red is allowed.

Requirement	**3.3.3.4.4.4 Connection Signal Group**
Objective	Verify specification of the signalGroup element for each connection
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool indicates the signal group values for each connection, and also provides an overlay of each lane geometry on satellite imagery. The signal group values for each connection are compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.
Pass Criteria	The signalGroup data element is populated for each specified connection.
Results and Explanation	This requirement is considered to be **met** for all intersections. A signal groups is specified for each connection in MAP messages at all intersections. The image below provides an example at intersection 7706 lane 1 which has two connections – both of which are controlled by signal group 8.

```
laneSet: 23 items
  Item 0
    GenericLane
      laneID: 1
      ingressApproach: 1
      laneAttributes
      maneuvers: a000 [bit length 12, 4 LSB pad bits, 1010 0000  0000 .... decimal value 2560]
      nodeList: nodes (0)
      connectsTo: 2 items
        Item 0
          Connection
            connectingLane
              lane: 19
              maneuver: 2400 [bit length 12, 4 LSB pad bits, 0010 0100  0000 .... decimal value 576]
            signalGroup: 8
        Item 1
          Connection
            connectingLane
              lane: 13
              maneuver: 8000 [bit length 12, 4 LSB pad bits, 1000 0000  0000 .... decimal value 2048]
            signalGroup: 8
```


Requirement	3.3.3.4.4.5 Include Only Permitted Connections
Objective	Verify that all connections reflect actual vehicle travel paths
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The tool provides an overlay of connections between lanes on satellite imagery. The connection (ingress-to-ingress or ingress-to-egress) is compared against ground truth in the satellite imagery, street view images, or on-the-ground observations.
Pass Criteria	The connection (ingress-to-ingress or ingress-to-egress) is compared against a visual inspection of the intersection. The specified connections reflect actual paths travel through the intersection.
Results and Explanation	This requirement is considered to be **met** for all intersections. All connections specified in the connectsTo data frame do not include connections that are not permitted.

Requirement	3.3.3.4.5.1 Default Speed Limit
Objective	Verify inclusion of default speed limit data
Method	Use Wireshark to view pcap files. Apply filter to only look at MAP messages (j2735_2016.messageId == 18). Display 'type' and 'speed' as a column (displays the type of speed limit and the speed value).
Pass Criteria	There is at least one RegulatorySpeedLimit entry in the SpeedLimitList. SpeedLimitType and Velocity data elements shall both be specified. A minimum of one entry must indicate a value of 'vehicleMaxSpeed' for the SpeedLimitType.
Results and Explanation	This requirement is considered to be **not met** for all intersections. Reference speed limits are not included in the speed limit list in the intersection geometry data frame. A regulatory speed limit (type: 'vehicleMaxSpeed') should be included in the IntersectionGeometry data frame in MAP messages at all intersections. Ideally, the speed specified should be for one or the roadways at the intersection. Note: variations to the default speed limit can be specified at lane node offset points.

Requirement	3.3.3.4.5.2 Change in Lane Speed Limit
Objective	Verify inclusion of speed limit data (if speed limit is different than default or if speed limit changes)

Method	Use Wireshark to view pcap files. Apply filter to only look at MAP messages (j2735_2016.messageId == 18). Display 'type' and 'speed' as a column (displays the type of speed limit and the speed value).
Pass Criteria	There is at least one RegulatorySpeedLimit entry in the SpeedLimitList. SpeedLimitType and Velocity data elements shall both be specified. The velocity shall match the actual speed limit for the given lane. A minimum of one entry must indicate a value of 'vehicleMaxSpeed' for the SpeedLimitType. (Alternatively, if the actual speed limit is the same as the reference speed limit, then the SpeedLimitList may not be included)
Results and Explanation	This requirement is considered to be **not met** for all intersections. Change in speed limit information is not found in any of the LaneDataAttribute data frames in MAP messages for all nodes for all lanes at all intersections. This indicates that the speed limit for all approaches should be equal to the reference speed limit in the Intersection Geometry data frame which is specified as 45 mph for all intersections. However, the reference speed limit is not specified at any intersection. Once a reference speed is established, speed limit of approach lanes should be specified, but only if they differ from the reference speed limit. Note that the change in speed limit applies in the same direction that the lane is defined, not necessarily the direction that traffic moves along that lane. See CTI 4501 Section 4.3.3.4.5.2 for more details.

Requirement	3.3.3.4.6 Revocable Lanes
Objective	Verify correct use of revocable lanes when intersection conditions change.
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The location of vehicle lanes is compared against satellite imagery. Lanes that are known to exhibit different operations at different times are assessed to determine if the enabled lanes bit of the lane attributes data element is asserted.
Pass Criteria	The RevocableLanes data are visualized and compared against a visual inspection. All intersection operational states are accounted for. This test is only applicable for intersections where revocable lanes are needed (i.e., have lane-specific MAP message attributes that may change during the course of normal intersection operations).
Results and Explanation	This requirement is considered **not applicable** for all intersections. None of the intersections require the use of revocable/enabled lanes.

Requirement	3.3.3.4.7 MAP Message – Accuracy
Objective	Verify lanes in MAP messages reflect the physical location and dimensions of all travel lanes traversing the intersection.
Method	The CAMP Online Tool (https://camp-llc.org/) is used to assess this requirement. The location of vehicle lanes is compared against satellite imagery.
Pass Criteria	All ingress and egress lanes should roughly reflect the actual location of the lanes (note: accuracy of lane points are verified in a different requirement)
Results and Explanation	This requirement is considered to be **met** for all intersections. The CAMP tool was used to view lane geometries were overlayed on satellite imagery. All lanes and crosswalks specified in the MAP messages reflect actual physical geometry.

Requirement	3.3.3.4.8.1 Matching Intersection Reference Identifier
Objective	Verify that roadRegulatorId and intersectionId match between SPaT and MAP

Method	Use Wireshark to view pcap files. Apply filter to look at MAP and SPaT messages (j2735_2016.messageId == 18 || j2735_2016.messageId == 19). Display 'region' and 'id' as a column.
Pass Criteria	The road regulator identifier and the intersection identifier in both the SPaT and MAP messages broadcast from an intersection match.
Results and Explanation	This requirement is considered to be **met** for all intersections. All MAP messages can be paired with SPaT messages with corresponding road regulator identifier and intersection identifier. An example of SPaT and MAP matching road regulator identifier (region) and intersection identifier (id) is provided below. No. | Epoch Time | messageId | id | region 15 | 2022-08-17 16:25:20.311198 | signalPhaseAndTimingMessage | 7706 | 17 | 2022-08-17 16:25:20.374714 | mapData | 7706 | Note that the road regulator id (region) is not currently specified. Once established, SPaT and MAP messages should be compared to ensure the established value is reflected in both messages.

Requirement	**3.3.3.4.8.2 Matching SPaT and MAP Version**
Objective	Verify contents of the SPaT message broadcast for an intersection are compatible with the MAP message broadcasted for the same intersection
Method	Video data is reviewed to determine if the signal state information displayed on the test tool roughly corresponds to the signal indication on the actual signal head.
Pass Criteria	This requirement is verified by viewing the simultaneous video capture of the test tool and actual signal head data. The visualized signal event data from the test tool is compared to the expected event state (as would be expected based on indications from the actual signal head) for each movement. If they closely match, this requirement is considered to pass.
Results and Explanation	This requirement is considered to be **met** for intersections 7706, 7707, 7708, 7709, and 7720. This requirement is considered to be **partially met** for intersections 7710. The video capture verifies that contents of the SPaT message broadcasted for an intersection are consistent/compatible with the MAP message broadcasted for the same intersection. One exception to this was observed at intersection 7710. The connection from lane 1 to 14 currently specifies signal group 2, which is the same signal group for conflicting northbound through movements. Any other minor differences between the data in SPaT and MAP messages and the ground truth conditions are considered to be a limitation of the functionality of the current system, not a deficiency of consistency/compatibility for matching the SPaT and MAP versions.

Requirement	**3.3.3.5.1 Positioning Corrections**
Objective	Verify content of position correction payloads
Method	Use Wireshark to view pcap files. Apply filter to look at RTCM messages (j2735_2016.messageId == 28). Display '' as a column. The RTCM message payloads are reviewed to determine which RTCM message types are included
Pass Criteria	the following RTCM message types are observed: 1005, 1006, 1033, 1013.
Results and Explanation	This requirement is considered to be **partially met** for all intersections. The bulleted list of RTCM message observations indicate the details of this requirement that are met or not met:

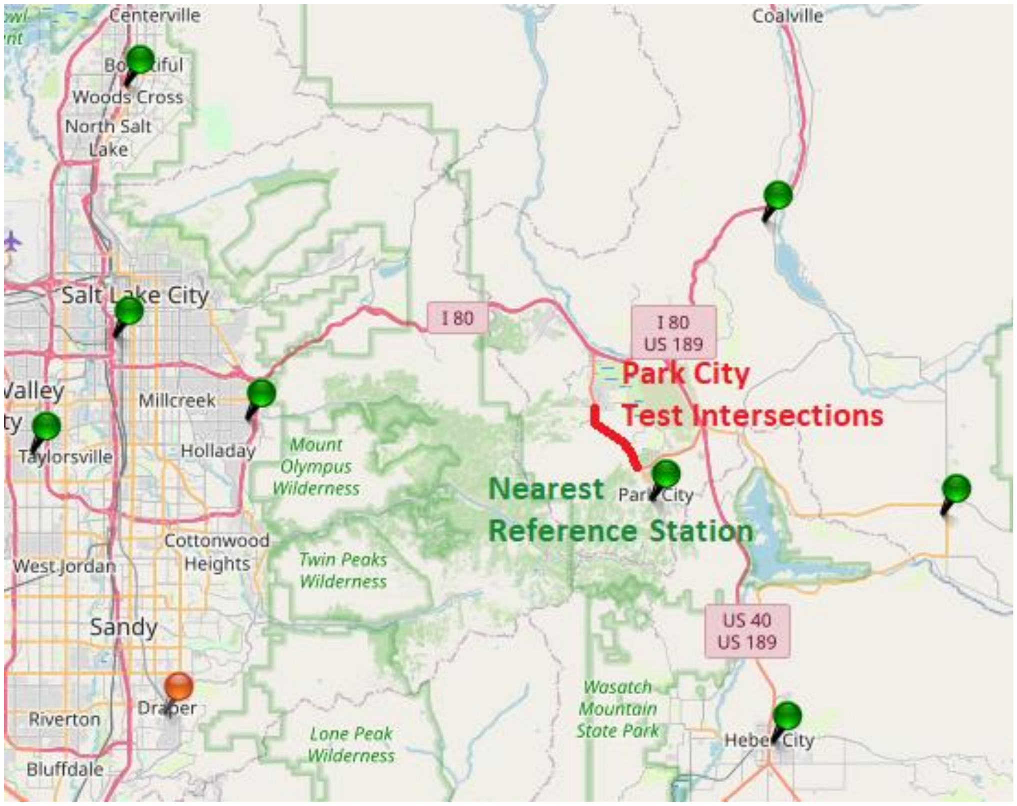
<table>
<tr>
<td></td>
<td>

The message count data element does not increment properly, as documented in the explanation for 3.3.3.2.2.7.
RTCM messages broadcast from all intersections have a revision value of rtcmRev3, which is in accordance with this requirement.
The minute of the year data element is not included in any RTCM messages from all intersections, which is in accordance with this requirement.
RTCM messages at all intersections provided a latitude, longitude, and elevation value in the anchor point data frame. However, the values provided are those of the intersection locations, not the reference station location, which is what is specified in the requirement.
RTCM messages at all intersections provided the year, month, day, hour, minute, and second in the utcTime data frame in the anchor point data frame. The values observed correspond to the time the message is sent. The time values are intended to indicate the time at which corrections information was received from the reference station.
RTCM messages at all intersections do not provide any other optional fields (other than what is specified in the above two observations) in the anchor point data frame, which is in accordance with this requirement.
RTCM messages at all intersections do not provide the RTCM header data element in the RTCM message frame, which is in accordance with this requirement.
The following RTCM message types are included in the RTCM message list in all RTCM messages:

<table>
<tr><th>Required</th><th>Observed</th></tr>
<tr><td>1006, 1013, 1033
combined into one message</td><td>1006, 1033
combined into one message

1013 not observed</td></tr>
<tr><td>1074, 1084 and/or 1124
combined into one message</td><td>1074, 1084
in separate messages</td></tr>
<tr><td>N/A</td><td>1007, 1030, 1031, 1032, 1230
In separate messages</td></tr>
</table>
To be compliant with this requirement, message type 1013, needs to be added to message types 1006 and 1033 in the same RTCM message and message types 1074 and 1084 should be included in the same RTCM message. It is not necessary to broadcast message types 1007, 1030, 1031, 1032, or 1230 to be compliant with this requirement.
</td>
</tr>
</table>

Requirement	**3.3.3.5.2.1 RSU Proximity**
Objective	Verify proximity of position correction system equipment
Method	Determine the location of reference stations in the vicinity of the intersection. Calculate the distance between each reference station and the intersection.
Pass Criteria	At least one reference station within 25 miles of the test site, or a calculated value from multiple reference stations is used.
Results and Explanation	This requirement is considered to be **met** for all intersections. There are 9 position corrections base stations within 25 miles of all 6 test intersections, as shown in the image below. One reference station to the south and east of the test intersections (located at Park City - City Hall) is 1.36 miles from the nearest intersection (7710) and 4.22 miles from the furthest intersection (7706).



http://turngps.utah.gov/Map/SensorMap.aspx

Requirement	**3.3.3.5.2.2 Minimum RTCM Corrections Broadcast Frequency**
Objective	Verify RTCM broadcast frequency
Method	Wireshark is used to export lat/lon data from the BSM and RTCM messages from each intersection. External data processing tools are used to relate RTCM messages to each BSM using timestamps. A +-500ms window around each BSM is used to search for the number received RTCM messages from each intersection. The BSM lat/long is used to display the number of RTCM messages received on a MAP. A RTCM reception map is generated for each intersection using all of the BSMs generated during the driving data capture.
Pass Criteria	RTCM messages received for all locations between the stop line and the minimum data coverage distance (a function of speed limit, upstream of each stop line) for each approach lane
Results and Explanation	This requirement is considered to be **partially met** for all intersections. All intersections broadcast the RTCM message types that are required except for message type 1013. The message types currently being broadcast from each intersection and the average rate at which they are broadcast are provided in the table below.

Expected Broadcast Rate									
Message Type	1074, 1084 *combined*		1006, 1013, 1033 *combined*		*not required*				
	< 1 Hz		1-10 Hz		-	-	-	-	-
Observed Reception Rate									
Message Type	1074	1084	1006, 1033	1013	1007	1030	1031	1032	1230

7706	0.69	0.22	0.15	-	0.99	0.99	0.99	0.97	0.075
7707	0.88	0.36	0.18	-	0.99	0.99	0.99	0.99	0.065
7720	0.98	0.77	0.14	-	0.98	0.99	0.99	0.99	0.20
7708	0.99	0.29	0.28	-	1.14	1.17	1.23	1.22	0.10
7709	0.25	0.19	0.42	-	0.99	0.99	0.99	0.80	0.13
7710	0.95	0.59	0.15	-	0.99	0.99	0.98	0.99	0.12

All intersections broadcast message types 1074 and 1084 at a rate of less than once per second which is in accordance with the broadcast rate requirement for these message types. However, observations indicate that message types 1074 and 1084 are being broadcast in separate RTCM messages. These message types are supposed to be included in the same RTCM message to be compliant with this requirement.

All intersections broadcast message types 1006 and 1033 in the same RTCM message. However, message type 1013 should also be included in the same RTCM message. Furthermore, the test intersections broadcast this RTCM message at an average rate of 0.14 to 0.42 Hz. This frequency should be between 1 and 10 times per second to be compliant with this requirement.

All intersections typically broadcast a total of 4 to 6 RTCM messages per second, at times as low as 2 per second and as high as 8 per second, the overall average of about 5 RTCM messages per second. By combining RTCM types 1006, 1013, and 1033 into the same message broadcast at once per second and combining RTCM types 1074 and 1084 into the same message broadcast once per second, the resulting average broadcast rate would be 2 RTCM messages per second – which could improve latency and periodicity issues currently experienced when RTCM messages are broadcast.

Unless critical for vehicles that maf34y be using message types 1007, 1030, 1031, 1032, and 1230, it is recommended that the transmission of RTCM messages containing these message types cease broadcast. Decreasing the number of RTCM messages broadcast may limit latency and periodicity issues experienced when RTCM messages are broadcast.

Appendix B. CAMP Online Tool Data Frames and Data Element Compliance

Note: The CAMP tool indicated that MAP and SPaT messages were not signed, however, after inspecting the pcap data in Wireshark, it was found that SPaT and MAP messages are signed.

Int Id	CAMP Online Tool MAP Report Data Summary	CAMP Online Tool SPaT Report Data Summary
7706	Msg Signed Flag: 0 (0=Unsigned, 1=Signed, 2=Verified) # of Sig Grp(s): 6; [1, 2, 4, 5, 6, 8] Sig Grp(s) & Assoc Lane ID: [1: 17]; [2: 4,5,6]; [4: 10,11,12]; [5: 7]; [6: 14,15,16]; [8: 1,2]	Message Signed Flag: 0 (0=Unsigned, 1=Signed, 2=Verified) # of Sig Group(s): 6 Sig Groups: [1, 2, 4, 5, 6, 8]
7707	Msg Signed Flag: 0 (0=Unsigned, 1=Signed, 2=Verified) # of Sig Grp(s): 8; [1, 2, 3, 4, 5, 6, 7, 8] Sig Grp(s) & Assoc Lane ID: [1: 17]; [2: 4,5,6]; [3: 2]; [4: 10]; [5: 7]; [6: 15,16,23]; [7: 11,12,13]; [8: 1]	Message Signed Flag: 0 (0=Unsigned, 1=Signed, 2=Verified) # of Sig Group(s): 8 Sig Groups: [1, 2, 3, 4, 5, 6, 7, 8]
7708	Msg Signed Flag: 0 (0=Unsigned, 1=Signed, 2=Verified) # of Sig Grp(s): 6; [1, 2, 4, 5, 6, 8] Sig Grp(s) & Assoc Lane ID: [1: 16]; [2: 4,5,6]; [4: 10,11]; [5: 7]; [6: 13,14,15]; [8: 1,2]	Message Signed Flag: 0 (0=Unsigned, 1=Signed, 2=Verified) # of Sig Group(s): 6 Sig Groups: [1, 2, 4, 5, 6, 8]
7709	Msg Signed Flag: 0 (0=Unsigned, 1=Signed, 2=Verified) # of Sig Grp(s): 4; [2, 4, 6, 8] Sig Grp(s) & Assoc Lane ID: [2: 5,6,7,8]; [4: 11,12]; [6: 14,15,16,17]; [8: 1,2,3]	Message Signed Flag: 0 (0=Unsigned, 1=Signed, 2=Verified) # of Sig Group(s): 4 Sig Groups: [2, 4, 6, 8]
7710	Msg Signed Flag: 0 (0=Unsigned, 1=Signed, 2=Verified) # of Sig Grp(s): 4; [1, 2, 4, 6] Sig Grp(s) & Assoc Lane ID: [1: 12]; [2: 1,5,6,7]; [4: 2,3]; [6: 10,11]	Message Signed Flag: 0 (0=Unsigned, 1=Signed, 2=Verified) # of Sig Group(s): 4 Sig Groups: [1, 2, 4, 6]
7720	Msg Signed Flag: 0 (0=Unsigned, 1=Signed, 2=Verified) # of Sig Grp(s): 4; [2, 4, 6, 8] Sig Grp(s) & Assoc Lane ID: [2: 4,5,6,7]; [4: 10,11]; [6: 13,14,15,16]; [8: 1,2]	Message Signed Flag: 0 (0=Unsigned, 1=Signed, 2=Verified) # of Sig Group(s): 4 Sig Groups: [2, 4, 6, 8]

CAMP Online Tool MAP Report Data Frames and Data Element Compliance (Results are same for all 6 intersections)

SAE J2735 MAP Data Frames and Elements	M/O/C in SAEJ2735	Pass/Fail J2735	M/O/C in CI Impl-RLVW	Pass/Fail CI R
messageId=DE_DSRCmsgID=18 (MAP UPER)	M	Pass	M	Pass
msgIssueRevision=DE_MsgCount	M	Pass	M	Pass
intersections=DF_IntersectionGeometryList=1 to 32 X DF_IntersectionGeometry	O	--	M	Pass
id=DF_IntersectionReferenceID	M	Pass	M	--Fail--
region=DE_RoadRegulatorID	O	--	M	--Fail--
id=DE_IntersectionID	M	Pass	M	Pass
revision=DE_MsgCount	M	Pass	M	Pass
refPoint=DF_Position3D	M	Pass	M	Pass
lat=DE_Latitude	M	Pass	M	Pass
long=DE_Longitude	M	Pass	M	Pass
elevation=DE_Elevation	O	--	M	Pass
laneWidth=DE_LaneWidth	O	--	M	Pass
speedLimits=DF_SpeedLimitList=1 to 9 x DF_RegulatorySpeedLimit	O	--	M	--Fail--
type=DE_SpeedLimitType	C	--	M	--Fail--
speed=DE_Velocity	C	--	M	--Fail--
laneSet=DF_LaneList=1 to 255 X DF_GenericLane	M	Pass	M	Pass
laneID=DE_LaneID	M	Pass	M	Pass
laneAttributes=DF_LaneAttributes	M	Pass	M	Pass
directionalUse=DE_LaneDirection	M	Pass	M	Pass
sharedWith=DE_LaneSharing	M	Pass	M	Pass
laneType=DF_LaneTypeAttributes (revocable)	M	Pass	M	Pass
maneuvers=DE_AllowedManeuvers	O	--	M	Pass
nodeList=DF_NodeListXY=Choice of DF_NodeSetXY OR DF_ComputedLane	M	Pass	M	Pass
nodes= DF_NodeSetXY=2 to 63 X DF_NodeXY	M	Pass	M	Pass
delta=DF_NodeOffsetPointXY	M	Pass	M	Pass
node-XY1=DF_Node_XY_20b	O	--	O	--
x=DE_Offset_B10	C	--	C	--
y=DE_Offset_B10	C	--	C	--
node-XY2=DF_Node_XY_22b	O	--	O	--

SAE J2735 MAP Data Frames and Elements	M/O/C in SAEJ2735	Pass/Fail J2735	M/O/C in CI Impl-RLVW	Pass/Fail CI R
x=DE_Offset_B11	C	--	C	--
y=DE_Offset_B11	C	--	C	--
node-XY3=DF_Node_XY_24b	O	--	O	--
x=DE_Offset_B12	C	--	C	--
y=DE_Offset_B12	C	--	C	--
node-XY4=DF_Node_XY_26b	O	--	O	--
x=DE_Offset_B13	C	--	C	--
y=DE_Offset_B13	C	--	C	--
node-XY5=DF_Node_XY_28b	O	--	O	--
x=DE_Offset_B14	C	--	C	--
y=DE_Offset_B14	C	--	C	--
node-XY6=DF_Node_XY_32b	O	--	O	--
x=DE_Offset_B16	C	--	C	--
y=DE_Offset_B16	C	--	C	--
attributes=DF_NodeAttributeSetXY	O	--	O	--
data=DF_LaneDataAttributeList=1 to 8 x DF_LaneDataAttribute	O	--	O	--
DF_LaneDataAttribute=Choice	O	--	C	--
speedLimits=DF_SpeedLimitList=1 to 9 X DF_RegulatorySpeedLimit	O	--	C	--
type=DE_SpeedLimitType	C	--	C	--
speed=DE_Velocity	C	--	C	--
dWidth=DE_Offset_B10	O	--	C	--
dElevation=DE_Offset_B10	O	--	C	--
computed=DF_Computed Lane	O	--	C	--
referenceLaneId=DE_LaneID	C	--	C	--
offsetXaxis=Choice	C	--	C	--
small=DE_DrivenLineOffsetSmall	O	--	O	--
large=DE_DrivenLineOffsetLarge	O	--	O	--
offsetYaxis=Choice	C	--	C	--
small=DE_DrivenLineOffsetSmall	O	--	O	--

SAE J2735 MAP Data Frames and Elements	M/O/C in SAEJ2735	Pass/Fail J2735	M/O/C in CI Impl-RLVW	Pass/Fail CI R
large=DE_DrivenLineOffsetLarge	O	--	O	--
rotateXY=DE_Angle	O	--	O	--
connectsTo=DF_ConnectsToList=1 to 16 X DF_Connection	O	--	M	Pass
connectingLane=DF_ConnectingLane	C	--	M	Pass
lane=DE_LaneID	C	--	M	Pass
maneuvers=DE_AllowedManeuver	O	--	M	Pass
signalGroup=DE_SignalGroupID	O	--	M	Pass

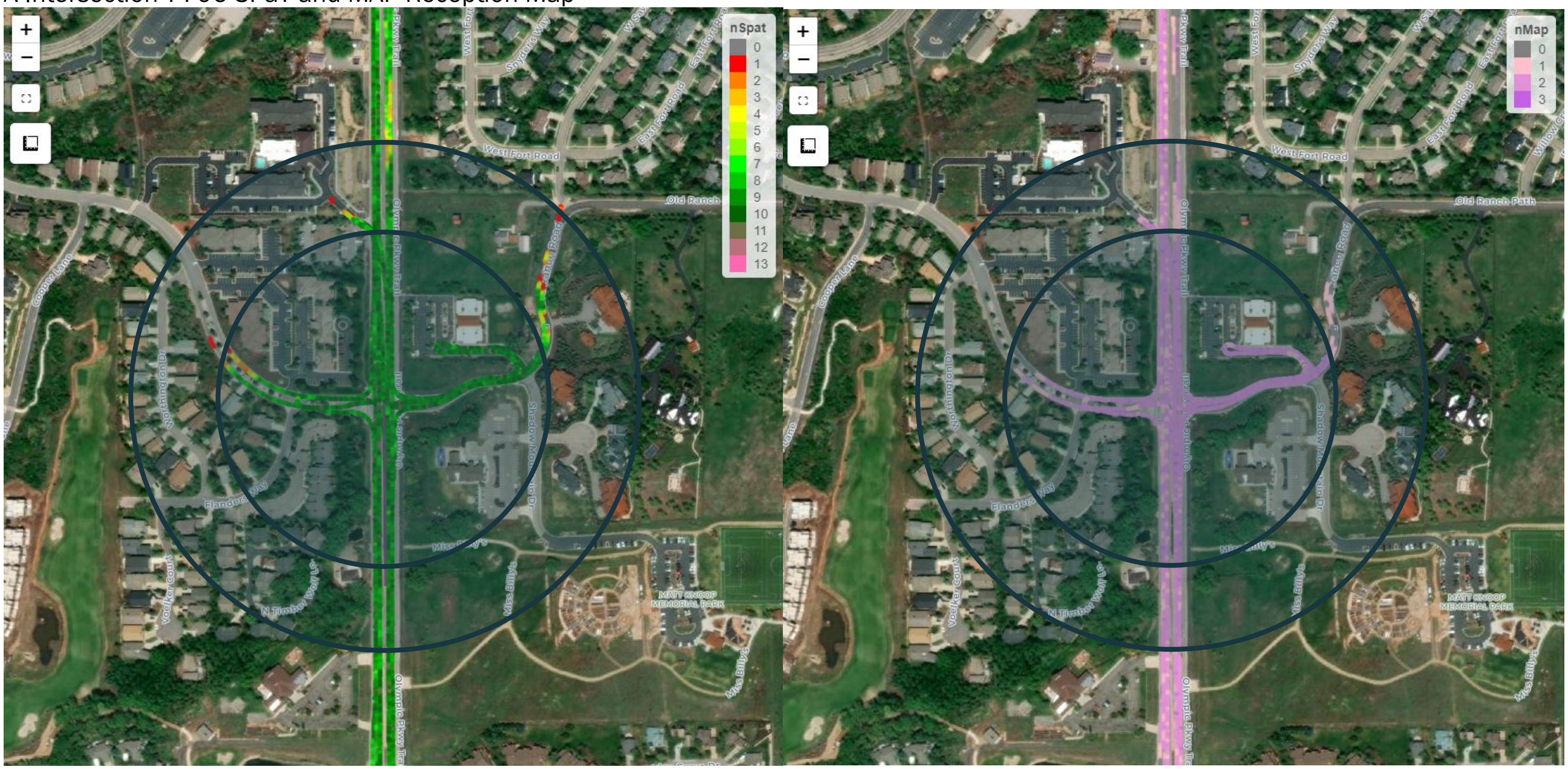
CAMP Online Tool SPaT Report Data Frames and Data Element Compliance (Results are same for all 6 intersections)

SAE J2735 MAP Data Frames and Elements	M/O/C in SAEJ2735	Pass/Fail J2735	M/O/C in CI Impl-RLVW	Pass/Fail CI R
messageId=DE_DSRC_MessageID=19 (SPaT UPER)	M	Pass	M	Pass
timeStamp=DE_MinuteOfTheYear	O	--	M	Pass
name=DE_DescriptiveName (only for debug)	O	--	O	--
intersections=DF_IntersectionStateList	M	Pass	M	Pass
name=DE_DescriptiveName (only for debug)	O	--	O	--
id=DF_IntersectionReferenceID	M	Pass	M	--Fail--
region=DE_RoadRegulatorID	O	--	M	--Fail--
id=DE_IntersectionID	M	Pass	M	Pass
revision=DE_MsgCount	M	Pass	M	Pass
status=DE_IntersectionStatusObject	M	Pass	M	Pass
moy=DE_MinuteOfTheYear	O	--	O	--
timeStamp=DE_Dsecond	O	--	M	Pass
enabledLanes=DF_EnabledLaneList	O	--	C	--
states=DF_MovementList=1 to 255 x DF_MovementState	M	Pass	M	Pass
movementName=DE_DescriptiveName (only for debug)	O	--	O	--
signalGroup=DE_SignalGroupID	M	Pass	M	Pass

state-time-speed=DF_MovementEventList	M	Pass	M	Pass
eventState=DE_MovementPhaseState	M	Pass	M	Pass
timing=DF_TimeChangeDetails	O	--	M	Pass
startTime=DE_TimeMark	O	--	C	--
minEndTime=DE_TimeMark	M	Pass	M	Pass
maxEndTime=DE_TimeMark	O	--	M	Pass
likelyTime=DE_TimeMark	O	--	--	--
confidence=DE_TimeIntervalConfidence	O	--	--	--
nextTime=DE_TimeMark	O	--	C	--

Appendix C. SPaT and MAP Reception Range Maps

A Intersection 7706 SPaT and MAP Reception Map

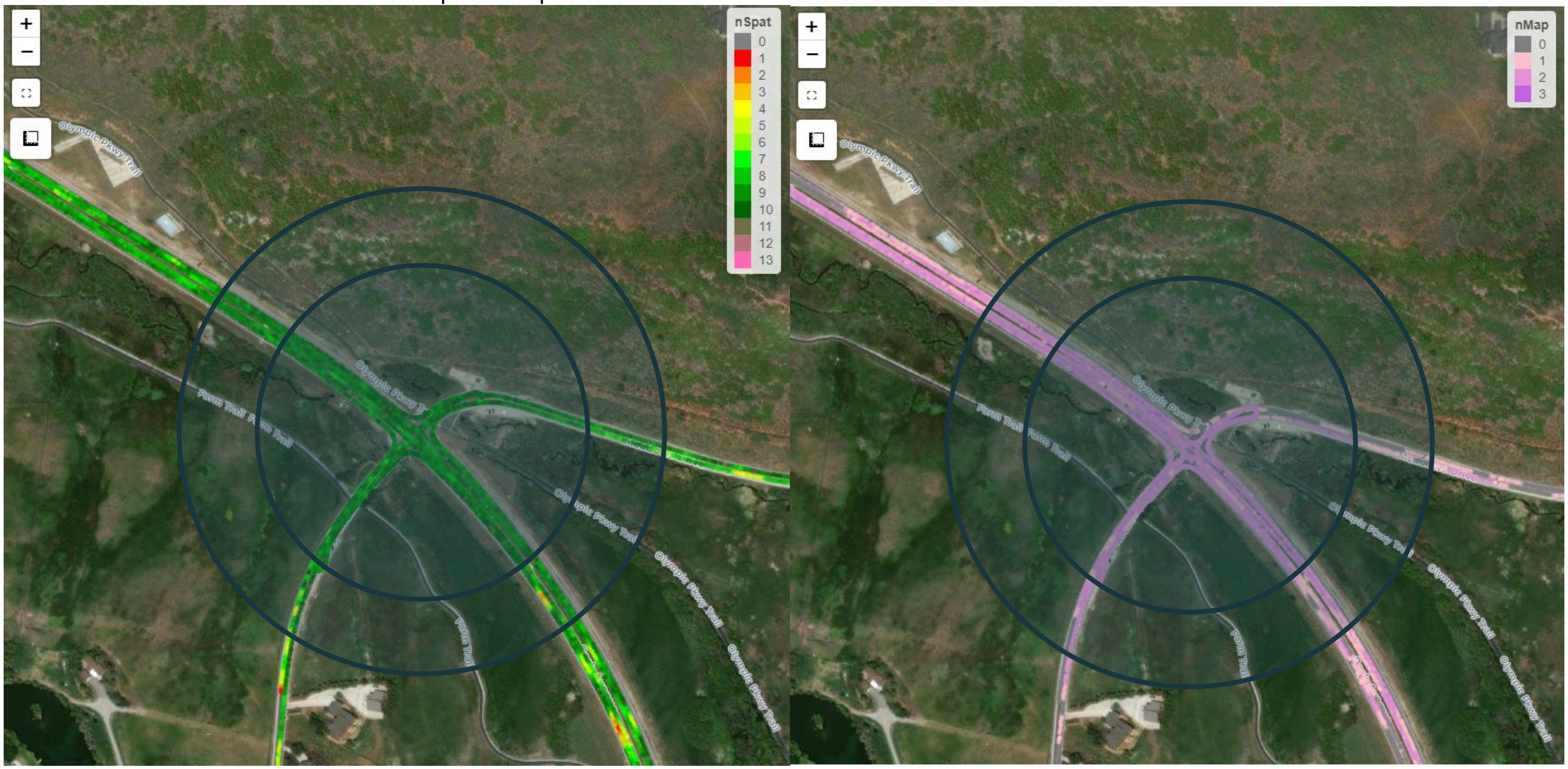


45 mph (NB/SB) and 25 mph (EB/WB) minimum reception ranges are represented by the outer and inner blue circles, respectively.

Intersection 7707 SPaT and MAP Reception Map

45 mph (NB/SB) and 25 mph (EB/WB) minimum reception ranges are represented by the outer and inner blue circles, respectively.

Intersection 7720 SPaT and MAP Reception Map



45 mph (NB/SB) and 35 mph (WB) minimum reception ranges are represented by the outer and inner blue circles, respectively. 25 mph (EB) minimum reception range is not shown.

Intersection 7708 SPaT and MAP Reception Map

40 mph (NB/SB) and 25 mph (WB/WB) minimum reception ranges are represented by the outer and inner blue circles, respectively.

Intersection 7709 SPaT and MAP Reception Map

40 mph (NB/SB) and 25 mph (WB/WB) minimum reception ranges are represented by the outer and inner blue circles, respectively.

Intersection 7710 SPaT and MAP Reception Map

35 mph (NB/SB/WB) minimum reception range is represented by blue circle.

Appendix D. MAP Ingress Lane Length vs. Advanced Notification Required Length

(3.3.3.4.1.17) (only ingress lanes shown). The overall requirement is considered to be met if the distance requirement is met or if the lane could not be extended further. If the distance requirement is not met and the lane could be extended further, then the overall requirement is considered to not be met.

Intersection	Lane	Speed limit (mph)	Distance Required (m)	Cumulative Distance (m)	Meets Distance Requirement	Can Lane be extended further	Overall Requirement Met
7706	1	25	143.38	111.24	No	Yes	No
	2	25	143.38	41.00-	No	No	Yes
	4	45	232.99	62.75	No	No	Yes
	5	45	232.99	197.35	No	Yes	No
	6	45	232.99	197.40	No	Yes	No
	7	45	232.99	56.17	No	No	Yes
	10	25	143.38	40.14	No	No	Yes
	11	25	143.38	150.25	Yes	Yes	Yes
	12	25	143.38	33.23	No	No	Yes
	14	45	232.99	75.3	No	No	Yes
	15	45	232.99	191.03	No	Yes	No
	16	45	232.99	191.25	No	Yes	No
	17	45	232.99	55.48	No	No	Yes
7707	1	25	143.38	77.56	No	Yes	No
	2	25	143.38	40.42	No	No	Yes
	4	45	232.99	49.12	No	No	Yes
	5	45	232.99	160.17	No	Yes	No
	6	45	232.99	191.96	No	Yes	No
	7	45	232.99	100.80	No	No	Yes
	10	25	143.38	57.70	No	No	Yes
	11	25	143.38	114.57	No	Yes	No
	12	25	143.38	111.13	No	Yes	No
	13	25	143.38	107.94	No	Yes	No
	15	45	232.99	200.09	No	Yes	No
	16	45	232.99	209.79	No	Yes	No
	17	45	232.99	48.16	No	No	Yes
	23	45	232.99	182.26	No	No	Yes
7720	1	35	188.18	108.01	No	Yes	No
	2	35	188.18	49.93	No	No	Yes
	4	45	232.99	94.36	No	No	Yes
	5	45	232.99	259.22	Yes	Yes	Yes
	6	45	232.99	257.24	Yes	Yes	Yes
	7	45	232.99	127.80	No	No	Yes
	10	25	143.38	74.11	No	Yes	No
	11	25	143.38	51.09	No	No	Yes
	13	45	232.99	124.05	No	No	Yes
	14	45	232.99	271.64	Yes	Yes	Yes

Intersection	Lane	Speed limit (mph)	Distance Required (m)	Cumulative Distance (m)	Meets Distance Requirement	Can Lane be extended further	Overall Requirement Met
	15	45	232.99	271.86	Yes	Yes	Yes
	16	45	232.99	134.84	No	No	Yes
7708	1	25	143.38	129.71	No	Yes	No
	2	25	143.38	69.46	No	No	Yes
	4	40	210.59	71.45	No	No	Yes
	5	40	210.59	244.77	Yes	Yes	Yes
	6	40	210.59	246.01	Yes	Yes	Yes
	7	40	210.59	82.05	No	No	Yes
	10	25	143.38	166.23	Yes	Yes	Yes
	11	25	143.38	57.56	No	No	Yes
	13	40	210.59	115.95	No	No	Yes
	14	40	210.59	214.22	Yes	Yes	Yes
	15	40	210.59	215.73	Yes	Yes	Yes
	16	40	210.59	89.19	No	No	Yes
7709	1	25	143.38	56.69	No	No	Yes
	2	25	143.38	86.53	No	Yes	No
	3	25	143.38	55.73	No	No	Yes
	5	40	210.59	54.93	No	No	Yes
	6	40	210.59	160.81	No	Yes	No
	7	40	210.59	161.26	No	Yes	No
	8	40	210.59	66.73	No	No	Yes
	11	25	143.38	115.58	No	Yes	No
	12	25	143.38	41.30	No	No	Yes
	14	40	210.59	90.84	No	No	Yes
	15	40	210.59	244.79	Yes	Yes	Yes
	16	40	210.59	244.89	Yes	Yes	Yes
	17	40	210.59	88.49	No	No	Yes
7710	1	35	188.18	182.72	No	Yes	No
	2	35	188.18	178.98	No	Yes	No
	3	35	188.18	150.2	No	No	Yes
	5	35	188.18	36.49	No	No	Yes
	6	35	188.18	136.83	No	Yes	No
	7	35	188.18	135.93	No	Yes	No
	10	35	188.18	180.30	No	Yes	No
	11	35	188.18	178.41	No	Yes	No
	12	35	188.18	89.31	No	No	Yes

Appendix E. Latency by Signal Group and Phase Transition

Int ID	Signal Group	Signal State Transition		Observed Latency	Average Latency (ms) (signal group)	Average Latency (ms) (intersection)
7706	NB Through	Green	Yellow	154.321	138	117
		Yellow	Red	204.371		
		Red	Green	120.954		
		Green	Yellow	171.005		
		Yellow	Red	145.979		
		Red	Green	100.1		
		Green	Yellow	108.441		
		Yellow	Red	175.175		
		Red	Green	66.733		
	NB Left	Red	Green	83.417	99	
		Green	Yellow	70.904		
		Yellow	Red	166.834		
		Red	Green	62.562		
		Green	Yellow	41.708		
		Yellow	Red	100.1		
		Red	Green	95.93		
		Green	Yellow	50.05		
		Yellow	Red	221.055		
	SB Through	Green	Yellow	83.417	133	
		Yellow	Red	171.005		
		Red	Green	129.296		
		Green	Yellow	91.758		
		Yellow	Red	66.733		
		Red	Green	225.225		
		Green	Yellow	112.613		
		Yellow	Red	200.2		
		Red	Green	116.783		
	SB Left	Red	Green	125.125	89	
		Green	Yellow	54.221		
		Yellow	Red	104.271		
		Red	Green	104.271		
		Green	Yellow	50.05		
		Yellow	Red	83.417		
		Red	Green	125.125		
		Green	Yellow	62.562		
		Yellow	Red	95.929		
	EB Through	Red	Green	212.712	143	
		Green	Yellow	100.1		
		Yellow	Red	154.321		
		Red	Green	95.929		
		Green	Yellow	112.612		
		Yellow	Red	216.883		
		Red	Green	133.467		
		Green	Yellow	95.929		
		Yellow	Red	171.005		

	WB Through	Red	Green	112.613	117	
		Green	Yellow	116.783		
		Yellow	Red	120.955		
		Red	Green	83.416		
		Green	Yellow	87.588		
		Yellow	Red	116.784		
		Red	Green	91.758		
		Green	Yellow	83.416		
		Yellow	Red	95.929		
7707	EB Left	Red	Green	141.808	117	116
		Green	Yellow	66.733		
		Yellow	Red	108.442		
		Red	Green	91.758		
		Green	Yellow	191.858		
		Yellow	Red	154.321		
		Red	Green	150.15		
		Green	Yellow	58.391		
		Yellow	Red	91.758		
	EB Through	Red	Green	141.808	103	
		Green	Yellow	66.733		
		Yellow	Red	83.417		
		Red	Green	91.758		
		Green	Yellow	112.612		
		Yellow	Red	95.929		
		Red	Green	116.783		
		Green	Yellow	58.391		
		Yellow	Red	162.663		
	WB Left	Red	Green	171.004	128	
		Green	Yellow	83.417		
		Yellow	Red	120.954		
		Red	Green	125.125		
		Green	Yellow	166.833		
		Yellow	Red	120.954		
		Red	Green	158.492		
		Green	Yellow	79.246		
		Yellow	Red	175.176		
		Red	Green	125.125		
		Green	Yellow	87.588		
	WB Through	Red	Green	162.662	131	
		Green	Yellow	79.246		
		Yellow	Red	229.395		
		Red	Green	87.588		
		Green	Yellow	166.833		
		Red	Green	116.783		
		Green	Yellow	125.125		
		Yellow	Red	100.1		
		Red	Green	162.662		
		Green	Yellow	83.416		
		Yellow	Red	129.296		
	NB Left	Red	Green	91.759	107	
		Green	Yellow	87.587		
		Yellow	Red	129.296		
		Red	Green	116.783		
		Green	Yellow	83.417		
		Yellow	Red	166.833		
		Red	Green	70.905		

		Green	Yellow	120.954		
		Yellow	Red	100.1		
	NB Through	Red	Green	191.859	118	
		Green	Yellow	87.587		
		Yellow	Red	83.416		
		Green	Yellow	83.417		
		Yellow	Red	87.587		
		Red	Green	129.295		
		Green	Yellow	120.954		
		Yellow	Red	120.954		
		Red	Green	162.662		
	SB Left	Red	Green	150.15	101	
		Green	Yellow	54.221		
		Yellow	Red	116.784		
		Red	Green	91.758		
		Green	Yellow	41.708		
		Yellow	Red	112.612		
		Red	Green	158.491		
		Green	Yellow	91.758		
		Yellow	Red	100.1		
	SB Through	Red	Green	150.15	120	
		Green	Yellow	116.784		
		Yellow	Red	183.516		
		Red	Green	91.758		
		Green	Yellow	75.075		
		Yellow	Red	125.125		
		Red	Green	158.491		
		Green	Yellow	62.562		
		Yellow	Red	120.954		
7720	NB Through	Green	Yellow	175.174	215	202
		Yellow	Red	158.492		
		Red	Green	200.2		
		Green	Yellow	141.808		
		Yellow	Red	175.175		
		Red	Green	621.454		
		Green	Yellow	145.979		
		Yellow	Red	166.833		
		Red	Green	150.15		
	WB Through	Red	Green	162.662	167	
		Green	Yellow	171.005		
		Yellow	Red	162.663		
		Red	Green	162.662		
		Green	Yellow	154.321		
		Yellow	Red	141.808		
		Red	Green	158.492		
		Green	Yellow	145.979		
		Yellow	Red	250.25		
	SB Through	Green	Yellow	358.692	241	
		Yellow	Red	608.942		
		Red	Green	166.833		
		Green	Yellow	150.15		
		Yellow	Red	216.884		
		Red	Green	154.321		
		Green	Yellow	158.492		
		Yellow	Red	162.662		
		Red	Green	196.03		

	EB Through	Red	Green	129.296	183	
		Green	Yellow	137.638		
		Yellow	Red	271.104		
		Red	Green	237.738		
		Green	Yellow	137.637		
		Yellow	Red	166.834		
		Red	Green	191.858		
		Green	Yellow	216.883		
		Yellow	Red	166.833		
7708	NB Through	Green	Yellow	120.954	161	195
		Yellow	Red	171.004		
		Red	Green	166.833		
		Green	Yellow	246.079		
		Yellow	Red	233.567		
		Red	Green	120.954		
		Green	Yellow	95.929		
		Yellow	Red	208.542		
		Red	Green	87.587		
		Green	Yellow	166.833		
		Yellow	Red	237.737		
		Red	Green	83.417		
	WB Through	Red	Green	208.542	232	
		Green	Yellow	212.712		
		Yellow	Red	258.592		
		Red	Green	191.859		
		Green	Yellow	271.104		
		Yellow	Red	179.346		
		Red	Green	187.688		
		Green	Yellow	204.37		
		Yellow	Red	375.375		
	SB Through	Green	Yellow	158.492	194	
		Yellow	Red	254.421		
		Red	Green	187.688		
		Green	Yellow	87.588		
		Yellow	Red	204.371		
		Red	Green	312.813		
		Green	Yellow	66.734		
		Yellow	Red	237.738		
		Red	Green	241.908		
	EB Through	Red	Green	183.517	204	
		Green	Yellow	200.2		
		Yellow	Red	200.2		
		Red	Green	208.541		
		Green	Yellow	162.663		
		Yellow	Red	241.909		
		Red	Green	279.446		
		Green	Yellow	166.834		
		Yellow	Red	200.2		
7709	NB Through	Green	Yellow	183.517	106	101
		Yellow	Red	91.758		
		Red	Green	83.416		
		Green	Yellow	62.562		
		Yellow	Red	70.904		
		Red	Green	116.783		
		Green	Yellow	125.125		
		Yellow	Red	62.563		

		Red	Green	158.492		
	WB Through	Red	Green	100.1	84	
		Green	Yellow	33.366		
		Yellow	Red	83.416		
		Red	Green	112.612		
		Green	Yellow	104.27		
		Yellow	Red	66.733		
		Red	Green	116.783		
		Green	Yellow	79.246		
		Yellow	Red	62.562		
	SB Through	Green	Yellow	95.929	109	
		Yellow	Red	75.075		
		Red	Green	108.442		
		Yellow	Red	108.442		
		Red	Green	208.542		
		Green	Yellow	179.346		
		Yellow	Red	83.417		
		Red	Green	100.1		
		Green	Yellow	87.587		
		Yellow	Red	70.904		
		Red	Green	83.416		
	EB Through	Red	Green	212.713	102	
		Green	Yellow	91.758		
		Yellow	Red	125.125		
		Red	Green	83.416		
		Green	Yellow	70.904		
		Yellow	Red	100.1		
		Red	Green	87.588		
		Green	Yellow	87.588		
		Yellow	Red	100.1		
		Red	Green	87.588		
		Green	Yellow	87.588		
		Yellow	Red	100.1		
7710	(NB Through)	Red	Green	179.346	211	204
		Green	Yellow	191.858		
		Yellow	Red	304.471		
		Red	Green	179.346		
		Green	Yellow	191.858		
		Yellow	Red	221.054		
	WB Left	Red	Green	246.079	219	
		Green	Yellow	179.345		
		Yellow	Red	275.275		
		Red	Green	166.833		
		Green	Yellow	275.275		
		Yellow	Red	233.566		
		Red	Green	196.029		
		Green	Yellow	241.908		
		Yellow	Red	162.662		
	SB Through	Red	Green	191.858	224	
		Green	Yellow	279.446		
		Yellow	Red	208.542		
		Green	Yellow	179.346		
		Yellow	Red	220.812		
		Red	Green			
		Red	Green	229.395		
		Green	Yellow	200.2		

		Yellow	Red	229.395		
		Red	Green	325.325		
		Green	Yellow	204.371		
		Yellow	Red	275.275		
		Red	Green	179.346		
		Green	Yellow	196.029		
		Yellow	Red	225.215		
	SB Left	Red	Green	150.15	175	
		Green	Yellow	246.08		
		Yellow	Red	196.029		
		Red	Green	150.15		
		Green	Yellow	150.15		
		Yellow	Red	116.783		
		Red	Green	191.858		
		Green	Yellow	200.2		
		Yellow	Red	208.542		
		Red	Green	154.321		
		Green	Yellow	166.833		
		Yellow	Red	204.371		
		Red	Green	137.637		
		Green	Yellow	154.321		
		Yellow	Red	200.2		
	Average latency of all transitions (ms):				149	