Connected Intersections Message Monitoring Systems Requirements & Prototype Development (CIMMS)

Software Design Document - FINAL

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Prepared by

FINAL

Contents

Tables

Figures

Acronyms

BSM ... Basic Safety Message
CBR ... Cease Broadcast Recommendation
CI ... Connected Intersection(s)
CIP ... Connected Intersection Project
CV ... Connected Vehicle
ECLA ... External Control Local Application
IEEE ... Institute of Electrical and Electronics Engineers
IOO ... Infrastructure Owner/Operator
ITS ... Intelligent Transportation System
MAP ... MapData
OBU ... Onboard Unit
OEM ... Original Equipment Manufacturer
PFS ... Pooled Fund Study
PSID ... Product Service Identifier
RLVW ... Red Light Violation Warning
RSU ... Roadside Unit
SAE ... Society of Automotive Engineers
SCMS ... Security and Credentials Management System
SPaT ... Signal Phase and Timing
TSC ... Traffic Signal Controller
V2X ... Vehicle-to-Everything
V2V ... Vehicle-to-Vehicle
V2I ... Vehicle-to-Infrastructure

Distribution and Updates

This draft report is located on the CIMMS shared projects folders, along with a comment response matrix to track the disposition of all comments received. The final, approved version is intended to be published on the CV PFS website - https://engineering.virginia.edu/cv-pfs

Figure 1. Software Design Document Revisions/Updates

Description	Issue Date	Author(s)	QA/QC
Preliminary Draft	February 21, 2023	Chris Toth, WSP	Frank Perry, WSP
Final	April 5, 2023	Chris Toth, WSP	Frank Perry, WSP

1. Introduction

1.1 DOCUMENT PURPOSE

The purpose of this Software Design Document (SDD) is to provide a description of the design of the Connected Intersection Message Monitoring System (CIMMS) fully enough to allow for software development to proceed with an understanding of what is to be built and how it is expected to be built.

The structure of this document is as follows:

- **Section 1** provides a document overview, and identifies all documents referenced and interviews conducted in developing this document.
- **Section 2** defines the design stakeholders and how each is expected to interact with and/or benefit from the system.
- **Section 3** presents the software architecture and describes components, functions, user interface design, and algorithm design in a highly detailed manner.
- **Section 4** outlines the minimum requirements that the existing system should meet to be compatible with the CIMMS and minimum requirements for hardware that the CIMMS will be running on.
- **Section 5** identifies any assumptions and constraints that are taken into account in the design of the CIMMS. It also identifies any potential development risks or external conditions that may result in the system not functioning as effectively.

1.2 PROJECT SCOPE

Since the inception of Connected Vehicle (CV) technology, researchers and deployers have sought new and innovative ways to use CV to improve transportation safety, mobility, and efficiency. Most of these efforts have focused on the ability of vehicles to react to the data they receive from other vehicles and from the infrastructure. Forward Collision Warning, Red-Light Violation Warning, Curve Speed Warning, etc., are all examples of critical CV safety applications that utilize CV data and as more data becomes available, these applications continue to mature. In parallel, numerous advances to ensure timely and authenticated data is being provided to the CV environment, continue. Robust fiber networks and the investment in the Security Credential Management Systems (SCMS) serve as proof of those investments. The assumption, however, has generally been that once a site had deployed and validated the broadcast messages, the data would remain correct. Two issues arise from this thinking:

- **Accuracy** – As has been the focus of the current CV PFS Connected Intersection project (CIP), and others before it, validation of message content goes beyond conformance to the SAE J2735 standard. To truly be considered conformant to the needs of OEMs, deployers need to ensure that broadcast messages truly match what is happening at the intersection. For instance, signal indications on the traffic signal must match those in the SPaT message.

- **Consistency and Changes** – The validation of message accuracy is not only needed at the time when CV equipment is deployed, but also throughout active operations of a CV system. Signal timing patterns change, road geometries change, and devices fail – it is important to confirm that these changes are properly accounted for in the CV system simultaneously after the changes are made. Presently, only limited capabilities exist to determine if a device is even operational, so it is not a simple matter to determine if the messages a CV system produces contain data that correctly reflect ground truth.

The CI project focused on validating a site's ability to conform to the newly published ITE CI Implementation Guide[1], guidance which the OEMs agree will uniformly support advanced safety applications, such as RLVW. CIP is a validation of the guidance itself, feedback which will be provided to the industry. It's important to note that in practice, use of the guidance would typically only occur at deployment however, and similarly validate a site's ability to conform to the guidance.

But what happens after a site validates in conformance to the guidance? Agencies don't have the bandwidth or budgets to subject every intersection to the same rigors as the CIP on a repetitive basis or over an extended period of time. Many agencies are also preparing to leverage increasingly larger amounts of Vehicle-to-Everything (V2X) data from intersections and from vehicles, especially as the number of V2X-equipped vehicles increases. The Concept of Operations proposes that this V2X data can be leveraged to continuously validate the correct operation of the infrastructure over a long-term time horizon. The broad goal of the Connected Intersection Message Monitoring System is to evaluate this potential.

Note that the scope for this project (initial implementation of the message monitor) is limited to receiving CV messages from an existing CV system, and using SPaT, MAP, and BSMs (driver behavior that provides a proxy for ground truth conditions) to assess the correctness of data within SPaT and MAP messages. The ability to use driver behavior to infer ground truth is predicated on the fact that a driver's response to traffic control devices and the roadway environment is generally predictable (though not perfect). Thus, it is reasonable to assume the data in SPaT and MAP messages should be consistent with general vehicular movement as evidenced in BSMs. The correctness of data in MAP and SPaT messages was initially cited as being a priority. Limiting the message monitor to SPaT, MAP, and BMS, simplifies the data and interfaces required between the existing system and the message monitor and minimizes the pre-requisites for the existing system. Any system for which CV data will be assessed should be able to produce and forward CV data to an external system such as the message monitor. Data from other (non-CV) sources, while useful for assessing SPaT and MAP accuracy, may not be available at every intersection. Thus, data from non-CV sources was not included for the initial implementation of the message monitor.

Other needs that have been identified during this process, such as the ability to assess message performance, generic message requirements, the correctness of position correction information in the RTCM message, and the impact of position correction data on the performance of message monitor algorithms that use BSM data are documented, but not considered in the initial implementation of the

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

message monitor. However, the message monitor will be designed in a way that allows the modification/addition of interfaces and algorithms so that data from other sources can be utilized and so other needs can be addressed in future system development efforts.

1.3 REFERENCES

This section contains documents and literature utilized to gather input for this document.

• Connected Intersection Message Monitoring System-Concept of Operations	11/2022 Final
• Connected Intersection Message Monitoring System-System Requirements	12/2022 Final
• CV PFS Map Guidance Document https://virginia.app.box.com/v/MAPGuidanceFinal	2021
• SAE J2735 2016-03. V2X Communications Message Set Dictionary. https://www.sae.org/standards/content/j2735_201603/	2016
• SAE J2735 2020-07. V2X Communications Message Set Dictionary. https://www.sae.org/standards/content/j2735_202007	2020
• CTI 4501 v01 – Connected Intersections (CI) Implementation Guide http://www.ite.org/pub/76270782-B7E4-7F75-BC72-D5E318B14C9A	2021
• CTI 4001 v01 - Roadside Unit (RSU) Standard http://www.ite.org/pub/764FB228-0F6C-BA02-6D7B-16A86B1F8108	2021
• SAE J2945/B Recommended Practices for Signalized Intersection Applications https://www.sae.org/standards/content/j2945/b/	(Work in progress)
• Operational Data Environment open-source decoder for MAP/SPaT/BSM https://github.com/usdot-jpo-ode/jpo-ode	2021 (latest version)
• CTI 4502 v01.00 – Connected Intersections Validation Report https://www.ite.org/pub/?id=59A8D354-F7B1-6A18-6FCC-1CECE6ACDE5B	2022
• Connected Intersections Program, Connected Vehicle Pooled Fund Study https://engineering.virginia.edu/cv-pfs-projects-and-research#accordion620710	

2. Design Stakeholders

2.1 INFRASTRUCTURE OWNER-OPERATOR (IOO)

The Infrastructure Owner-Operator (IOO) is the primary user of the CIMMS. They will receive, interpret, and act upon outputs from the CIMMS to determine if there are any issues with SPaT and/or MAP messages being broadcast, make modifications accordingly, and provide a reasonable resolution that addresses the issue based on knowledge and experience with traffic engineering and other disciplines involved in the design of CV systems. This might involve making changes to MAP messages, proposing corrections to software that generates the content for SPaT messages, proposing corrections that might be causing latency issues, etc.

To accomplish the goal of providing useful information to identify potential issues in SPaT and MAP messages, the CIMMS is designed with an IOO-focused user interface (see section 3.1.6, and section 3.3) to provide access to data regarding the current system status, notifications that indicate active issues, data visualizations, and settings modifications.

In the context of integrating the CIMMS with the existing system, the IOO will be responsible for making any necessary RSU configuration changes, modifying network settings, or otherwise allowing existing roadside CV equipment to send CV data to the CIMMS.

2.2 INDIRECT USERS: ORIGINAL EQUIPMENT MANUFACTURER (OEM) AND DRIVERS

Automotive Original Equipment Manufacturers (OEM) and Vehicle Operators continue to be stakeholders in the CIMMS systems engineering process, but in this step of the process, serve more to validate the design rather than dictating design. In other words, OEMs and drivers are not expected to propose changes to message, or for that matter, recommend changes to algorithm that determine if a notification should be issued, but instead, for confirming that SPaT and MAP messages contain data that are useable for driver-focused applications. For the evaluation of this project, this involves particular emphasis on SPaT and MAP data elements the CIMMS is assessing for use in the Red Light Violation Warning application.

It is also important to note that the driver indirectly benefits from the proposed system when the proposed system identifies an issue in a message that is corrected by the IOO. Improved message performance is expected to improve application performance for the driver’s OBU, thereby improving public perception of the technology.

3. Message Monitor System Decomposition

3.1 SYSTEM ARCHITECTURE AND FUNCTIONAL DESCRIPTION OF COMPONENTS

The system architecture represents the design decisions related to overall system structure and behavior. Architecture helps stakeholders and developers understand and analyze how the system will meet the requirements contained in the System Requirements document.

It is important to first understand how the CIMMS fits within the context of the existing system. The context diagram shown in Figure 2 indicates the message monitor interacts with the RSU (or other roadside processing equipment) to ingest CV data and provides a user interface for the IOO.

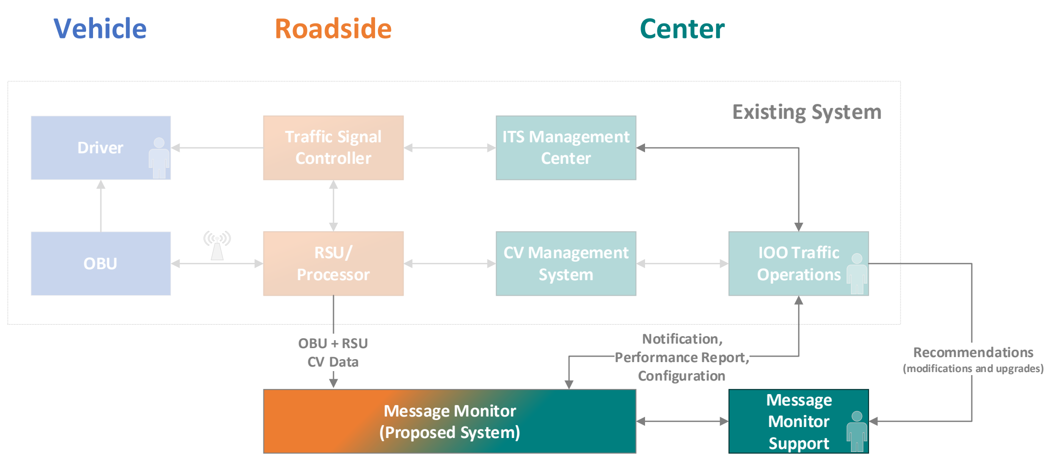


Figure 2. System Context Diagram

The software design architecture diagram shown in Figure 3 decomposes the Message Monitor Component from the context diagram (Figure 2) into more compartmentalized components, so that the design of the system can be more readily communicated to developers. OBU and RSU CV data from the context diagram is represented in the top left side of the system architecture, flowing between roadside devices, and the Operational Data Environment component in the CIMMS. Notifications, performance reports, and configuration in the context diagram are represented in the html and email flows on the bottom left side of the communications diagram.

There are several components internal to the CIMMS, which are required to process and manage data to meet the needs of the IOO Traffic Operations. Each component and the functions defined for each have extended descriptions provided in the subsections below.

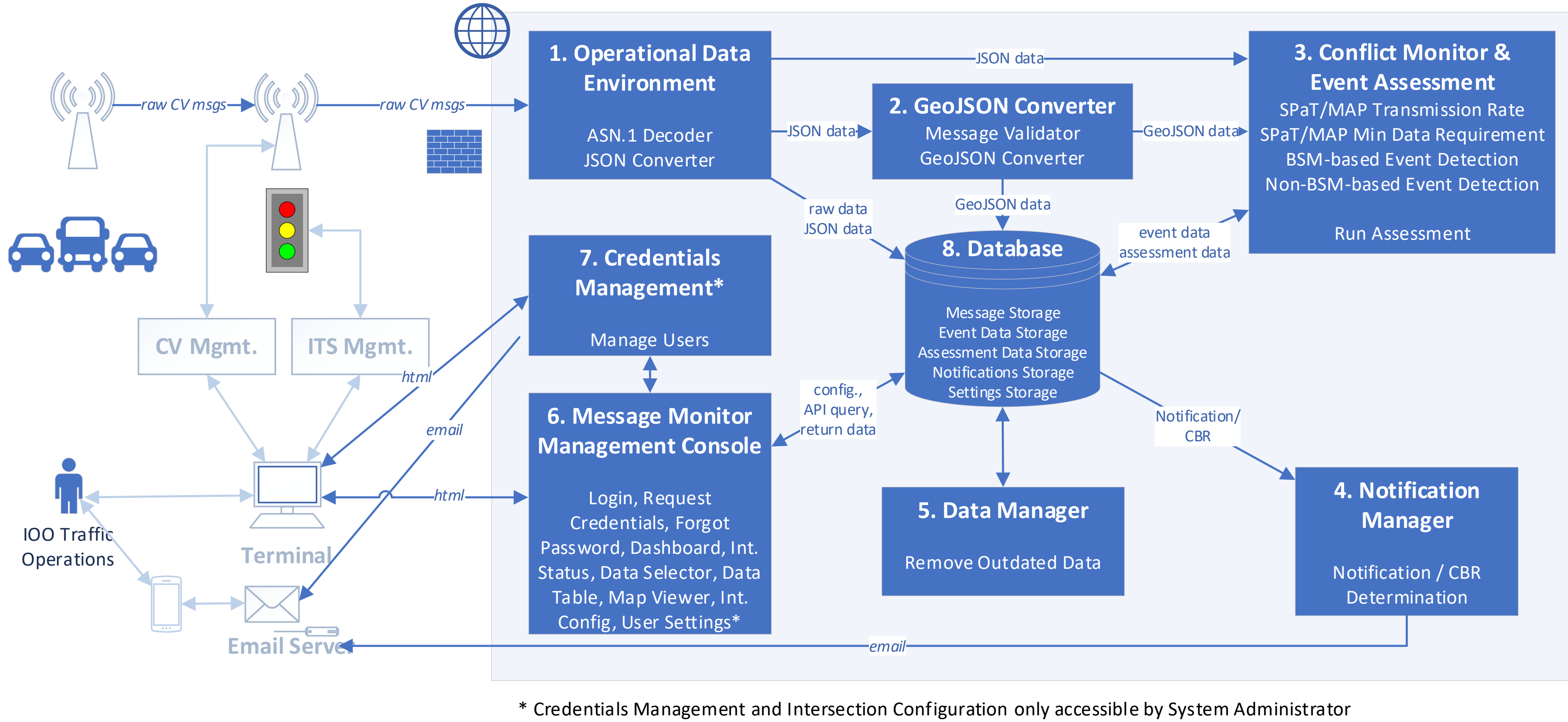


Figure 3. System Architecture Diagram

3.1.1 Component 1. Operational Data Environment

The Operational Data Environment (ODE) is an open-source software developed and maintained by the US Department of Transportation (USDOT) Intelligent Transportation Systems (ITS) Joint Program Office (JPO). It is a real-time virtual data router that ingests and processes operational data from various connected devices - including vehicles, infrastructure, and traffic management centers - and distributes it to other devices and subscribing transportation management applications.

For the purpose of the CIMMS, the ODE is the first process that raw CV data encounters as it is received by the system.

The ODE processes SAE J2735 messages to generate a JSON-formatted version of the raw CV data. Ideally, these JSON messages are encoded in a manner that makes them compatible with the CI test tools that CAMP has developed. Both the raw CV message and the JSON-formatted version of the message are sent to the database for storage. The data may be partitioned by month, day, message type, intersection id, etc. to improve efficiency of access. The JSON-formatted version is also sent to Component 2. GeoJSON Converter / Message Validator.

3.1.2 Component 2. GeoJSON Converter / Message Validator

Due to the nature of the data in CV messages and the algorithms that have been proposed for the CIMMS, there will be a significant amount of spatial analysis that will need to be performed. These spatial analyses are more easily performed on GeoJSON formatted data. GeoJSON is a format for encoding a variety of data about geographic features, their properties, and their spatial extents. The primary benefit of encoding data in a GeoJSON format is that it can be used by a library of efficient spatial analysis functions which can be leveraged to execute algorithms. The GeoJSON-formatted message produced by this function is sent to the database for storage. The data may be partitioned by month, day, message type, intersection id, etc. to improve efficiency of access.

3.1.3 Component 3. Conflict Monitor and Event Assessment

The conflict monitor component executes functions related to the processing of CV data (JSON or GeoJSON format) and generating event data. The following functions are executed as new data is available in the system, or at recurring intervals.

SPaT/MAP Transmission Rate. This function determines the rate at which SPaT and MAP messages are broadcast from each intersection over a 10-seocnd period and generates an event (Stored in the database) if the number of SPaT messages is less than or greater than configured values or the number of MAP messages is less than or greater than configured values.

SPaT/MAP Minimum Data Requirement. This function determines if the data in SPaT and MAP messages contain minimum data required by SAE J2735 and CTI 4501. Note that this function does not assess message content, only the inclusion of required data elements. If a particular message does not meet a minimum data requirements, and event is generated and stored in the database. Detailed explanations of these algorithms are provided in Section 3.5.

BSM-based Event Detection. This function processes SPaT, MAP, and BSMs to compare vehicle movements (BSM) against ground truth conditions, as SPaT and MAP, to determine if actual vehicle movements align with expectation. If a vehicle movement does not align with its expected movement, an event is generated and stored in the database. These algorithms, initially presented in the Concept of Operations, are as follows:

- Stop Line Passage Event (see section 3.5.1)
- Stop Line Stop Event (see section 3.5.2)
- Direction of Travel (see section 3.5.3)
- Connection of Travel (see section 3.5.4)

If upon performing any of these algorithms, additional BSMs from a given vehicle are obtained and this results in new information about the vehicle's movement that changes outcome of an event, then the previously stored event is overwritten with the latest event data. Furthermore, if additional BSM's from a given vehicle ID are obtained after a previous event has been created from the same vehicle ID. The system will treat the new BSM's as a new vehicle (independent of the first) that can generate its own events just like the original vehicle. The events from the two vehicles will not overwrite each other.

One of the primary considerations for this function is the time synchronization between SPaT messages and BSMs. The ability to perform this association is dependent on the availability and accuracy of time data elements in these messages or in message headers. It will be important that a common time source is used to promote the effectiveness of these algorithms in generating accurate event data.

Non-BSM-based Event Detection. This function processes SPaT and/or MAP messages only (without BSMs) to assess for data conflicts in these messages. If a conflict is noted, an event is generated and stored in the database. These algorithms, initially presented in the Concept of Operations, are as follows:

- Signal State Conflict Monitor (see section 3.5.5)
- Time Change Details Monitor (see section 3.5.6)

Run Assessment. Due to variation in driver behavior and randomness that may be exhibited in BSM data elements (especially latitude and longitude), secondary processing is needed to determine if certain types of event data generated is indicating if a potential issue is present. The Event Assessment component aggregates event data (by intersection, lane id, connection, etc.), and uses probabilistic analysis to determine the percentages of events with different event outcomes. The assessment result is compared against user-specified thresholds (for determining if a notification should be issued). Each time one of these events is generated, the event assessment related to the event type is performed as follows:

- When a Stop Line Passage Event is generated a Stop Line Passage Event Assessment (see section 3.5.7) is performed.
- When a Stop Line Stop Event is generated, a Stop Line Stop Event Assessment (see section 3.5.8) is performed.
- When a Vehicle Travel Direction Event is generated a Vehicle Travel Direction Event Assessment (see section 3.5.9) is performed.
- When a Connection of Travel Event is generated, a Connection of Travel Event Assessment (see section 3.5.910) is performed.

An assessment is performed every time an event is generated to determine at the earliest moment possible if a notification is warranted. The assessment result is saved and stored on the database.

3.1.4 Component 4. Notification Manager

This component determines if an email needs to be sent to a user based on system notifications and user configurations. When a notification or cease broadcast recommendation (CBR) is issued, the Notification Manager sends an email to users, provided the user settings indicate the user wants to receive email notifications. However, if a notification or CBR has already been provided for a particular issue for a particular intersection, lane, etc., and the associated notification or CBR has not been cleared (by an admin) via the online interface, then this function will not send an email to users. Furthermore, if the user settings indicate they do not want to receive emails from the CIMMS, then this function will not send emails to that user.

3.1.5 Component 5. Data Manager

The data manager is responsible for checking the stored CV data, event data, assessment data, etc. in the database on a periodic basis (once per day or more frequently), and releases data from long-term memory if it is older than user-provided configuration for data retention.

3.1.6 Component 6. CIMMS Console

The CIMMS Console contains the web design and also pushes and pulls data from the database as necessary to provide information is a visual format to the user. Two types of users are accommodated by the CIMMS Console: Administrator, and View-Only User. The primary difference between the administrator and the view-only user is that the administrator has the ability to change system settings that affect how algorithms perform, when data is cleared, and clear notifications that are generated – essentially any settings or functions that manipulate how data is generated, stored, or modified in the database. The View-Only user is simply able to view information on the various pages that comprise the CIMMS Console, as well as download data.

The user interface design, including the flow between interfaces and examples of the user interface layouts is detailed in section 3.3.

3.1.7 Component 7. Credentials Management

The Credentials Management component plays a critical role in account creation, password recovery, and account authentication (during user log in) and manages the list of users allowed to control access to the CIMMS Console. Keycloak is an open-source identity and access management tool that will be used to perform all functions of the Credentials Management component.

Keycloak will have a separate user interface from the CIMMS Console that will only be accessible to Administrator users. It is also important to note that Keycloak contains a small database separate from the CIMMS database (see section 3.1.8. Component 8. Database) solely for the purposes of storing data associated with Credentials Management.

For account creation, Keycloak takes account creation request information (includes an email address at a minimum, along with other user information) entered by the user (via the CIMMS Console) and provides an email notification to Administrator users to approve or deny the request. If/once approved, Keycloak will create a temporary password, add the email address (which doubles as the user name) and temporary password to its internal database, and sends an email to the new user with instructions to log in and a temporary password.

For password recovery, Keycloak takes user information (email address, supplied through the CIMMS Console), and if this matches against the list of users in its internal database, creates a temporary password, modifies the user's password to the temporary password, and sends an email to the user with the temporary password.

Finally, Keycloak will exchange information with CIMMS Console to authenticate user name and password information entered by a user during the login process. When the correct credentials are provided, Keycloak generates and sends a token to the CIMMS Console which authenticates the user during an active session. The token can be refreshed and invalidated if needed.

3.1.8 Component 8. Database

The database is the repository where all data is stored. Many of the other components save data to the database, pull data from the database, or release data from memory, as described in sections 3.1.1 through 3.1.5. Details regarding the types of data stored on the database and its structure are provided in section 3.4. MongoDB is the data platform that will be used to build the database.

3.2 EXTERNAL SYSTEM (ROADSIDE EQUIPMENT) INTERFACE DESIGN

3.2.1 Overview

RSUs are expected to capture and forward messages to the CIMMS for ingestion, storage, and processing. Message forwarding is a feature RSUs should exhibit to be compliant with CTI 4001 – Roadside Unit Standard.

- BSMs are produced by CV-equipped vehicles. As equipped vehicles travel within range of an RSU, the BSMs are captured by the RSU, which immediately forwards them to the CIMMS. The CIMMS ingests all BSMs sent by RSUs.

- SPaT and MAP messages broadcast by each RSU are simultaneously forwarded to, and ingested by, the CIMMS.

3.2.2 Communication Profile

The communications profile in Table 1 below indicates the communications protocols necessary to transport data for the information flow between the RSU (existing system) and the CIMMS.

Table 1: RSU-CIMMS Communication Profile

Layer	Applicable Standards
ITS Application Information Layer	SAE J2735_202211 OR 202007 OR 201603 ASN.1
Application Layer	HTTPS
Session Layer	IETF TLS, IETF DTLS
Transport Layer	IETF UDP, IETF TCP
Network Layer	IETF IPv6
Data Link Layer	LLC and MAC compatible with Physical and Network
Physical Layer	IEEE 802.3
Security Plane	IEEE 1609.2, IETF TLS, IETF, DTLS

3.2.3 Data Flows

All data flows across the interface from the roadside equipment to the CIMMS system. This consists of raw SAE J2735 messages. While all message types defined in this standard may flow across this interface, the three types used by the CIMMS in this initial prototype include the BSM, SPaT, and the MAP messages, as described below. There is no data that is passed directly back from the CIMMS to the roadside equipment.

- **Basic Safety Message.** The basic safety message (BSM) is used in a variety of applications to exchange safety data regarding vehicle state. This message is broadcast frequently to surrounding vehicles with data content as required by safety and other applications. Part I data is expected to be included in every BSM as defined in SAE J2735. BSM Part II data items are optional, and may or may not be present. BSMs received by the RSU are immediately forwarded to the CIMMS. Each RSU is configured to forward BSMs (PSID 0x20) to the CIMMS IP address.

- **Signal Phase and Timing Message.** SPaT messages are used to convey the current status of one or more signalized intersection. Along with the MAP message (which describes a full geometric layout of an intersection) the receiver of this message can determine the state of the signal phasing and when the next expected phase will occur. SPaT messages are expected to contain required data elements as defined in SAE J2735 and ITE CTI 4501. Each SPaT message broadcast by the RSU is immediately forwarded to the CIMMS. Each RSU is configured to forward SPaT messages (PSID 0x82) to the CIMMS IP address.

- **MapData Message.** MAP messages are used to convey many types of geographic road information. At the current time its primary use is to convey one or more intersection lane geometry maps within a single message. The map message content includes such items as complex intersection descriptions, road segment descriptions, high speed curve outlines (used in curve safety messages), and segments of roadway (used in some safety applications). MAP messages are expected to contain required data elements as defined in SAE J2735 and ITE CTI 4501. Each MAP message broadcast by the RSU is immediately forwarded to the CIMMS. Each RSU is configured to forward MAP messages (PSID 0x20-40-97) to the CIMMS IP address.

3.3 USER INTERFACE DESIGN

3.3.1 Overview of Objects and Actions

The primary means by which the CIMMS provides information to the IOO Traffic Operations is through a user interfaces. This interface will be accessed through a web browser on any computer connected to the same network as the CIMMS (or if cloud-based, any computer connected to the internet). Tables, graphs, maps, and notifications are used to convey information in a manner that allows the user to quickly understand the status of an intersection and to investigate potential issues that the CIMMS may be pointing to. The remainder of this section provide more detail as to how this interface works.

Figure 4 provides the webpage flow for the CIMMS Console (section 3.1.6). The dark blue boxes represent pages that the user can navigate to, and the light blue boxes indicates actions (links or buttons) that the user can select while on a page. Arrow heads represent the page a user is taken to when an action is taken. A page-by-page description is provided below the figure.

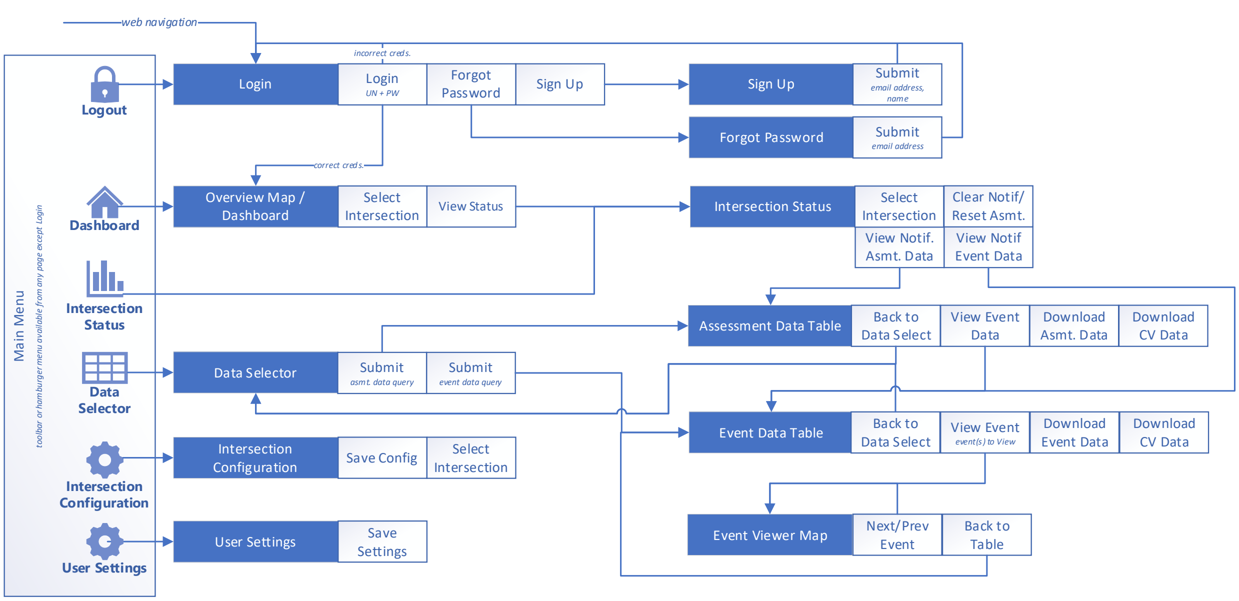
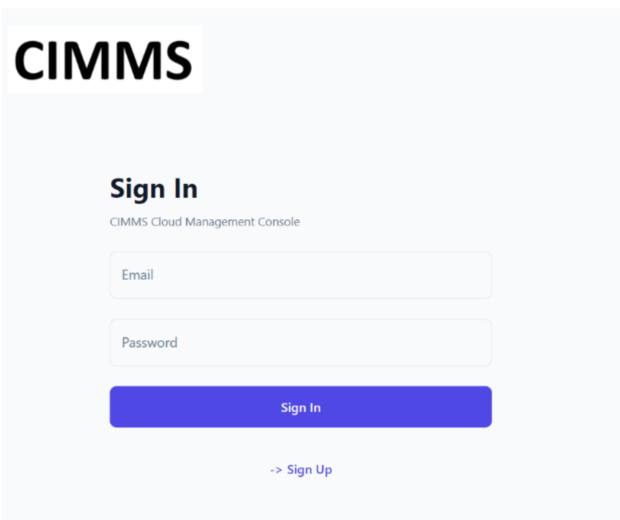


Figure 4. Webpage Flow

3.3.2 Login

The login screen allows the user to provide username and password credentials to access the main features of the User Interface. Upon clicking on the “Sign In” button, this function takes the user-supplied credentials and determines if the credentials matches those of the list of approved users stored on Keycloak’s internal user store. If credentials match, Keycloak will generate a token (which is used by the CIMMS Console to authenticate the user’s identity by checking with Keycloak each time the user attempts to perform an action during an active session), and the user is presented with the Overview Map / Dashboard screen. If they do not match, the user remains on the login screen, and the user is provided with a message to indicate that the username and/or password could not be authenticated. The login screen also provides a “Sign Up” link that when selected, takes the user to the Request Credentials screen, and a “Forgot Password” link that when selected, takes the user to the Forgot Password screen. A representative example of the Login screen is provided in Figure 5.

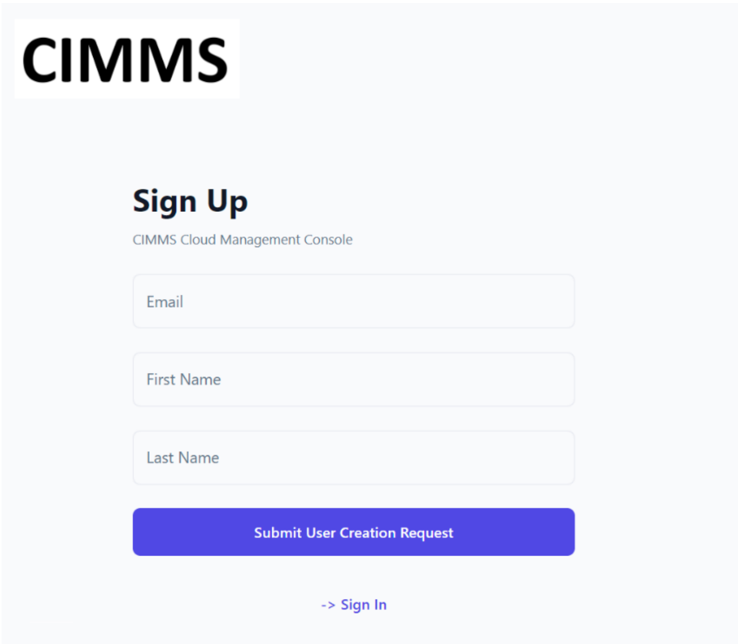


Note: The image in this figure is based on development to date, and while representative, the final product may actually look different than shown in this figure.

Figure 5. Login Screen Example

3.3.3 Sign Up

The Sign Up screen allows the user to enter information to request a username and password. Upon clicking on the “Submit” button, this function sends the user-supplied information to Credentials Management (Keycloak), which prompts a system administrator to approve or deny the request. The user is provided with a pop-up message to indicate that the request was successfully received, and that a temporary password will be sent to the email address provided, if the request is approved. A representative example of the Sign Up screen is provided in Figure 6.



Note: The image in this figure is based on development to date, and while representative, the final product may actually look different than shown in this figure.

Figure 6. Request Credentials Screen Example

3.3.4 Forgot Password

The forgot password screen allows the user to enter information to reset their password. Upon clicking on the “submit” button, this function sends the user-supplied information to Credentials Management (Keycloak), which, if valid, generates and sends a temporary password to the user via e-mail. The user is provided with a pop-up message to indicate that the request was received and that a temporary password will be sent to the email if it is associated with an account.

3.3.5 Overview Map / Dashboard

The Overview Map / Dashboard screen is considered to be the home screen for a user that is logged in. This page shows a map with icons located at each intersection where there is an RSU sending data to the CIMMS. The map is initially centered and zoomed at a level so that all icons are visible, and so that either the northernmost and southernmost icons, or the easternmost and westernmost icons are near the edges of the map. The map is initially oriented with north pointing toward the top of the map. This map at a minimum allows the user to pan and zoom (changing orientation is optional) and has a button that resets the map to the initial view.

The icons indicate if there are notifications or cease broadcast recommendations present.

- If there are no active notifications and no active cease broadcast recommendations, a green check icon (or similar) is used.
- If notifications are active, but there are no active cease broadcast recommendations, a yellow triangular warning icon with an exclamation point is used. A number next to the icon should be used that corresponds to the number of notifications present.
- If any CBRs are active, a red triangular warning icon with an exclamation point is used. A number next to the icon should be used that corresponds to the number of cease broadcast recommendations present.

When the user clicks on an icon, they are taken to the Intersection Status screen, with information populated for the selected intersection

3.3.6 Intersection Status

A list of intersection IDs and descriptive names from RSU Source Information (see Table 35) is provided in a drop down menu in the upper left corner of the screen. Based on the intersection selected, current status information and historical assessment data for the selected intersection are provided to the user.

Aggregated historical data is displayed in graphs to allow the user to study current performance details and high-level performance over time. The types of graphs that can be displayed are as follows:

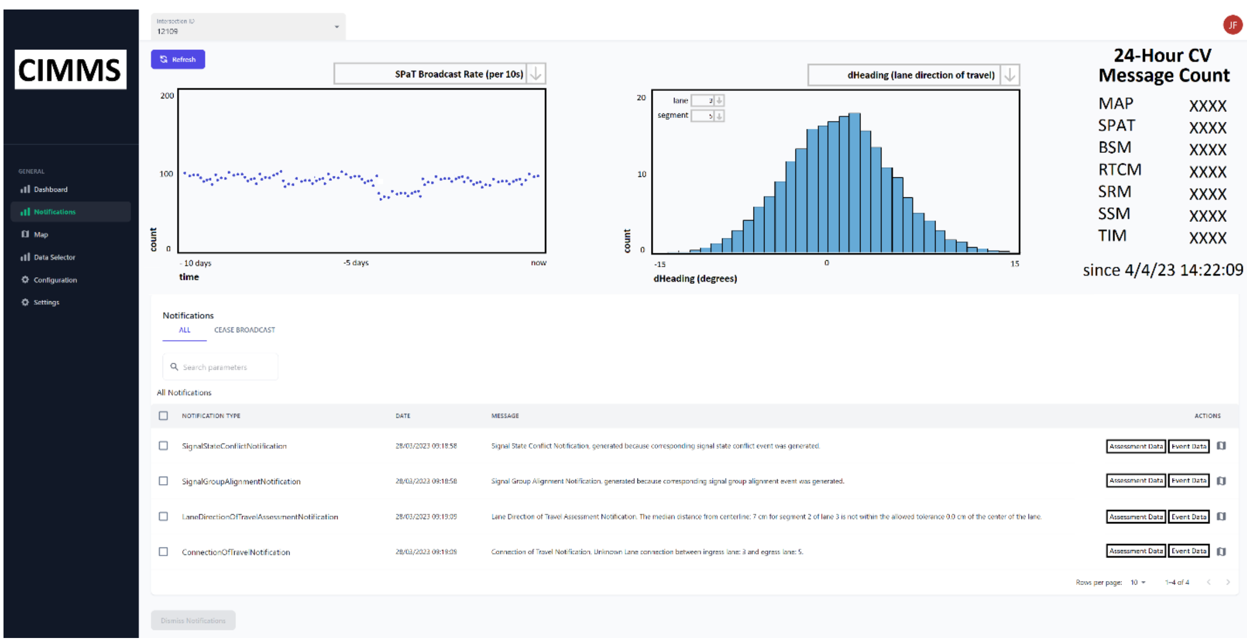
- Histograms
    - Number of heading (dHeading) values in 1-degree increments (lane direction of travel events)
    - Number of distance to centerline (dHeading) values in 1-foot increments (lane direction of travel events)
    - A two-dimensional histogram, showing all ingress lane IDs on one axis, and all egress lane IDs on the other axis. The value in a cell indicates the number of vehicles traveling from the given ingress lane to the given egress lane (connection of travel events).
- Time series graphs
    - SPaT Broadcast rate over time
    - MAP broadcast rate over time
    - Percentage of vehicles crossing the stop line during a “red” “yellow” and “green” event state (stop line passage assessment) over time.
    - Percentage of time vehicles are stopped at the stop line during a “red” “yellow” and “green” event states (stop line stop assessment) over time.
    - Heading difference (dHeading) values over time (lane direction of travel assessment)
    - Median distance from centerline values over time (lane direction of travel assessment)
- Bar Charts
    - Number of Stop Line Passage Events per day
    - Number of Stop Line Stop Events per day
    - Number of Lane Direction of Travel Events per day
    - Number of Connection of Travel Events per day.
    - Number of Signal State Conflict Events per day
    - Number of Time Change Details Events per day

The user is provided with a means of selection (e.g., drop down menu) so that the type of information displayed in the visualization may be changed as needed by the user. For graphs, the axes are to be adjusted as necessary so the data “fits” the graph. When hovered over, hover text should be displayed to provide more information about the data on the graph.

A list of notifications and CBRs is also provided on this screen. If a particular notification/CBR type has already been provided for a particular lane, connection, etc., then only the information for the latest related notification/CBR is provided. The user is able to select a button next to each notifications/CBRs to view the notification/CBR details (which takes the user to the Assessment Data Table showing the assessments that resulted in the notifications/CBRs or the event table showing the events that results in the notifications/CBRs). A button next to each notification/CBR is provided for administrator users to clear the notification/CBR from the list, and the current notification status for the intersection is cleared in the database (note: this does not clear any notification logs).

The latest 24-hour count of each CV message type received by the CIMMS from the selected intersection is also provided on the Intersection Status screen. A timestamp corresponding to the beginning of the 24-hour period (24 hours before the current time) is indicated using a 24-hour format (e.g., mm/dd/yyyy hh:mm:ss), which is adjusted to the user’s device’s time zone.

A representative example of the Intersection Status screen is provided in Figure 7.



Note: The image in this figure is partially based on development to date and has been partially rendered by hand, and while representative, the final product will likely look different than shown in this figure.

Figure 7. Intersection Status and Performance Screen Example

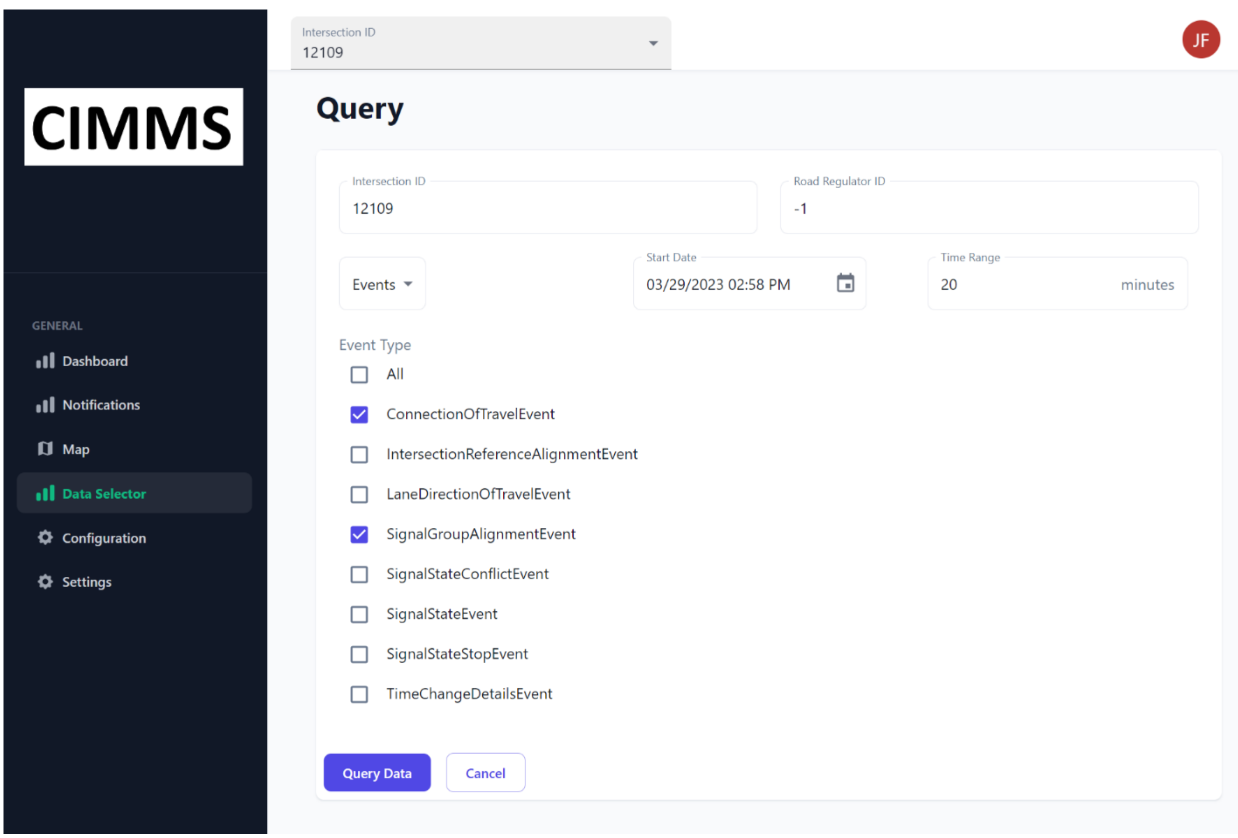
If navigating to the Intersection Status screen from the navigation toolbar on the left side of the screen, the Intersection Status screen is initially blank, and the drop-down menu prompts the user to select an intersection. However, if navigating to the Intersection Status screen from the Overview Map, then the Intersection Status screen is populated with information from the selected intersection and the drop-down menu is populated with the intersection ID.

3.3.7 Data Selector

The data selector allows the user to query historical event data and assessment data. The simple query inputs allow the user to provide basic criteria including the event or assessment type, intersection IDs/descriptive names, start time, and end time.

A drop-down list allows the user to select whether the query is for event data or assessment data. When the event data option is selected, a selectable list of event types appears on the screen, and when the assessment data selection option is selected, a selectable list of assessment types appears on the screen.

A "Query Data" button is provided to submit the query. When this button is selected, the user is taken to either the Event Data Table screen or the Assessment Data Table screen (depending on whether the event data option or assessment data option is selected) where the results of the query are provided.



Note: The image in this figure is based on development to date, and while representative, the final product may actually look different than shown in this figure.

Figure 8. Data Selector/Data Table Screen Example

3.3.8 Event Data Table

Results based on an event data query are returned in the Event Data Table screen. A back button takes the user back to the Data Selector screen with the previous query options selected. Text at the top of the screen indicates the number of event data records returned from the query, along with A "Download Event Data" button, and a "Download CV Data" button (discussed below).

Event data records are displayed in a tabular format, showing the event type, the start time of the event, and other data associated with the event records in columns with column headings. Records are initially ordered in time-descending order (reverse chronological). When a column heading is clicked, event records are sorted by ordering values in the selected column in an ascending fashion. If clicked again, event records are sorted by ordering values in the selected column in a descending fashion. Each row, or event record, is accompanied with a link to the Map Viewer. When the user selects a link, the user is taken to the Event Viewer Map, where the user can visualize CV data specific to the selected event. Each row, or event record, is also accompanied with a check box that allows the user to select individual records for download. The column header above the checkboxes contains a high-level checkbox that will check or un-check all event record check boxes when selected.

Results may be provided on multiple "pages" - the current page number and total page count along with buttons that allow the user to easily navigate between pages and select the number of results shown on each page (e.g., 50, 100, 500) are provided at the top and bottom of the results table.

The "Download Event Data" button when clicked provides the user a comma separated value file containing a unique event identifier, and all data associated with the selected (checked) event results. The "Download CV Data" button when clicked provides the user a comma separated value file containing a unique event identifier, and a JSON-formatted CV message that is associated with that event, for the selected (checked) event results. In order to preserve optimal system operations, some limits may be placed on the size of downloaded data. If a limit is reached, the user is notified by a pop-up on top of the active page.

3.3.9 Assessment Data Table

Results based on an assessment data query are returned in the Assessment Data Table screen. A back button takes the user back to the Data Selector screen with the previous query options selected. Text at the top of the screen indicates the number of assessment data records returned from the query, along with a "Download Assessment Data" button (discussed below).

Assessment data records are displayed in a tabular format, showing the assessment type, the start time of the assessment, and other data associated with the assessment records in columns with column headings. Records are initially ordered in time-descending order (reverse chronological). When a column heading is clicked, assessment records are sorted by ordering values in the selected column in an ascending fashion. If clicked again, assessment records are sorted by ordering values in the selected column in a descending fashion. Each row, or assessment record, is accompanied with a link to the Event Data Table, where the user is provided with a list of events associated with that assessment. Each row, or event record, is also accompanied with a check box that allows the user to select individual records for download. The column header above the checkboxes contains a high-level checkbox that will check or un-check all assessment record check boxes when selected.

Results may be provided on multiple “pages” - the current page number and total page count along with buttons that allow the user to easily navigate between pages and select the number of results shown on each page (e.g., 50, 100, 200, 500) are provided at the top and bottom of the results table.

The “Download Assessment Data” button when clicked provides the user a comma separated value file containing a unique assessment identifier, and all data associated with the selected (checked) assessment results. In order to preserve optimal system operations, some limits may be placed on the size of downloaded data. If a limit is reached, the user is notified by a pop-up on top of the active page.

3.3.10 Event Viewer Map

The Event Viewer Map is the primary means of visualizing event data. It provides a “replay” of CV data associated with a single event on a satellite map.

MAP message lane geometries and connections are displayed on the satellite image using colors and symbols to indicate important data for each lane:

- Placing a small circle symbol on the first point that defines a lane
- Placing an arrow-type symbol on each lane segment
    - Arrows on ingress lanes point in the opposite direction in which the lane is defined
    - Arrows on egress lanes point in the same direction in which the lane is defined
    - Note multiple arrows are used if a lane is defined as an ingress and egress lane, and no arrows are used if a lane is defined as neither.
- Using different colors and or line types to represent different lane types (e.g., vehicle, crosswalk, sidewalk, bicycle, other).

The SPaT message event state is represented by the line type and color of the line that represents the connection. For example:

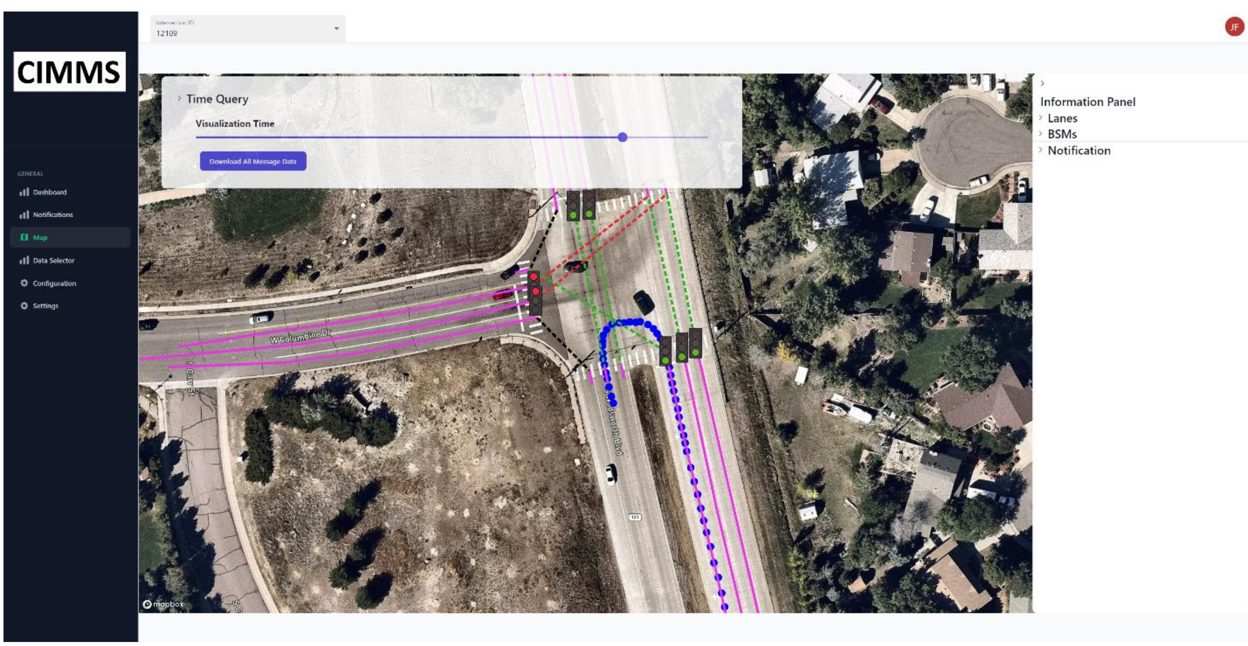
- A protected-Movement-Allowed event state is represented by a dark green/thick/solid line
- A permissive-Movement-Allowed event state is represented by a light green/narrow/dashed line.
- A protected-Clearance event state is represented by a dark amber/thick/solid line
- A permissive-Clearance event state is represented by a light amber/narrow/dashed line.
- A “stop-And-Remain” event state were right turn on red is not permitted is represented by a solid red line.
- A “stop-Then-Proceed” or a “stop-And-Remain” event state were right turn on red is permitted is represented by a dashed red line.
- Other event states are represented using other colors, line types, and line weights accordingly, and should all differ from each other.

BSM vehicle locations are displayed on the satellite image. BSM data is represented using a uniquely shaped symbol, so that it easily distinguishable from other data on the satellite image. The symbol should change orientation based on the orientation in the BSM, and the color should change based on the speed in the BSM.

The user is provided with a playback menu with a button to play/pause the visualization, a button to go back one step in the visualization, a button to go forward one step in the visualization, a draggable playback bar that allows the user to navigate to a specific time in the visualization, and playback speed options (e.g., 0.5x, 1x, 2x).

A playback time value is provided in a conventional 24-hour format (e.g., mm/dd/yyyy hh:mm:ss.000), which is adjusted to the user's device's time zone. SPaT, MAP, and BSM data are provided in a text-based hierarchical format where data frames and elements can be expanded and collapsed by the user. The playback time value and the SPaT, MAP, and BSM data are continuously updated as data is played back through the visualization. Care should be taken so that the location of any data element (that a user may be watching) does not move on the screen as message data is updated as the visualization is playing back.

A button is also provided to take the user back to the Event Data Table. Other buttons also provide a means to toggle (or other means of navigating search results) to allow the user to conveniently switch from one event record to the next without having to return to the Event Data Table to select another record. A representative example of the Event Viewer Map screen is provided in Figure 9.

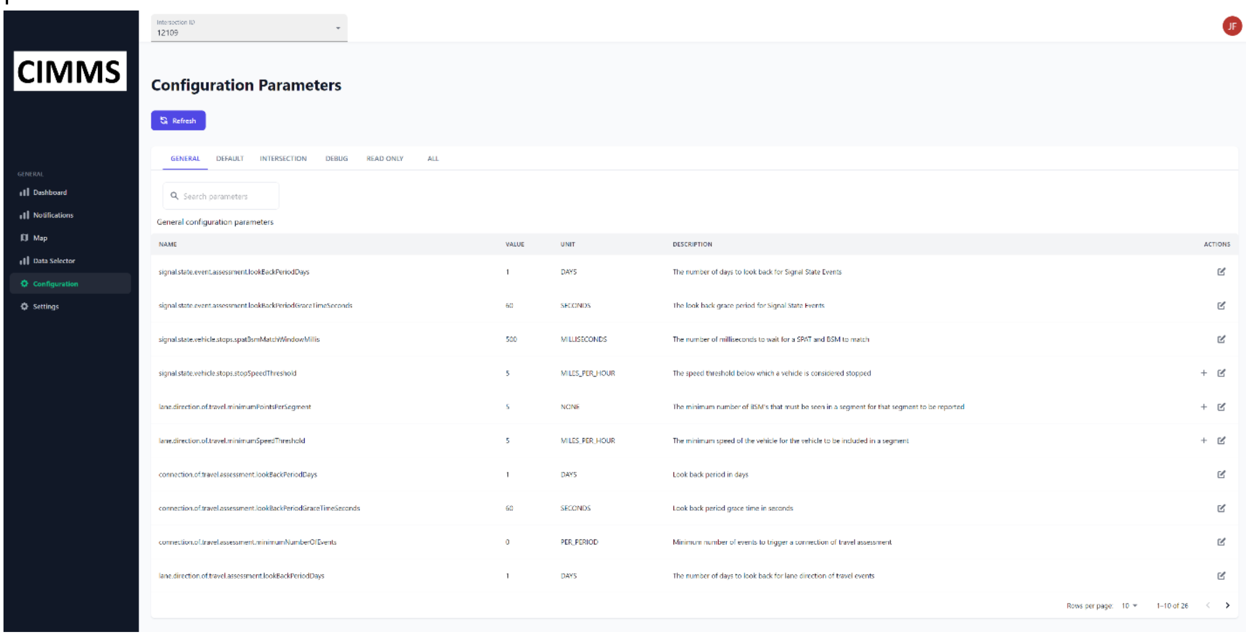


Note: The image in this figure is based on development to date, and while representative, the final product may actually look different than shown in this figure.

Figure 9. Map Viewer – Conflict Monitor Vehicle Simulator Screen

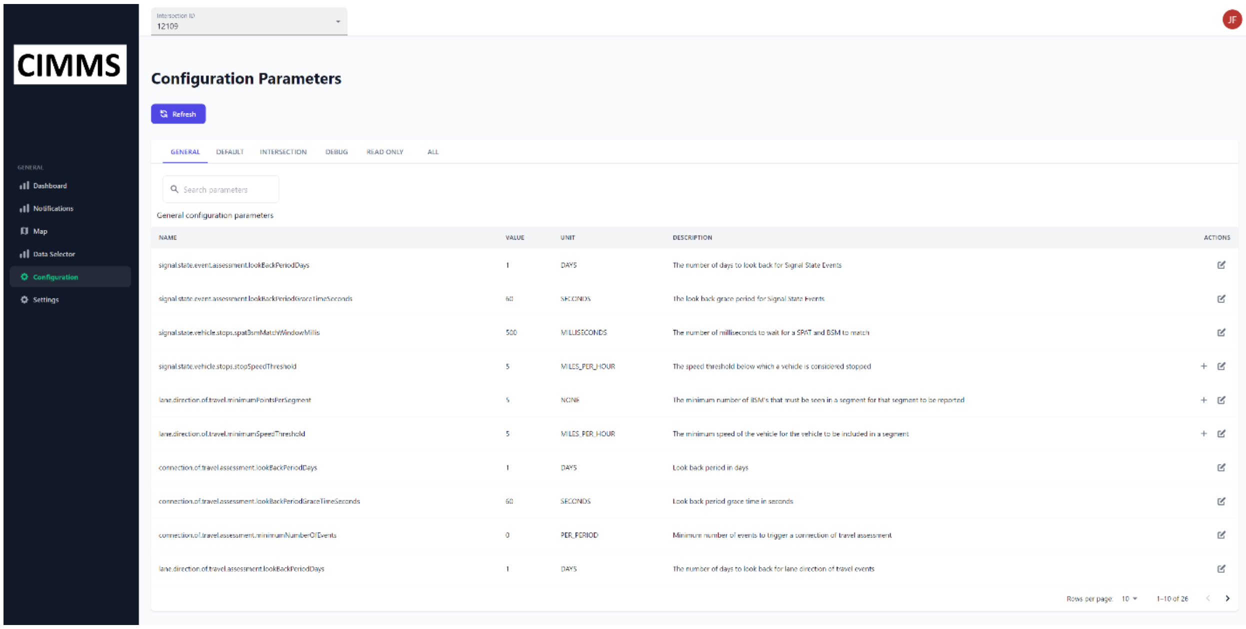
3.3.11 Algorithm Parameter Configuration.

The settings screen provides a list of fields that allows the user to specify a value for each setting. The types of settings that are configurable are provided in section 3.4, as indicated by data structures that use "Configuration" in the title. The fields on this screen may include text boxes, radio buttons, drop-down menus, check boxes, etc. as needed. When the user clicks on a "Save Settings" button, the settings are saved to the database. The Algorithm Parameter Configuration screen is restricted to the administrator access only (since these parameters modify the operational functions that generate events or assessments). A representative example of the Algorithm Parameter Configuration screen is provided in section



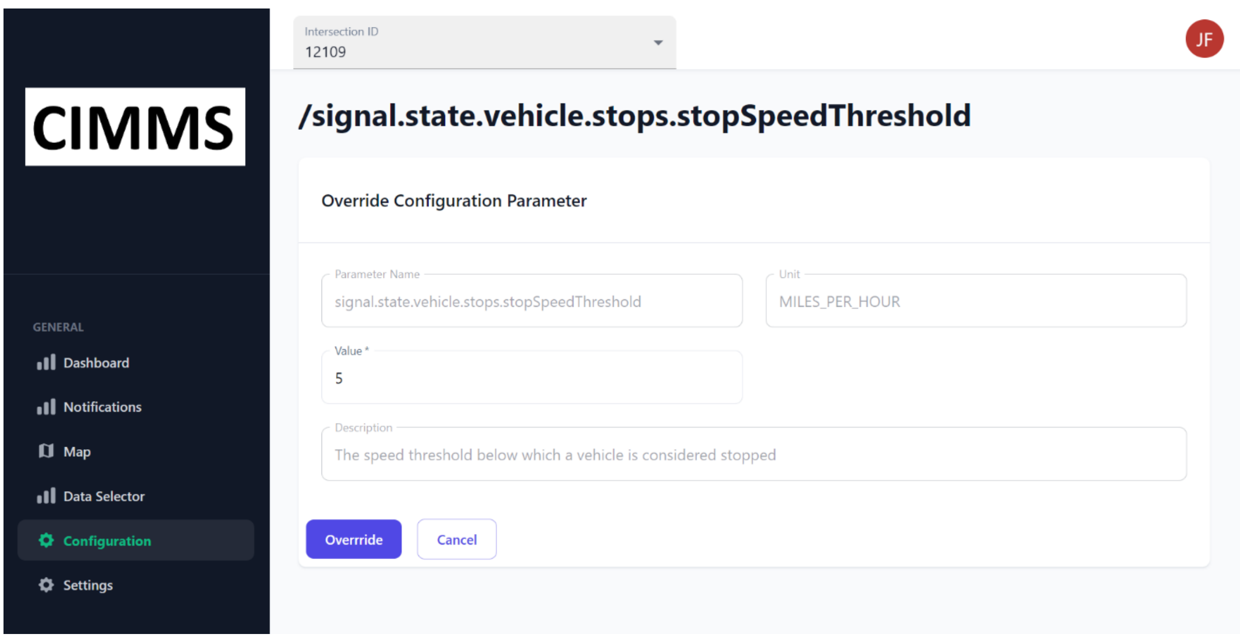
Note: The image in this figure is based on development to date, and while representative, the final product may actually look different than shown in this figure.

Figure 10.



Note: The image in this figure is based on development to date, and while representative, the final product may actually look different than shown in this figure.

Figure 10. Settings Screen Example



Note: The image in this figure is based on development to date, and while representative, the final product may actually look different than shown in this figure.

Figure 11. Intersection-Specific Setting

3.3.12 User Settings Configuration

The User Settings Configuration allows the user to select their preference for receiving emails based on notifications from the CIMMS. Each user is given access to their own User Settings Configuration.

3.4 DATA STRUCTURES AND DESCRIPTION

The CIMMS will utilize the data structures listed in Table 2. The data elements included in these data structures are provided in the remaining tables in this section. The data type, any applicable standards, and a description of each data element are provided.

Table 2. List of Data Structures

CV Message Storage	Table 3. Raw J2735 CV Messages
	Table 4. JavaScript Object Notation (JSON) CV Messages
	Table 5. GeoJSON CV Messages
Fundamental SPaT/MAP Broadcast Data	Table 6. Intersection Reference Alignment Event
	Table 7. Signal Group Alignment Event
	Table 8. SPaT Broadcast Rate Event
	Table 9. SPaT Broadcast Rate Notification Configuration
	Table 10. MAP Broadcast Rate Event
	Table 11. MAP Broadcast Rate Notification Configuration
	Table 12. SPaT Minimum Data Event
	Table 13. MAP Minimum Data Event
Stop Line Passage Event Data	Table 14. Stop Line Passage Event
	Table 15. Stop Line Passage Event Configuration
	Table 16. Stop Line Passage Assessment
	Table 17. Stop Line Passage Assessment/Notification Configuration
Stop Line Stop Event Data	Table 18. Stop Line Stop Event
	Table 19. Stop Line Stop Event Configuration
	Table 20. Stop Line Stop Assessment
	Table 21. Stop Line Stop Assessment/Notification Configuration
Lane Direction of Travel Data	Table 22. Lane Direction of Travel Event
	Table 23. Lane Direction of Travel Event Configuration
	Table 24. Lane Direction of Travel Assessment
	Table 25. Lane Direction of Travel Assessment/Notification Configuration
Connection of Travel Data	Table 26. Connection of Travel Event
	Table 27. Connection of Travel Assessment
	Table 28. Connection of Travel Assessment/Notification Configuration
Signal State Conflict Data	Table 29. Signal State Conflict Event
	Table 30. Signal State Conflict Event Configuration
Time Change Details Data	Table 31. Time Change Details Event
Settings Data	Table 32. Other Configurable Settings
	Table 33. Data Retention Configuration
	Table 34. User Configuration
	Table 35. (RSU) Source Information

Table 3. Raw J2735 CV Messages

Data	Type	Standards	Description
Time Received	string	ISO 8601	Time that the RSU received and/or forwarded the data contained in the payload element
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The source ID field is added by the ODE when the message is received from a given RSU. It is selected based upon the device the ODE receives data from.*
Message Type	string OR integer	SAE J2735 7.42	Acronym commonly used for message types (e.g., SPaT, MAP, BSM, etc.) OR integer value associated with the message ID.
ASN.1 Payload	string	J2735 ASN_202211	ASN.1 UPER hex-encoded message payload.

Table 4. JavaScript Object Notation (JSON) CV Messages

Data	Type	Standards	Description
Time Received	string	ISO 8601	Time that the RSU received and/or forwarded the data contained in the payload element
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Message Type	string OR integer	SAE J2735 7.42	Acronym commonly used for message types (e.g., SPaT, MAP, BSM, etc.) OR integer value associated with the message ID.
JSON Payload	string	N/A	JSON-encoded message payload. The JSON payload shall be structured in a manner similar to the structure of the message defined in SAE J2735 and use element names that are same as data frame and data element names specified in SAE J2735. *Note: Ideally, these JSON messages are compatible with the CI test tools that CAMP has developed.*

Table 5. GeoJSON CV Messages

Data	Type	Standards	Description
Time Received	string	ISO 8601	Time that the RSU received and/or forwarded the data contained in the payload element
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Message Type	string OR integer	SAE J2735 7.42	Acronym commonly used for message types (e.g., SPaT, MAP, BSM, etc.) OR integer value associated with the message ID.
GeoJSON Payload	string	N/A	GeoJSON-encoded message payload.

Table 6. Intersection Reference Alignment Event

Data	Type	Standards	Description
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Begin Timestamp	String	ISO 8601	Timestamp corresponding to the beginning of the period over which SPaT and MAP messages were processed to generate the results below.
End Timestamp	String	ISO 8601	Timestamp corresponding to the end of the period over which SPaT and MAP messages were processed to generate the results below.
Road Regulator ID List (SPaT)	Integer array	SAE J2735 7.168	A list of unique road regulator IDs (listed in increasing order) from SPaT messages from the given source broadcast from the begin timestamp until the end timestamp.
Road Regulator ID List (MAP)	Integer array	SAE J2735 7.168	A list of unique road regulator IDs (listed in increasing order) from MAP messages from the given source broadcast from the begin timestamp until the end timestamp.
Intersection ID List (SPaT)	Integer array	SAE J2735 7.62	A list of unique intersection IDs (listed in increasing order) from SPaT messages from the given source broadcast from the begin timestamp until the end timestamp.
Intersection ID List (MAP)	Integer array	SAE J2735 7.62	A list of unique intersection IDs (listed in increasing order) from MAP messages from the given source broadcast from the begin timestamp until the end timestamp.

Table 7. Signal Group Alignment Event

Data	Type	Standards	Description
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Begin Timestamp	String	ISO 8601	Time that represents the beginning of the period over which MAP and SPaT messages are processed for the purpose of generating the list of Signal Group IDs in the elements below.
End Timestamp	String	ISO 8601	Time that represents the end of the period over which MAP and SPaT messages are processed for the purpose of generating the list of Signal Group IDs in the elements below.
Signal Group ID List (SPaT)	Integer array	SAE J2735 7.182	A list of unique signal group IDs (listed in increasing order) from SPaT messages from the given source broadcast from the begin timestamp until the end timestamp.
Signal Group ID List (MAP)	Integer array	SAE J2735 7.182	A list of unique signal group IDs (listed in increasing order) from MAP messages from the given source broadcast from the begin timestamp until the end timestamp.

Table 8. SPaT Broadcast Rate Event

Data	Type	Standards	Description
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Begin Timestamp	String	ISO 8601	Time that represents the beginning of the period over which SPaT messages are processed for the purpose of generating the number of observed messages in the element below.
End Timestamp	String	ISO 8601	Time that represents the end of the period over which SPaT messages are processed for the purpose of generating the number of observed messages in the element below.
Number of Observed Messages	Integer	N/A	The number of SPaT messages broadcast from the given source from the begin timestamp until the end timestamp.

Table 9. SPaT Broadcast Rate Notification Configuration

Data	Type	Standards	Description
Min. 10-sec reception (notification)	Integer	N/A	The minimum number of SPaT messages allowed in a SPaT Broadcast Rate Event for issuing a notification.
Max. 10-sec reception (notification)	integer	N/A	The maximum number of SPaT messages allowed in a SPaT Broadcast Rate Event for issuing a notification.
Min. 10-sec reception (CBR)	Integer	N/A	The minimum number of SPaT messages allowed in a SPaT Broadcast Rate Event for issuing a CBR.
Max. 10-sec reception (CBR)	integer	N/A	The maximum number of SPaT messages allowed in a SPaT Broadcast Rate Event for issuing a CBR.

Note: This configurable setting can only be modified by an administrator level user.

Table 10. MAP Broadcast Rate Event

Data	Type	Standards	Description
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Begin Timestamp	String	ISO 8601	Time that represents the beginning of the period over which MAP messages are processed for the purpose of generating the number of observed messages in the element below.
End Timestamp	String	ISO 8601	Time that represents the end of the period over which MAP messages are processed for the purpose of generating the number of observed messages in the element below.
Number of Observed Messages	String array	N/A	The number of MAP messages broadcast from the given source from the begin timestamp until the end timestamp.

Table 11. MAP Broadcast Rate Notification Configuration

Data	Type	Standards	Description
Min. 10-sec reception (notification)	Integer	N/A	The minimum number of MAP messages allowed in a SPaT Broadcast Rate Event for issuing a notification.
Max. 10-sec reception (notification)	integer	N/A	The maximum number of MAP messages allowed in a SPaT Broadcast Rate Event for issuing a notification.
Min. 10-sec reception (CBR)	Integer	N/A	The minimum number of MAP messages allowed in a SPaT Broadcast Rate Event for issuing a CBR.
Max. 10-sec reception (CBR)	integer	N/A	The maximum number of MAP messages allowed in a SPaT Broadcast Rate Event for issuing a CBR.

Note: This configurable setting can only be modified by an administrator level user.

Table 12. SPaT Minimum Data Event

Data	Type	Standards	Description
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Begin Timestamp	String	ISO 8601	Time that represents the beginning of the period over which SPaT messages are processed for the purpose of generating the data element list in the element below.
End Timestamp	String	ISO 8601	Time that represents the end of the period over which SPaT messages are processed for the purpose of generating the data element list in the element below.
Data Element List	String array	N/A	A list of CTI 4501 data elements required, but not included in SPaT messages broadcast from the given source from the begin timestamp until the end timestamp

Table 13. MAP Minimum Data Event

Data	Type	Standards	Description
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Begin Timestamp	String	ISO 8601	Time that represents the beginning of the period over which MAP messages are processed for the purpose of generating the data element list in the element below.
End Timestamp	String	ISO 8601	Time that represents the end of the period over which MAP messages are processed for the purpose of generating the data element list in the element below.
Data Element List	String array	N/A	A list of CTI 4501 data elements required, but not included in MAP messages broadcast from the given source from the begin timestamp until the end timestamp

Table 14. Stop Line Passage Event

Data	Type	Standards	Description
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Timestamp	String	ISO 8601	Time from the vehicle BSM when the vehicle is considered to have passed the stop line (i.e., end of ingress lane, see algorithm).
Road regulator ID	Integer	SAE J2735 7.168	The road regulator id from the MAP (or matching SPaT) message containing the lane that the BSM-producing vehicle is driving along.
Intersection ID	integer	SAE J2735 7.62	The intersection id from the MAP (or matching SPaT) message containing the lane that the BSM-producing vehicle is driving along.
Lane ID	Integer	SAE J2735 7.94	The lane ID of the lane that the BSM-producing vehicle is driving along.
Signal Group	Integer	SAE J2735 7.182	The signal group associated with the movement the vehicle makes through the intersection.
Event State	String	SAE J2735 7.110	The event state of the signal group at the time the vehicle is considered to have passed the stop line.
Vehicle ID	Integer	SAE J2735 7.199	The vehicle id of the vehicle from the BSM.
Vehicle Latitude	double	SAE J2735 7.97	The latitude (decimal degrees) of the vehicle from the BSM at the time the vehicle is considered to have passed the stop line.
Vehicle Longitude	double	SAE J2735 7.101	The longitude (decimal degrees) of the vehicle from the BSM at the time the vehicle is considered to have passed the stop line.
Vehicle Heading	double	SAE J2735 7.58	The heading (decimal degrees, 0 is N increasing clockwise) of the vehicle from the BSM at the time the vehicle is considered to have passed the stop line.
Vehicle Speed	double	SAE J2735 7.191	The speed (mph) of the vehicle from the BSM at the time the vehicle is considered to have passed the stop line.

Table 15. Stop Line Passage Event Configuration

Data	Type	Standards	Description
Stop Line Min Distance	Double	N/A	Distance (ft) that the vehicle must pass within of the center of the stop line (end of ingress lane) for an event to be generated.
Heading tolerance	Double	N/A	Tolerance of the lane heading (decimal degrees) that the vehicle must be traveling within for an event to be generated.

Note: This configurable setting can only be modified by an administrator level user. The system uses two generalized data structures for the stop line passage event configuration – a default configuration structure, and an intersection-specific configuration structure, which a user can specify for each intersection.

Table 16. Stop Line Passage Assessment

Data	Type	Standards	Description
Begin Timestamp	String	ISO 8601	Time that represents the beginning of the period over which Stop Line Passage Events are processed for the purpose of generating results contained in data elements below.
End Timestamp	String	ISO 8601	Time that represents the end of the period over which Stop Line Passage Events are processed for the purpose of generating results contained in data elements below. This is the time the assessment is performed.
Road regulator ID	Integer	SAE J2735 7.168	The road regulator id from the Stop Line Passage Event that number of events contained in this data structure are aggregated by.
Intersection ID	integer	SAE J2735 7.62	The intersection id from the Stop Line Passage Event that number of events contained in this data structure are aggregated by.
Signal Group Results	Signal Group Results array	N/A	See below. Size of array is equal to the number of unique signal groups
Signal Group Results			
Signal Group	Integer	SAE J2735 7.182	The signal group from the Stop Line Passage Event that number of events contained in this data structure are aggregated by.
Number of events (eventState red),	Integer	N/A	The number of events (with the given road regulator ID, intersection I, and signal group) with a 'stop-and-remain' event state.
Number of events (eventState yellow),	Integer	N/A	The number of events (with the given road regulator ID, intersection I, and signal group) with a 'protected-clearance' or 'permissive-clearance' event state.
Number of events (eventState green	Integer	N/A	The number of events (with the given road regulator ID, intersection I, and signal group) with a 'protected-movement-allowed' or 'permissive-movement-allowed' event state.
Notification	Boolean	N/A	Indicates if the assessment results in a notification.

Table 17. Stop Line Passage Assessment/Notification Configuration

Data	Type	Standards	Description
Look Back Period	integer	N/A	The period of time (days) looking back from the current time, that event data is searched to perform the Stop Line Passage Assessment.
Speed Threshold	Double	N/A	Minimum speed (mph) that the vehicle must be traveling (as indicated in the Stop Line Passage Evet event) for the event to be included in the assessment.
Minimum red light percentage threshold (notification)	Integer	N/A	A threshold value that once exceeded, results in a notification (unless min. number of events has not been met)
Minimum red light percentage threshold (CBR)	Integer	N/A	A threshold value that once exceeded, results in a CBR (unless min. number of events has not been met)
Min number of events	Integer	N/A	The minimum number of events that must be included in an assessment in order for a notification or CBR to be issued.

Note: This configurable setting can only be modified by an administrator level user. The system uses two generalized data structures for the stop line passage assessment/notification configuration – a default configuration structure, and an intersection-specific configuration structure, which a user can specify for each intersection.

Table 18. Stop Line Stop Event

Data	Type	Standards	Description
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Road regulator ID	Integer	SAE J2735 7.168	The road regulator id from the MAP (or matching SPaT) message containing the lane that the BSM-producing vehicle stops in.
Intersection ID	integer	SAE J2735 7.62	The intersection id from the MAP (or matching SPaT) message containing the lane that the BSM-producing vehicle stops in.
Ingress Lane	Integer	SAE J2735 7.94	The lane ID of the lane that the BSM-producing vehicle comes to a stop in.
Signal Group	Integer	SAE J2735 7.182	The signal group associated with the movement the vehicle makes through the intersection.
Vehicle ID	Integer	SAE J2735 7.199	The vehicle id of the vehicle from the BSM.
Vehicle Latitude	Double	SAE J2735 7.97	The latitude (decimal degrees) of the vehicle from the BSM at the time the vehicle initially comes to a stop at the stop line.
Vehicle Longitude	Double	SAE J2735 7.101	The longitude (decimal degrees) of the vehicle from the BSM at the time the vehicle initially comes to a stop at the stop line.
Vehicle Heading	Double	SAE J2735 7.58	The heading (decimal degrees, 0 is N increasing clockwise) of the vehicle from the BSM at the time the vehicle initially comes to a stop at the stop line.
Initial Event State	String	SAE J2735 7.110	The event state of the signal group at the time the vehicle initially comes to a stop.
Initial Timestamp	String	ISO 8601	The time the vehicle initially comes to a stop.
Final Event State	String	SAE J2735 7.110	The event state of the signal group just prior to the vehicle starting to move again (the final moment it was at a stop).
Final Timestamp	String	ISO 8601	The time just prior to the vehicle starting to move again (the final moment it was at a stop).
Time stopped during Red	Double	N/A	The amount of time (seconds) the event state was 'stop-and-remain' while the vehicle was stopped.
Time stopped during Yellow	Double	N/A	The amount of time (seconds) the event state was 'protected-clearance' or 'permissive-clearance' while the vehicle was stopped.
Time stopped during Green	Double	N/A	The amount of time (seconds) the event state was 'protected-movement-allowed' or 'permissive-movement-allowed' while the vehicle was stopped.

Table 19. Stop Line Stop Event Configuration

Data	Type	Standards	Description
Upstream Search Distance	Double	N/A	Starting from the stop line and moving upstream, the length (ft) of the ingress lane a vehicle must come to a stop in for an event to be generated.
Heading tolerance	Double	N/A	Tolerance of the lane heading (decimal degrees) that the vehicle must be traveling within for an event to be generated.
Speed Threshold	Double	N/A	Maximum speed (mph) that the vehicle must be traveling under for a vehicle considered to be stopped. *Note: BSMs from some OBUs will intermittently exhibit non-zero (very low) speed values even while the vehicle is at a complete stop.*
Min Time Stopped	Integer	N/A	The minimum amount of time (seconds) (between the time a vehicle initially comes to a stop until the last moment the vehicle is stopped) for a Stop Line Stop event to be generated.

Note: This configurable setting can only be modified by an administrator level user. The system uses two generalized data structures for the stop line stop event configuration – a default configuration structure, and an intersection-specific configuration structure, which a user can specify for each intersection.

Table 20. Stop Line Stop Assessment

Data	Type	Standards	Description
Begin Timestamp	String	ISO 8601	Time that represents the beginning of the period over which Stop Line Passage Events are processed for the purpose of generating results contained in data elements below.
End Timestamp	String	ISO 8601	Time that represents the end of the period over which Stop Line Passage Events are processed for the purpose of generating results contained in data elements below. This is the time the assessment is performed.
Road regulator ID	Integer	SAE J2735 7.168	The road regulator id from the Stop Line Passage Event that number of events contained in this data structure are aggregated by.
Intersection ID	integer	SAE J2735 7.62	The intersection id from the Stop Line Passage Event that number of events contained in this data structure are aggregated by.
Signal Group Results	Signal Group Results array	N/A	See below. Size of array is equal to the number of unique signal groups
Signal Group Results			
Signal Group	Integer	SAE J2735 7.182	The signal group from the Stop Line Passage Event that number of events contained in this data structure are aggregated by.
Number of Events	Integer	N/A	The total number of events represented in the aggregated values below.
Time stopped during Red	Double	N/A	The total amount of time (seconds) vehicles were stopped during a ‘stop-and-remain’ event state.
Time stopped during Yellow	Double	N/A	The total amount of time (seconds) vehicles were stopped during a ‘protected-clearance’ or ‘permissive-clearance’ event state.
Time stopped during Green	Double	N/A	The total amount of time (seconds) vehicles were stopped during a ‘protected-movement-allowed’ or ‘permissive-movement-allowed’ event state.
Notification	Boolean	N/A	Indicates if the assessment results in a notification.

Table 21. Stop Line Stop Assessment/Notification Configuration

Data	Type	Standards	Description
Look Back Period	integer	N/A	The period of time (days), looking back from the current time, that event data is searched to perform the Stop Line Passage Assessment.
Percentage of time Stop During Green Threshold (notification)	Integer	N/A	A threshold value that once exceeded, results in a notification (unless min. number of events has not been met)
Percentage of time Stop During Green Threshold (CBR)	Integer	N/A	A threshold value that once exceeded, results in a CBR (unless min. number of events has not been met)
Min number of events	Integer	N/A	The minimum number of events that must be included in an assessment in order for a notification or CBR to be issued.

Note: This configurable setting can only be modified by an administrator level user. The system uses two generalized data structures for the stop line stop assessment/notification configuration – a default configuration structure, and an intersection-specific configuration structure, which a user can specify for each intersection.

Table 22. Lane Direction of Travel Event

Data	Type	Standards	Description
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This value is populated*
Road regulator ID	Integer	SAE J2735 7.168	The road regulator id from the MAP (or matching SPaT) message containing the lane that the BSM-producing vehicle is traveling in.
Intersection ID	integer	SAE J2735 7.62	The intersection id from the MAP (or matching SPaT) message containing the lane that the BSM-producing vehicle is traveling in.
Lane ID	Integer	SAE J2735 7.94	The lane ID of the lane that the BSM-producing vehicle is traveling in. May be an ingress or an egress lane.
Segment Results	Segment Results Array	N/A	An array of Segment Results. This is an indexed array, where the array index corresponds to the order of points in the MAP message that comprises each lane segment. See description below
Segment Results			
Timestamp	String	ISO 8601	The timestamp when the vehicle is first observed in the segment.
Total Segment Length	Double	N/A	The length of the segment, based on offsets in the MAP message.
Length of Travel in Segment	Double	N/A	The distance between the first and last BSM latitude/longitude points in the segment.
Expected Heading	Double	N/A	The heading of the segment, based on the offsets in the MAP message
Vehicle Median Heading	Double	N/A	The median heading (decimal degrees, 0 is N increasing clockwise) of the vehicle while it is located in the segment, based on the headings in BSMs
Vehicle Number of Points	Integer	N/A	The number of BSM latitude/longitude points located in the lane segment.
Vehicle Median Distance from CL	Double	N/A	The median distance (feet) the vehicle is from the centerline while in the segment.

Table 23. Lane Direction of Travel Event Configuration

Data	Type	Standards	Description
Speed Threshold	Double	N/A	The minimum speed that a vehicle must be traveling for its heading data to be included in the calculations of segment results.
Number of points	Integer	N/A	The minimum number of BSM latitude/longitude points located in the entire lane to determine if an event should be generated.

Note: This configurable setting can only be modified by an administrator level user. The system uses two generalized data structures for the lane direction of travel configuration – a default configuration structure, and an intersection-specific configuration structure, which a user can specify for each intersection.

Table 24. Lane Direction of Travel Assessment

Data	Type	Standards	Description
Begin Timestamp	String	ISO 8601	Time that represents the beginning of the period over which Lane Direction of Travel Events are processed for the purpose of generating results contained in data elements below.
End Timestamp	String	ISO 8601	Time that represents the end of the period over which Lane Direction of Travel Events are processed for the purpose of generating results contained in data elements below. This is the time the assessment is performed.
Road regulator ID	Integer	SAE J2735 7.168	The road regulator id from the Lane Direction of Travel Event that number of events contained in this data structure are aggregated by.
Intersection ID	integer	SAE J2735 7.62	The intersection id from the Lane Direction of Travel Event that number of events contained in this data structure are aggregated by.
Segment Results	Segment Results Array	N/A	An array of segment-based results.
Segment Results			
Lane ID	Integer	SAE J2735 7.94	The Lane ID containing the segment this result is for
Segment Number	Integer		The segment number of the given Lane ID this result is for.
Number of events	Integer	N/A	The total number of events represented in the aggregated values below
Heading Difference (dHeading)	Double	N/A	The difference between the median value of the Vehicle Median Heading of all events and the actual lane heading (decimal degrees, 0 is the true direction of the lane increasing clockwise)
Median Distance from CL	Double	N/A	The median value (feet) of the Vehicle Median Distance from CL of all events
Notification	Boolean	N/A	Indicates if the assessment results in a notification.

Table 25. Lane Direction of Travel Assessment/Notification Configuration

Data	Type	Standards	Description
Look Back Period	integer	N/A	The period of time (days), looking back from the current time, that event data is searched to perform the Stop Line Passage Assessment.
Heading Tolerance (notification)	Double	N/A	When the difference between the median heading from the assessment results and the actual heading is greater than this value (decimal degrees), a notification is issued.
Max Dist from Lane CL (notification)	Double	N/A	When the Median Distance from CL exceeds this value (feet), a notification is issued.
Heading Tolerance (CBR)	Double	N/A	When the difference between the median heading from the assessment results and the actual heading is greater than this value (decimal degrees), a CBR is issued.
Max Dist from Lane CL (CBR)	Double	N/A	When the Median Distance from CL exceeds this value (feet), a CBR is issued.
Min number of events	Integer	N/A	The minimum number of events that must be included in the segment assessment in order for a notification or CBR to be issued.

Note: This configurable setting can only be modified by an administrator level user. The system uses two generalized data structures for the lane direction of travel assessment/notification configuration – a default configuration structure, and an intersection-specific configuration structure, which a user can specify for each intersection.

Table 26. Connection of Travel Event

Data	Type	Standards	Description
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Timestamp	String	ISO 8601	Time from the vehicle BSM when the vehicle is considered to have passed the stop line (i.e., end of ingress lane, see algorithm).
Road regulator ID	Integer	SAE J2735 7.168	The road regulator id from the MAP message containing the ingress and egress lanes that the BSM-producing vehicle travels between.
Intersection ID	integer	SAE J2735 7.62	The intersection id from the MAP message containing the ingress and egress lanes that the BSM-producing vehicle travels between.
Ingress Lane ID	integer	SAE J2735 7.94	The lane ID of the ingress lane that the vehicle is traveling on when it crosses the stop line. This value may be null if an ingress lane was not identified.
Egress Lane ID	Integer	SAE J2735 7.94	The lane ID of the egress lane that the vehicle is traveling on when it initially exits the intersection. This value may be null if an egress lane was not identified.
Connection Identified	Boolean	N/A	Indicates if the MAP message contains a connection for the ingress-egress pair given above.

Note: There are no configuration settings for the Connection of Travel Event

Table 27. Connection of Travel Assessment

Data		Type	Standards	Description
Begin Timestamp		String	ISO 8601	Time that represents the beginning of the period over which Connection of Travel Events are processed for the purpose of generating results contained in data elements below.
End Timestamp		String	ISO 8601	Time that represents the end of the period over which Lane Connection of Travel Events are processed for the purpose of generating results contained in data elements below. This is the time the assessment is performed.
Ingress-Egress Pair Results		Ingress-Egress Pair Results Array	N/A	An array of results for each ingress-egress pair.
	Ingress-Egress Pair Results			
	Ingress Lane ID	Integer	SAE J2735 7.94	The ingress Lane ID this result is for. This value may be null if an ingress lane was not identified.
	Egress Lane ID	Integer	SAE J2735 7.94	The egress Lane ID this result is for. This value may be null if an egress lane was not identified.
	Connection not identified	Integer	N/A	Indicates the number of times the given ingress-egress pair was not identified as a connection in the MAP message. Note: if the MAP message does not change, this value will either be 0 or equal to the number of events.
	Number of events	Integer	N/A	The number of events during the assessment period that pass between the given ingress lane ID and egress lane ID.
	Notification	Boolean	N/A	Indicates if the assessment results in a notification.

Table 28. Connection of Travel Assessment/Notification Configuration

Data	Type	Standards	Description
Look Back Period	Integer	N/A	The period of time (days), looking back from the current time, that event data is searched to perform the Connection of Travel Assessment.
Max number of events (notification)	Integer	N/A	The maximum allowable value for the Connection Not Identified in the ingress-egress pair connection of travel assessment in order for a notification to be issued.
Max number of events (CBR)	Integer	N/A	The maximum allowable value for the Connection Not Identified in the ingress-egress pair connection of travel assessment in order for a CBR to be issued.

Note: This configurable setting can only be modified by an administrator level user. The system uses two generalized data structures for the connection of travel assessment/notification configuration – a default configuration structure, and an intersection-specific configuration structure, which a user can specify for each intersection.

Table 29. Signal State Conflict Event

Data	Type	Standards	Description
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Timestamp	String	ISO 8601	The timestamp from the SPaT message when the conflict is observed.
Road Regulator ID	Integer	SAE J2735 7.168	The road regulator id from the SPaT message.
Intersection ID	integer	SAE J2735 7.62	The intersection id from the SPaT message.
Protected or Permissive	String	N/A	Indicates if the type of conflict is associated with a protected movement or a permissive movement. If one or more of the conflicting movements is protected, then this value will indicate protected. Otherwise, it will indicate permissive.
Conflicting Signal Group ID A	Integer	SAE J2735 7.182	The Signal Group ID of one of the conflicting connections
Ingress Lane A	Integer	SAE J2735 7.94	The ingress lane ID associated with the first conflicting connection
Egress Lane A	Integer	SAE J2735 7.94	The egress lane ID associated with the first conflicting connection
Event State A	String	SAE J2735 7.110	The event state of the first conflicting connection, when the conflict is noted.
Conflicting Signal Group ID B	Integer	SAE J2735 7.182	The Signal Group ID of one of the other conflicting connection
Ingress Lane B	Integer	SAE J2735 7.94	The ingress lane associated with the second conflicting connection
Egress Lane B	Integer	SAE J2735 7.94	The egress lane associated with the second conflicting connection
Event State B	String	SAE J2735 7.110	The event state of the second conflicting connection, when the conflict is noted.

Table 30. Signal State Conflict Event Configuration

Data		Type	Standards	Description
Allowed concurrent permissive movements		Allowed concurrent permissive movements array	N/A	An array of signal group pairs that are allowed to be concurrently permissive.
	Allowed Concurrent Permissive Movements			
	Signal Group ID A	Integer	SAE J2735 7.182	The signal group indicated here is allowed to be permissive at the same time as Signal Group ID B.
	Signal Group ID B	Integer	SAE J2735 7.182	The signal group indicated here is allowed to be permissive at the same time as Signal Group ID A.

Note: This configurable setting can only be modified by an administrator level user. The system uses two generalized data structures for the signal state conflict event configuration – a default configuration structure, and an intersection-specific configuration structure, which a user can specify for each intersection.

Table 31. Time Change Details Event

Data	Type	Standards	Description
Source	string OR integer	N/A	Value used by the CIMMS to identify a unique intersection, such as an index, numerical ID, IP address, intersection name, etc. *Note: The content in this field is not to be derived from message content received from the RSU. This is a value configured during the system setup.*
Road Regulator ID	Integer	SAE J2735 7.168	The road regulator id from the SPaT message.
Intersection ID	integer	SAE J2735 7.62	The intersection id from the SPaT message.
Signal Group ID	Integer	SAE J2735 7.182	The signal group for which the issue in the time change details progression is observed.
TimeMark Type	String	SAE J2735 6.147	The timemark type (e.g., minEndTime, maxEndTime) from the time change details for which values are not progressing properly.
Timestamp A	String	ISO 8601	The timestamp from the first SPaT message when the conflict is observed.
TimeMark A	Integer	SAE J2735 7.206	The time mark value from the first SPaT message when the conflict is observed.
Event State A	String	SAE J2735 7.110	The event state value from the first SPaT message when the conflict is observed.
Timestamp B	String	ISO 8601	The timestamp from the second (subsequent) SPaT message when the conflict is observed.
TimeMark B	Integer	SAE J2735 7.206	The time mark value from the second (subsequent) SPaT message when the conflict is observed.
Event State B	String	SAE J2735 7.110	The event state value from the second (subsequent) SPaT message when the conflict is observed.

Note: There are no configuration settings for the Time Change Details Event

Table 32. Other Configurable Settings

Data	Type	Standards	Description
Event Processing Frequency	integer	N/A	The periodicity (seconds) with which CV data are processed to

Table 33. Data Retention Configuration

Data	Type	Standards	Description
CV Message Data Retention	Integer	N/A	The amount of time (days) of CV data (ASN.1, JSON, and GeoJSON) are stored on the database. Stored messages older than the value specified are released from memory.
Event Data Retention	Integer	N/A	The amount of time (days) of Events are stored on the database. Stored event data older than the value specified are released from memory.
Assessment Data Retention	Integer	N/A	The amount of time (days) that assessment results are stored on the database. Stored assessment results older than the value specified are released from memory.

Table 34. User Configuration

Data	Type	Standards	Description
Notifications	Boolean	N/A	True: will receive email notifications, False: will not receive email notifications.

Note: This configurable setting can be modified by all user types. Each user may only modify the user configuration for their profile. The message monitor database does not store any user-related information required for credentials management, and thus is not defined here or elsewhere in other data structures. Keycloak is an open-source identity and access management tool that will be used to perform all functions of the Credentials Management component, and store data related to credentials management including but not limited to username, password, name, email, and access level (admin or view only).

Table 35. (RSU) Source Information

Data	Type	Standards	Description
Source ID	String	N/A	The source ID field is added by the ODE when the message is received from a given RSU. It is selected based upon the device the ODE receives data from, and not editable by the user.
IP Address	String	N/A	The IP address of the RSU
MAC Address	String	N/A	The MAC address of the RSU
Descriptive Name	String	N/A	A location description (e.g., intersection cross streets). *Note: this field is provided only for user reference purposes and is also displayed during any inputs when the user is selecting an intersection. This is not automatically populated with information from SPaT or MAP messages.*
Intersection ID	String	N/A	An optional numerical reference for the intersection. *Note: this field is provided only for user reference purposes and is also displayed during any inputs when the user is selecting an intersection. This is not automatically populated with information from SPaT or MAP messages.*
Controller	String	N/A	The name of the manufacturer/model of traffic signal controller located at the intersection *Note: this field is provided only for user reference purposes.*
Notes	String	N/A	Notes related to the RSU. *Note: this field is provided only for user reference purposes.*
Connectivity	Boolean	N/A	1 Connected, 2 Not Connected

Note: This configurable setting can only be modified by an administrator level user.

3.5 SOFTWARE / ALGORITHM DESIGN

Note: The algorithms defined in sections, 3.5.1, 3.5.2, 3.5.3, 3.5.4, 3.5.5, and 3.5.6 were initially presented in the Concept of Operations. These algorithms were developed earlier than usual in the systems engineering development process to determine if the concept behind the CIMMS project was reasonable before moving forward with requirements and detailed system design. As a result of the consensus reached amongst stakeholders for these algorithms during the development of the Concept of Operations, the details remain largely unchanged.

3.5.1 Stop Line Passage Event

In previous documents, this algorithm was referred to as "Signal State when Vehicle Crosses Stop Line"

The MAP message provides the intersection geometry data that is used to determine which intersection approach a vehicle is on. Specifically, the first point in each ingress approach lane geometry is used to determine the location of the stop line for each approach. The MAP messages use position offsets to calculate the location of lane centerline coordinates. To find the first point of each ingress lane (i.e., the location of the center of the stop line), the intersection reference latitude/longitude point is adjusted by the first offset value provided for the lane.

A fixed-distance buffer is applied to the location of stop line point at the end of each lane. This buffer is used as an initial means of filtering BSM data by location and has a configurable radius (initially set at 15 feet). The heading of the vehicle (extracted from the BSM) is also compared to the heading of the lane (i.e. the arctangent of the next x-y lane point offset) associated with the buffer to filter out vehicles that are moving in the incorrect direction relative to the direction of travel for traffic approaching the stop line – this intends to remove information associated with vehicles that are making a different movement through the intersection such as an opposing through movement or an intersecting left turn movement that may cut across or near the approach of interest. A configurable tolerance (initially set at ±20 degrees) from the calculated lane heading is allowed. Vehicle headings that fall outside of this tolerance are filtered out. This is flexible enough to capture vehicles moving across the stop line in the correct direction, but may have started a turning movement, while filtering out traffic that are not moving across the stop line in the correct direction.

At this point, there may be multiple BSMs (from the same vehicle having the same vehicle identifier) that fall within one or more stop line buffers (since they overlap). In this case, BSMs are processed sequentially to determine if one BSM falls closer to any stop line centerpoint than a previously identified BSM. If this is the case, data associated with the BSM (timestamp), the MAP message (lane ID), and the distance between the BSM and the stop line centerpoint are temporarily recorded. This is repeated for all BSMs with the same vehicle ID – once exhausted, the last values recorded contain the ingress lane ID of the stop line that the vehicle passes closest to, and the time when the vehicle is closest. The MAP message is used to determine the connections and signalGroup data associated with the identified lane. If the lane the vehicle is in has more than one connection, and those connections have multiple signal groups, then the egress lane is determined (see *Ingress and Egress Lane Direction of Travel* algorithm) and the connection is determined.

Finally, the SPaT message closest to the BSM timestamp is identified. The signal state of the identified signalGroup indicates the signal state (according to the SPaT message) when the vehicle crosses the stop line. Figure 12 on the following page provides a graphical reference for the logic described above.

The Message Monitor creates a Stop Line Passage Event. The data contained in the Stop Line Passage Event is provided in Section 3.4.

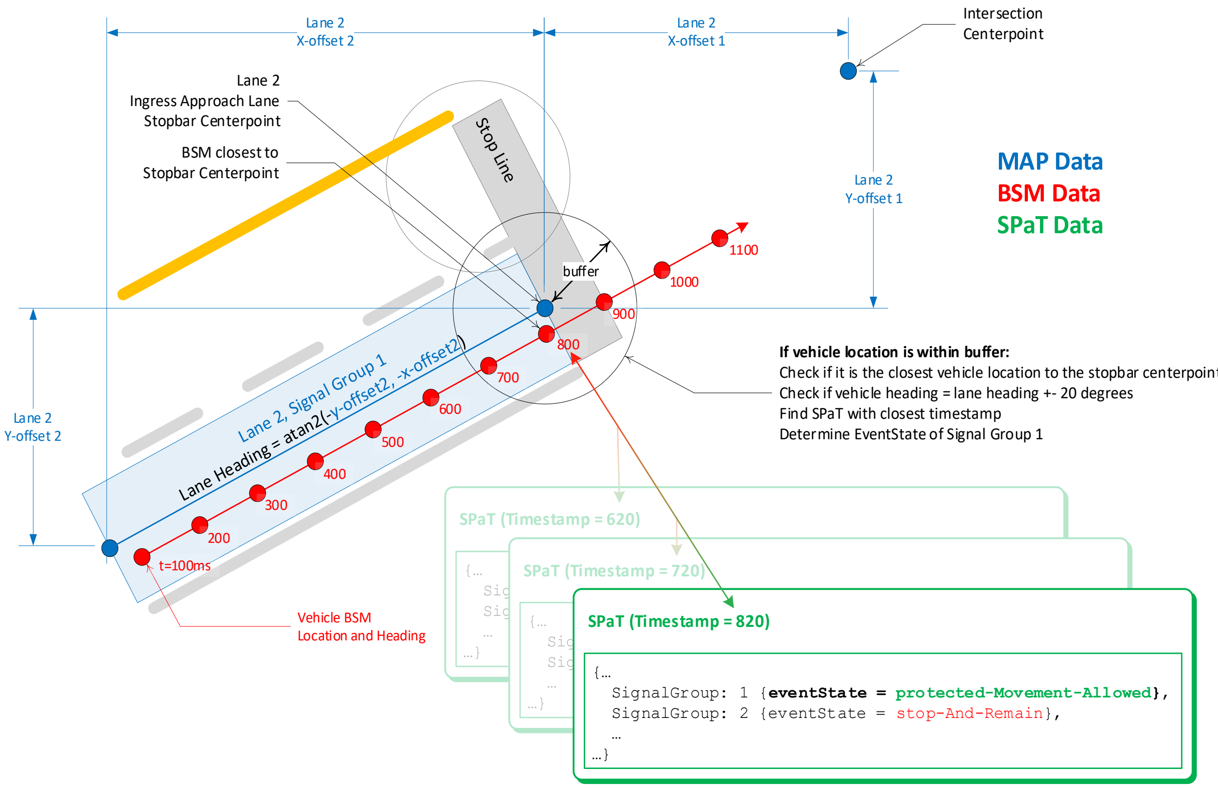


Figure 12: Visual Representation of Logic for determining Signal State when a Vehicle Crosses a Stop Line

3.5.2 Stop Line Stop Event

In previous documents, this algorithm was referred to as "Signal State when Vehicle Stops at Stop Line"

This algorithm follows a similar logic as the Stop Line Passage Event algorithm, described in the subsection above. The primary difference is this algorithm is looking for instances where the vehicle comes to a complete stop upstream of the stop line.

Using a similar process as defined previously for associating MAP, SPaT, and BSMs, the timestamp when a vehicle initially comes to a compete stop within a buffer (defined by the lane centerline, lane width, the stop line location, and the configured length value) is identified, and the final moment the vehicle is at a complete stop while in the buffer is also identified (Note: For simplicity, the vehicle is considered to be stopped at all times in between). All SPaT messages between these two timestamps are identified. The event state of the identified signalGroup for all relevant SPaT messages are determined. The amount of time the event state is "stop-and-remain", 'protected-clearance", "permissive-clearance, "protected-movement-allowed", and "permissive-movement-allowed" are identified. Figure 13 provides a graphical reference for the logic for this algorithm.

For each vehicle that comes to a stop within a buffer, the Message Monitor creates a Stop Line Stop Event. The data contained in the Stop Line Stop Event is provided in Section 3.4.

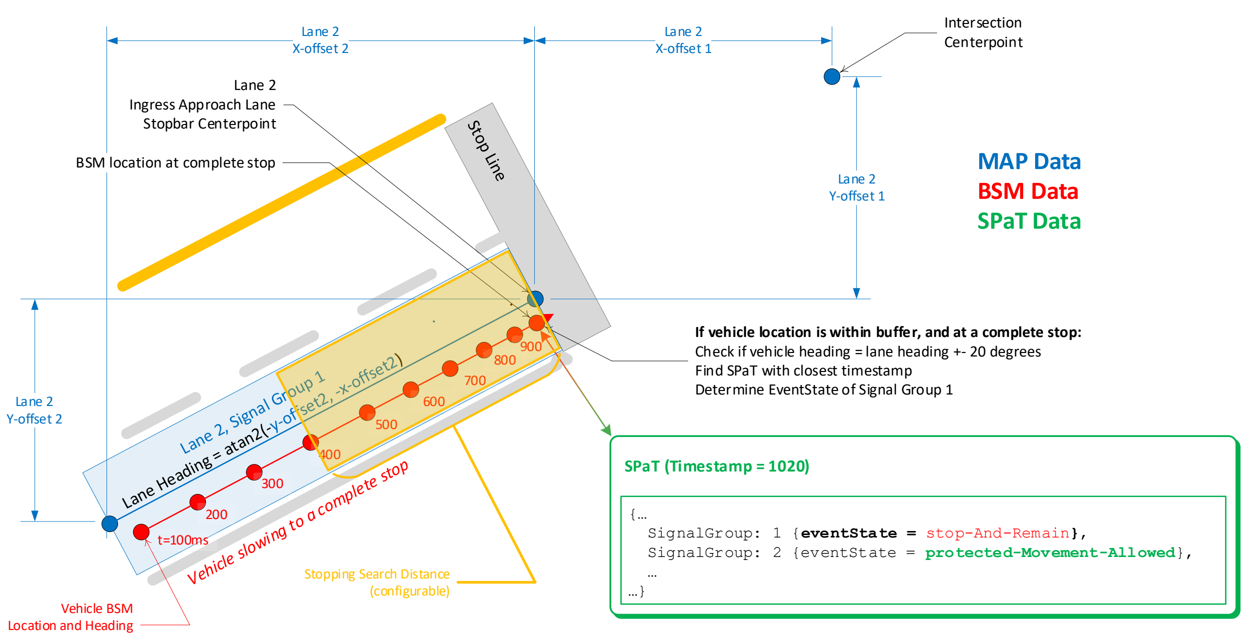


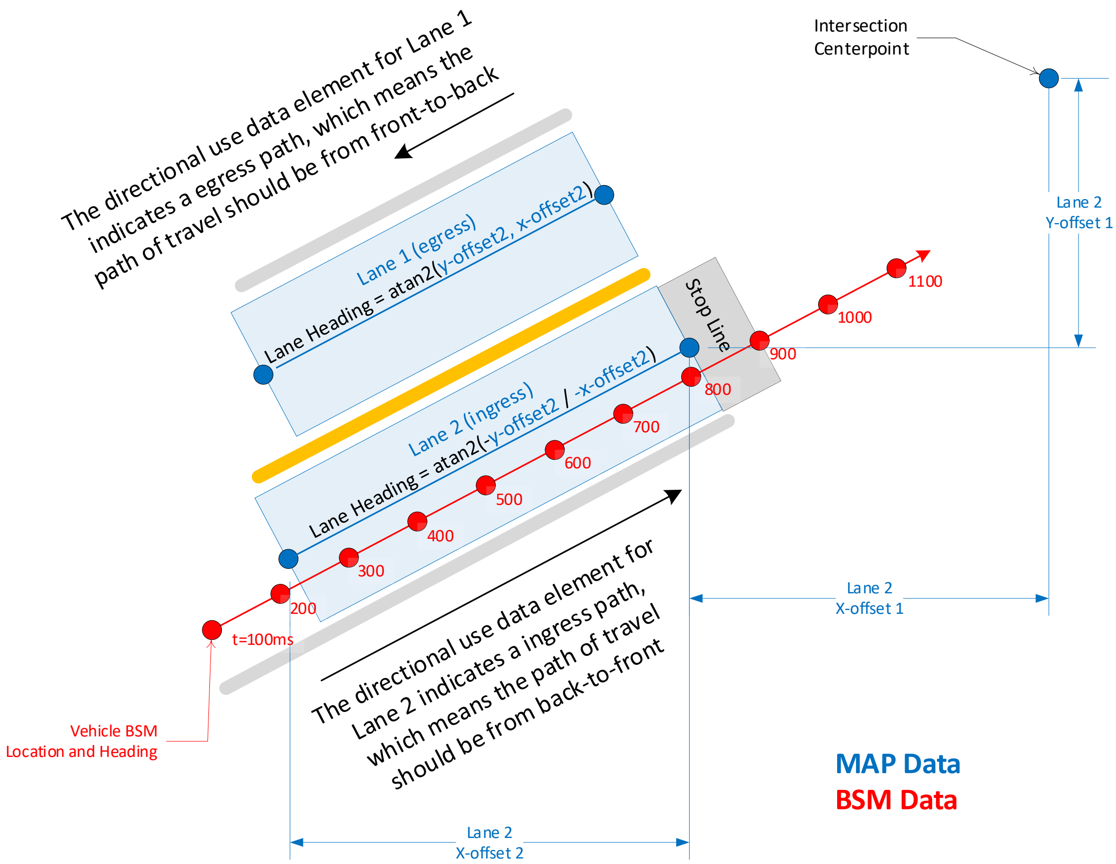
Figure 13: Visual Representation of Logic for determining Signal State when a Vehicle Stops at a Stop Line

3.5.3 Direction of Travel

The MAP message provides the lane centerline point data that is used to determine which ingress or egress approach a vehicle is on. Lane node point offsets and lane width offsets are used to generate polygons for each ingress and egress lane segment. A point-in-polygon sub-algorithm is used to determine if a BSM latitude and longitude point falls within each lane segment polygon. If the BSM latitude and longitude falls within the polygon, the vehicle ID, lane ID, and vehicle heading are temporarily recorded. If a configurable minimum number of BSM points from the same vehicle fall within in the lane polygon, the assessment continues.

All headings from the same vehicle are aggregated to the median heading – this represents the vehicle direction of travel within the lane segment. The aggregated heading is compared to the lane heading computed from the offset data, and the difference between these two values is recorded. All timestamps from the same vehicle are aggregated to the median timestamp. Figure 3 provides a graphical reference for the logic described above.

The Message Monitor creates an event log with the following data at a minimum: Event Type (lane direction), time (aggregated BSM timestamp), vehicle direction (aggregated BSM heading), difference between vehicle direction and computed lane direction, intersection id (from MAP), lane id (from MAP), lane segment number (from MAP), lane type (ingress/egress from MAP).



A minimum number of BSM points must fall within the lane polygon
BSM headings from the same vehicle (that fall inside of the polygon) are aggregated to the median heading.
This median vehicle heading is compared against the computed lane heading and this difference is recorded.

*Note that the lane heading equations vary slightly for ingress and egress lanes. Both arguments (offsets) of the atan2 function are positive for the egress lane, and are negative for the ingress lane since points are defined in the opposite order of the lane direction.

Figure 14: Visual Representation of Logic for determining Direction of Travel

3.5.4 Connection of Travel

This algorithm leverages many of the same processes that are used in the signal state determination algorithm. MAP messages and BSMs are used to determine which ingress lane stop line centerpoint the vehicle passes closest to – as well as the BSM timestamp when this occurs. Similarly, MAP messages and BSMs are used to determine which egress lane (initial) centerpoint the vehicle passes closest to – as well as the BSM timestamp when this occurs. Both an ingress lane and egress lane must be identified. If the BSM timestamp associated with the egress lane is greater than the BSM timestamp associated with the ingress lane, then it is assumed that the vehicle has traversed the intersection using these identified ingress and egress lanes. If this ingress-egress lane pair matches the ingress and egress lanes associated with the connections (in the MAP message), then the connection id is logged. If there is not a connection id associated with the identified ingress and egress lane ids, then this value is null.

The Message Monitor creates an event log with the following data at a minimum: Event Type (connection), ingress time (from BSM timestamp), egress time (from BSM timestamp), intersection id (from MAP), ingress lane id (from MAP), egress lane id (from MAP), ingress (stop line) location (from MAP), egress (initial) location (from MAP), connection number (from MAP).

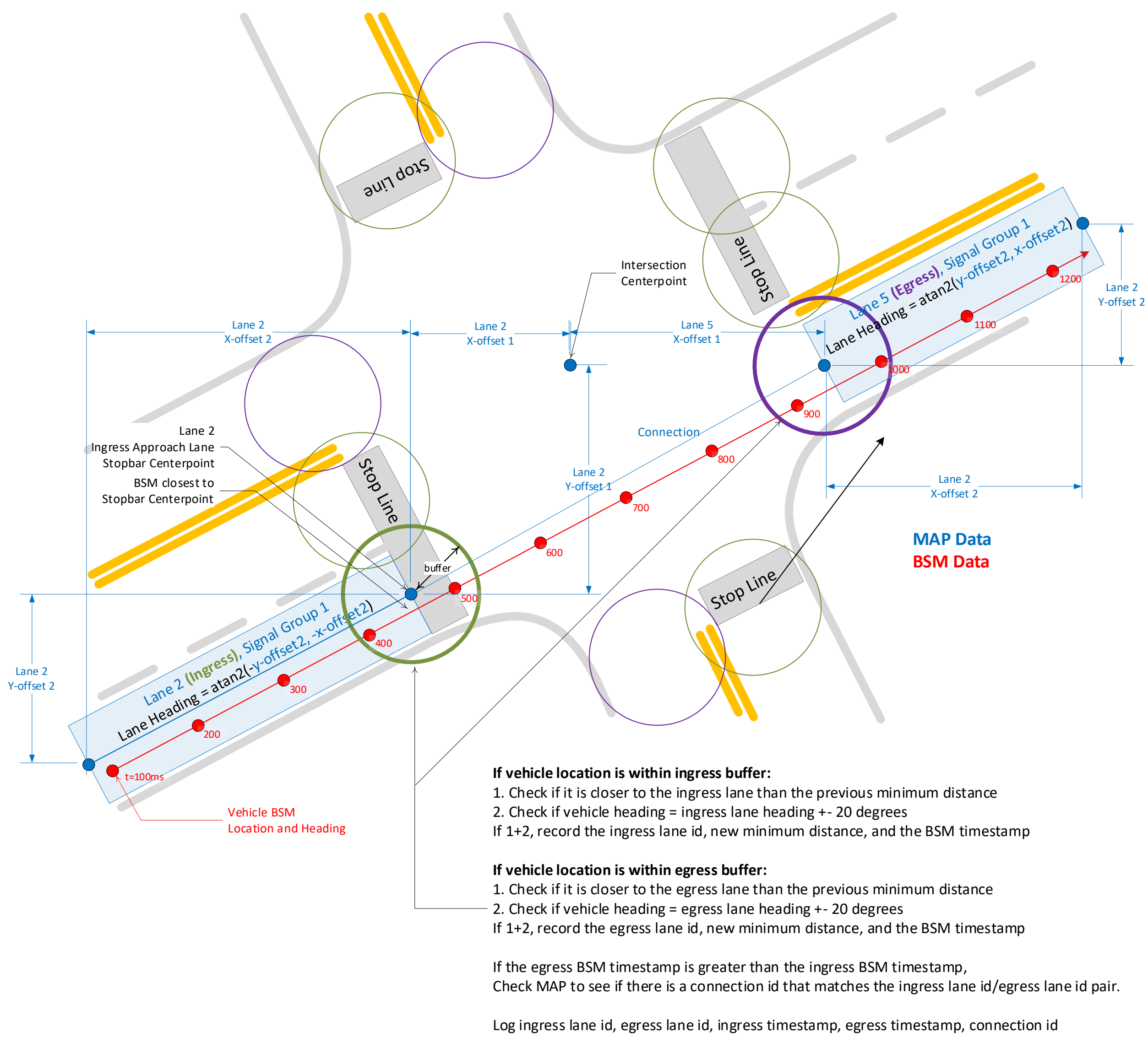


Figure 15: Visual Representation of Logic for determining Alignment Between Connections and Vehicle Movements

3.5.5 Signal State Conflict Monitor

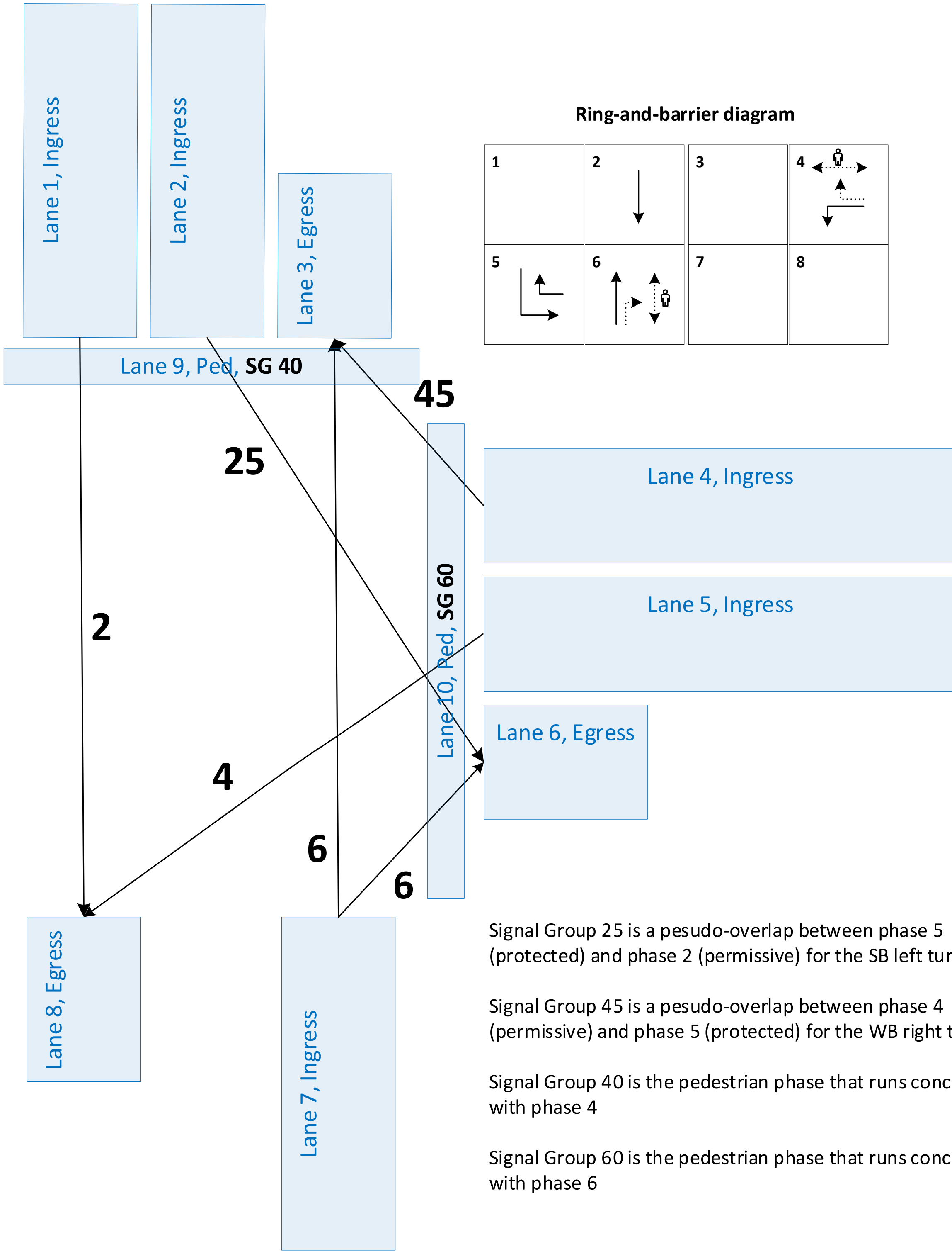
This algorithm determines if there is any conflicting event state data being provided in a SPaT message based on information about the intersection of connections.

The MAP message can be used to determine which connections intersect. A graphical representation of the endpoints of a connection is created by taking the first points of the ingress and egress lanes that it connects.

These endpoints for all possible pairs of connections are used to determine which pairs of connections intersect – generating a list of intersecting connections. The SPaT message is then used to determine the event state for each connection. The event states for each pair of intersecting connections are compared to ensure there is no connection that has a protected green or a protected yellow event state at the same time an intersecting connection as a protected green, permissive green, protected yellow, or permissive yellow event state. That is if the event state for a connection is protected green or protected yellow, then the event state for all other intersecting connections should be red (stop-and-remain). An exception to this rule is made if the intersecting connections originate from the same ingress lane (e.g., an ingress lane allows both a through and a right turn controlled by different signal groups).

There may also be intersecting connections where permissive movements may or may not be allowed to occur simultaneously. For instance, a northbound (NB) through movement could be permissive at the same time as a southbound (SB) permissive left turn movement, but not at the same time as an EB right turn movement. Even though the connection that represents the NB through would intersect with the connection for the SB left turn and the eastbound (EB) right turn, the outcomes should be different for both. In order to provide effective output, the system would need to know which of these intersecting connections are allowed to be permissive at the same time. One method of accomplishing this is to allow a user to specify this information as a manually configurable setting.

The figure on the following page shows a 3-leg intersection with a protected-permissive SB left turn and a pseudo overlapping westbound (WB) right turn (the signal groups for these connections / movements are represented as a combination of the numbers of the controlling phases). Table 36 following the figure lists all intersecting connections that are determined from using the start (ingress) and end (egress) points of each connection. This table also indicates which intersecting connections are allowed to be simultaneously permissive – this is likely information that will need to be populated by a user.



Signal Group 25 is a pesudo-overlap between phase 5 (protected) and phase 2 (permissive) for the SB left turn

Signal Group 45 is a pesudo-overlap between phase 4 (permissive) and phase 5 (protected) for the WB right turn

Signal Group 40 is the pedestrian phase that runs concurrent with phase 4

Signal Group 60 is the pedestrian phase that runs concurrent with phase 6

Figure 16: Conflict Detection Example

Table 36: Example List of Intersecting Connections

Intersecting Connections Signal Groups		Can be permissive at same time? (user specified)
SG	SG	
2	4	NO
25	4	NO
25	6	YES
4	6	NO
6	45	NO
2	40	NO
25	40	NO
6	40	NO
45	40	YES
45	60	NO
4	60	NO
25	60	YES
6	60	YES

Table 37 shows the event states of all signal groups for 4 different SPaT messages for the setup above. The first two SPaT messages provide examples of event states that do not conflict. In the first example signal groups 25 and 6 are allowed to both be permissive at the same time, and no other conflicts are present. The second example shows a protected movement for signal group 25 – all other event states for intersecting connections are red, which is expected. In the third example. The third example shows a protected movement for signal group 25 that is simultaneous with a permissive movement for signal group 6 and 60, which is results in a conflict, as the connections for these signal groups intersect, and a protected signal state cannot be active (green or yellow) at the same time as another signal state from an intersecting connection. The final example shows permissive movements for signal group 2 that is simultaneous with a permissive movement with signal group 4 and 40. The example table above indicates that permissive movements cannot be simultaneously active for these signal groups, resulting in a conflict.

When a conflict is noted, the Message Monitor creates an event log with the following data at a minimum: Event Type (Protected Conflict or Permissive conflict), time (from SPaT), intersection id (from MAP), signal group id 1 (from SPaT/MAP), signal group id 2 (from SPaT/MAP), event state 1 (from SPaT), event state 2 (from SPaT).

The generation of a Signal State Conflict Event results in the immediate issuance of a CBR.

Table 37: Example Event State Data and Output

Example SPaT	Event State							Output
	SG 2	4	6	25	45	40	60	
	SB T	WB L	NB T	SB L	WB R	E-W Ped	N-S Ped	
1	Permissive green	Red	Permissive green	Permissive green	Red	Red	Permissive green	*none* (OK)
2	Permissive green	Red	Red	Protected Yellow	Red	Red	Red	*none* (OK)
3	Permissive green	Red	**Permissive green**	**Protected Yellow**	Red	Red	**Permissive green**	PROTECTED CONFLICT (25 Protected Yellow, 6 permissive green), (25 Protected Yellow, 60 permissive green)
4	**Permissive green**	**Permissive green**	Red	Red	Permissive green	**Permissive green**	Red	PERMISSIVE CONFLICT (2 permissive green, 4 permissive green), (2 permissive green, 40 permissive green)

3.5.6 Time Change Details Monitor

The SPaT message provides the time change details that are used to determine the amount of time remaining in the current phase. These time change details that are typically of the most interest are the minimum time that the current phase ends and the maximum time that the phase ends, these play the biggest role in communicating when the signal state will next change. Due to limitations of the existing system to produce data regarding future event state, this algorithm will only focus on the current event state.

In order to be reliable, the minimum time that the current phase ends should never decrease, and the maximum time that the current phase ends should never increase (unless the signal state changes). Unknown times may be specified, but once a definite min end time or max end time has been specified, the value should not change back to unknown under non-interrupted conditions (e.g., no preemption).

When a signal state transition is observed, time data in the SPaT message can be compared against the most recent minEndTime and maxEndTime values to determine if the signal transitioned to the subsequent event state at the indicated minEndTime and maxEndTime. Ideally the actual signal state transition is no more than 100ms (configurable) earlier than the minEndTime and no more than 100ms (configurable) greater than the maxEndTime. MinEndTime and MaxEndTime should be equal during all yellow signal states. Table 38 provides example event state and time change details data for a single signal group. The example data contains highlights a few scenarios that indicate when the algorithm will and will not log an event.

- **Example 1.** In the first example, at first the max end time is unknown. The SPaT data changes to provide an actual value (2400) for the maxEndTime– this is considered normal operation, and no event is generated. The SPaT data changes again to increase the minEndTime (2200 to 2220) – again, this is considered normal operation, and no event is generated. The SPaT data changes again to decrease the minEndTime (2220 to 2200), which is not expected, and an event is generated. The SPaT data changes again to increase the maxEndTime (2400 to 2600), which is not expected, and an event is generated.
- **Example 2.** The next example shows an event state transition from permissive green to permissive yellow. The maxEndTime increases, which is permissible only when the event state changes. Furthermore, the minEndTime (3000) and maxEndTime (3000) specified when the event state was permissive green is within 100 ms (configurable) of the actual time of the transition (3000). This is considered normal operation, and no event is generated.
- **Example 3.** The final example shows an event state transition from permissive green to permissive yellow. However, in this case, the minEndTime (4050) specified when the event state was permissive green is not within 100 ms (configurable) of the actual time of the transition (4000) (actual difference is 1s). This is not expected operation, and an event is generated.

Table 38: Example Time Change Details Data and Output

Timestamp (0.1 s)	Signal Group 1			SG X					Output
	Event state	minEndTime (0.1 s)	maxEndTime (0.1 s)						
Example 1									
2000-2009	Permissive green	2200	unknown						…
2010-2019	Permissive green	2200	2400						*none* (OK)
2020-2029	Permissive green	2220	2400						*none* (OK)
2030-2039	Permissive green	2200	2400						minEndTime DECREASE(SG:1, timestamp1: 2029, timestamp2: 2030, minEndTime1: 2220, minEndTime2: 2200
2040-2049	Permissive green	2200	2600						maxEndTime INCREASE(SG:1, timestamp1: 2029, timestamp2: 2030, minEndTime1: 2400, minEndTime2: 2600
Example 2									
2990-2999	Permissive green	3000	3000						…
3000-3029	Permissive yellow	3030	3030						*none* (OK)
Example 3									
3990-3999	Permissive green	4050	4200						…
4000-4039	Permissive yellow	4040	4040						minEndTime EVENT STATE TRANSITION(SG:1, minEndTimeTransition:4050, actualTransitionTime: 4000, eventState1: permissive green eventState2: permissive yellow

When a time change detail issue is noted, the Message Monitor creates an event log with the following data at a minimum: Event Type (time change detail issue), time (from SPaT), intersection id (from SPaT), issue type (minEndTime decreases, maxEndTime increases, state transition time issue),

The generation of a Time Change Details Event results in the immediate issuance of a notification.

3.5.7 Stop Line Passage Event Assessment

In previous documents, this algorithm was referred to as the "Signal State when Vehicle Crosses Stop Line Assessment"

This assessment involves the aggregation of Stop Line Passage Event data. The assessment first identifies all stop line passage event data generated after a point in time equal to the current time minus the configured lookback period. Events with vehicle speeds that do not exceed the configured threshold are not included in this group of events.

Results are aggregated by road regulator ID, intersection ID, and signal group. Each Stop Line Passage Event contains the event state of the signal group that is controlling the vehicle's movement as indicated in the SPaT and MAP messages. For each unique combination of road regulator ID, intersection ID, and signal group, a count of the number of events with an event state of 'stop-and-remain' is determined, a count of the number of events with an event state of 'protected-clearance' or 'permissive-clearance' is determined, and a count of the number of events with an event state of 'protected-movement-allowed' or 'permissive-movement-allowed' is determined. These aggregated counts are used to populate the respective 'number of events…' elements in the Stop Line Passage Event Assessment.

Once the counts for all signal groups have been processed, the percentage of events when the signal state is red is calculated. If this value is greater than the configured notification threshold, and the total sum of all events exceeds the configured threshold, then the notification value is set to 'true'. Otherwise, this value is set to false. If this value is greater than the configured CBR threshold, and the total sum of all events exceeds the configured threshold, then the CBR value is set to 'true'

3.5.8 Stop Line Stop Event Assessment

In previous documents, this algorithm was referred to as "Signal State when Vehicle Stops at Stop Line Assessment"

This assessment involves the aggregation of Stop Line Stop Event data. The assessment first identifies all stop line stop event data generated after a point in time equal to the current time minus the configured lookback period.

Results are aggregated by road regulator ID, intersection ID, and signal group. Each Stop Line Stop Event contains the amount of time stopped on green, yellow and red signal indications. For each unique combination of road regulator ID, intersection ID, and signal group, a sum of the amount of time stopped on green, a sum of the amount of time stopped on yellow, and a sum of the amount of time stopped on red is determined. These aggregated times are used to populate the respective 'time stopped during…' elements in the Stop Line Stop Event Assessment.

Once the times for all signal groups have been processed, the percentage of time when the vehicle is stopped on green is calculated. If this value is greater than the configured notification threshold, and the total sum of all events exceeds the configured threshold, then the notification value is set to 'true'. Otherwise, this value is set to false. If this value is greater than the configured CBR threshold, and the total sum of all events exceeds the configured threshold, then the CBR value is set to 'true'. Otherwise, this value is set to false.

3.5.9 Lane Direction of Travel Assessment

This assessment involves the aggregation of Direction of Travel Event data. The assessment first identifies all vehicle direction of travel event data generated after a point in time equal to the current time minus the configured lookback period.

Results are aggregated by road regulator ID, intersection ID, lane ID and segment number. Each Direction of Travel Event contains a single vehicle's median heading and median distance from the lane centerline for each segment. For each unique combination of road regulator ID, intersection ID, lane ID, and segment number, the median heading of all events, and the median distance from the centerline is determined. This aggregated value is used to populate the respective 'median heading' and 'Median Distance from Centerline' elements in the Direction of Travel Event Assessment.

Once the counts for all segments have been processed, if the median heading is not withing the configured notification heading tolerance of the actual heading of the lane, and the count of events exceeds the configured threshold, then the notification value is set to 'true'. Otherwise, this value is set to false. If the median heading is not withing the configured CBR heading tolerance of the actual heading of the lane, and the count of events exceeds the configured threshold, then the CBR value is set to 'true'. Otherwise, this value is set to false.

Note: Heading values wrap-around from 360 to 0, and this should be taken into account when performing the assessment. For example, if the expected heading is 355 degrees, and the heading tolerance is 20 degrees, then a notification would only be issued if the median heading is less than 335 degrees or greater than 15 degrees.

3.5.10 Connection of Travel Assessment

This assessment involves the aggregation of Connection of Travel Event data. The assessment first identifies all vehicle connection of travel event data generated after a point in time equal to the current time minus the configured lookback period.

Results are aggregated by road regulator ID, intersection ID, ingress lane ID, and egress lane ID. Each Connection of Travel Event identifies the vehicles ingress lane ID, egress lane ID that it uses when traveling through the intersection, and also indicates whether that pair is represented in connections in the MAP message. For each unique combination of road regulator ID, intersection ID, ingress lane ID, and egress lane ID, the count of all events is determined (Note: the value for ingress lane or egress lane may be null, if not identified), and a count of events where a connection is not identified between the ingress-egress pair is also determined (Note: if the MAP message does not change, this value will either be 0 or equal to the number of events). These aggregated values are used to populate the respective elements in the Connection of Travel Event Assessment.

Once the count for all ingress-egress pairs have been processed, if the count of unidentified connection events is greater than the configured notification threshold and the count of all events exceeds the configured threshold, then the notification value is set to 'true'. Otherwise, this value is set to false. If the count of unidentified connection events is greater than the configured CBR threshold and the count of all events exceeds the configured threshold, then the CBR value is set to 'true'. Otherwise, this value is set to false.

4. Minimum/Recommended System Requirements

4.1 ROADSIDE EQUIPMENT AND SITE MINIMUM REQUIREMENTS

Assumptions

- Site has an operational CV system broadcasting J2735 SPaT and MAP messages based on ITE CTI 4501
- Prototype will need to store a revolving 1 to 2 months' worth of project data

General IT Requirements

- Ability to support Firewall configurations between RSUs and Prototype, including IPv6
- A bandwidth of 6 to 10 Mb/s to each intersection to support data upload from each RSU to the CIMMS

Intersection Requirements

- 3 or more 4 leg intersections should be available
- Intersection types should range in operation\timing plans (Permissive turns, Protected turns, through lanes, etc.)

Vehicle Penetration Requirements

- A minimum of 10 equipped vehicles should pass through each intersection on a given weekday

MAP Message Content Requirements

The following data elements are required in the MAP message for each supported intersection:

- timeStamp: MinuteOfTheYear
- layerType: LayerType
- layerID: LayerID
- intersections: IntersectionGeometryList
    - id: IntersectionReferenceID
        - region: RoadRegulatorID
        - id: IntersectionID
    - refPoint: Position3D
    - laneWidth: LaneWidth
    - laneSet: LaneList
        - laneID: LaneID
        - laneAttributes: LaneAttributes
            - directionalUse: LaneDirection
            - sharedWith: LaneSharing
            - laneType: LaneTypeAttribute
        - maneuvers: AllowedManeuvers (Not strictly required, but desirable)
        - nodeList: NodeListXY
            - nodes: NodeSetXY
        - connectsTo: ConnectsToList
            - connectingLane: ConnectingLane
                - lane: LaneID
                - maneuver: AllowedManeuvers

- signalGroup: SignalGroupID

SPaT Message Content Requirements
The following data elements are required in the SPaT message for each supported intersection:

- intersections: IntersectionStateList
    - id: IntersectionReferenceID
        - region: RoadRegulatorID
        - id: IntersectionID
    - moy: MinuteOfTheYear
    - timeStamp: DSecond
    - states: MovementList
        - signalGroup: SignalGroupID
        - state-time-speed: MovementEventList
            - eventState: MovementPhaseState
            - timing: TimeChangeDetails
                - minEndTime: TimeMark

maxEndTime: TimeMark

4.2 MESSAGE MONITOR HARDWARE MINIMUM REQUIREMENTS

Hosting the Prototype in a Cloud Service

- An estimated cost of $2k-5k/month will be required for a cloud-based service meeting the Server Requirements stated below

Hosting the Prototype at a TMC

- TMC must be able to perform daily backups of all relevant servers hosting the prototype and its data.

Server Requirements

- A 2-4 terabytes of data storage will be required over the life of the project
- 3 to 6 Linux Virtual Machines, with each VM having:
    - 16-32 GB RAM
    - 2-4 2GHz Cores

4.3 DESIGN RATIONALE

The system design is predominately based on the concept of operations and system requirements developed previously in the project. Content in previous project documents was developed with the primary scope of the CIMMS project in mind. The primary purpose of the CIMMS project is to provide increased awareness to IOO Traffic Operations to the inaccuracies that may be present in SPaT and MAP messages. CTI 4501 Connected Intersection Implementation Guide serves as the baseline for determining if the content in CV messages is accurate. This initial implementation of the CIMMS will only account for a fraction of the overall SPaT and MAP message and performance requirements specified in CTI 4501. The CIMMS is designed in an open-source fashion so that new functionality can be added as different needs arise. These needs may be related to other SPaT, MAP, or RTCM requirements in CTI 4501 that are not considered as part of this initial implementation, or the desire to understand other aspects of SPaT, MAP, RTCM, or any other SAE J2735 message types outside of the current scope of CTI 4501.

The ability of the CIMMS to address the needs of IOOs, OEMs, and drivers depends on the availability of hardware and software solutions. It is anticipated that the CIMMS can be deployed on location (at a local facility such as a TMC) or remotely in the cloud with some minimum requirements. Software development is needed. This document provides the design details that developers need to assemble code needed to make the CIMMS operate as intended. It is important to note that iterations to this document may be necessary to account for ambiguities or to accommodate development decisions that must be made for the sake of efficiency or simplification of implementation.

High-level controlled tests will be performed as part of the CIMMS deployment to ensure the various functions are operating as intended.

5. Design Concerns

5.1 ASSUMPTIONS

- Roadside Unit is broadcasting SPaT and MAP message and can forward BSMs to a remote host.
- Roadside Unit is compliant with CTI-4001 requirements related to immediate forwarding of CV messages.
- Roadside equipment is network connected. This can be traditional physical agency-owned backhaul, or cellular communications service, as long as the service can support the volume of CV data required to be transferred to the CIMMS.
- The security settings on the agency-owned network can be modified to allow communication with CIMMS, as an external system.
- The CIMMS will need to adhere to any local laws and regulations as well as agency policies for handling CV data. It is important to recognize that the design of the CIMMS as detailed in this document does not give any particular consideration or special handling of certain messages (or data in messages) that may be considered potentially personally identifiable information. Thus, it is assumed that the CIMMS will only be deployed in jurisdictions where the storage of unprocessed CV data is permitted.

5.2 CONSTRAINTS

- The proposed system will use open-source software practices consistent with those currently in use by FHWA, such as the ITS Code Hub.
- Only SPaT and MAP as defined in applicable portions of the ITE CTI 4501v01 Connected Intersection Guidance and SAE J2735 V2X Message Set Dictionary Standard will be supported.
- Only BSMs as defined in the SAE J2735 V2X Message Set Dictionary Standard will be supported
- Only RSUs compliant with message forwarding functionality as defined in CTI 4001 v01 will be supported
- SPaT and MAP will be assessed based on applicable requirements and design details contained in CTI 4501v01
- Only common intersection types will be supported
- For any type of temporal association of data, the message monitor will only use time data contained in messages, and not any timestamps associated with the capturing of the message

5.3 RISKS

5.3.1 SPaT and MAP Data Requirements not Met

The RSU is expected to forward SAE J2735-compliant messages. However, many of the data frames and data elements are optional (particularly for SPaT and MAP messages). Algorithms proposed in section 3.5 require the availability of data elements that are considered optional in SAE J2735. If certain data elements are not present, it will limit the ability of certain algorithms to be performed. This results in a limitation for demonstrating the primary concept behind the CIMMS. To mitigate this risk, site selection criteria will involve demonstrating the ability for the system to produce SPaT and MAP messages with the data elements required by algorithms.

5.3.2 BSM Positional Accuracy and Driver Behavior Expectation Violation

The system, to a certain degree relies on some level of accuracy in vehicle position data and also drivers operating vehicles in an expected manner. The inability for BSM-producing vehicles to accurately position themselves may result in driver behavior not being accurately captured (e.g., inaccurate position data produced by a vehicle may locate the vehicle in a lane adjacent to the lane the vehicle is actually utilizing). Similarly, if there are too many drivers operating vehicles in a manner that is unexpected, then the system may produce unexpected results. For instance, if there are too many vehicle running red lights (say, when a police officer directs traffic), the system may indicate there is an issue – and while it would not be incorrect to indicate an issue in this instance, it is not the result of an issue with the SPaT or MAP messages being broadcast, which could potentially result in some confusion.

As evidenced in the algorithm descriptions provided in section 3.5, the CIMMS will attempt to utilize clustering algorithms or by use of statistical methods to handle normally occurring variances in driver behavior, vehicle positioning, and to account for a normally occurring variance in vehicle positioning errors. However, if these variances are too large, or there are biases in vehicle positioning that are present over time, this will impact the system's ability to provide accurate outputs. As vehicle positioning technologies continue to improve, this is expected to be less of an issue.

5.3.3 CV Penetration Rate

As described previously, due to variations in driver behavior and the potential for accuracy issues in vehicle position data in BSMs, multiple vehicle passages through the intersection are expected to be needed for the system to provide outputs using BSM-based analyses (Stop Line Passage, Stop Line Stop, Direction of Travel, Connection of Travel). The less frequently BSM-producing vehicles traverse RSU-equipped signalized intersections the longer it would take for the system to obtain enough BSM data to provide a result. Thus, the main risk presented is timeliness in identifying issues that these analyses are attempting to uncover.

To mitigate this risk, site selection criteria is expected to include the frequency with which BSM-producing vehicles pass through the test intersections. It is ideal if movements made by BSM-producing vehicles is representative of all approaches and movements within the intersection, as this would allow the robustness of the CIMMS to be tested. However, a sufficient penetration of BSM-producing vehicles even if only along particular approaches or movements, should be enough to demonstrate the fundamental concept the CIMMS.

5.3.4 Network Connectivity

The ability for RSUs to send CV data to the CIMMS is predicated on the availability of a backhaul network. A network-based disruption would cease the transmission of CV data to the CIMMS, which would prevent the CIMMS from assessing messages and data during the period of the network outage. A network that experiences frequent and/or extended outages may miss capturing CV data and/or vehicle-based events generated from that CV data. The main drawback of outages would be gaps in the performance history as well as timeliness in identifying issues that these analyses are attempting to uncover. To mitigate this risk, part of the site selection criteria will be to ascertain the network uptime.