Concept of Operations

SwRI Project No. 10.24479

Using Third-parties to Deliver Infrastructure-to-Vehicle (I2V)

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1 Introduction

The Connected Vehicle Pool Fund Study (CV PFS) group is a team of 28 state and regional transportation agencies who are responsible for CV infrastructure equipment. These agencies are varied in nature from state DOTs, counties, national and international transportation agencies (see Figure 1).

Figure 1: Icons Representing 27 of the 28 CV PFS Group Members

CV PFS group members select projects to fund that impact the participants, with a focus on improving the implementation of CV across their regions. Projects are typically 18 months in duration and draw from industry experts. A full description of the CV PFS is available here: http://www.cts.virginia.edu/cvpfs/

1.1 Project Overview

Using Third-Parties to Deliver I2V

The participants in the CV PFS team are managing large amounts of data relevant to connected and non-connected vehicles. This data can be provided to vehicle operators through third-party companies or system integrators. To help scale and standardize the distribution of this data, the CV PFS team has funded a project called "Using Third-Parties to Deliver I2V." This project is focused on the system engineering and standardization of data that is transmitted from states and other infrastructure owners and operators (IOOs) to third-parties and Original Equipment Manufacturers (OEMs). A description for the project is available here: http://www.cts.virginia.edu/cvpfs_research/.

Through this project, stakeholder interviews will be conducted along with interviews of state and IOO participants. This information will allow the team to gather an understanding of the breadth of efforts that are already in place (or planned for the future) regarding the usage of vehicular data by third-party companies and OEMs. This Concept of Operations (ConOps) document serves to describe the users, user needs, functions and features, operational scenarios, constraints, and context diagrams. Based on this ConOps, a System Requirements (SysReqs) document will be generated, again with strong collaboration from the stakeholders. The SysReqs document will include the requirements that will need to be met for the scenarios and user needs described in this ConOps. The final system engineering document will be an Interface Control Document (ICD) and will define the interfaces that are used to connect to the system components.

1.2 System Overview

The focus of this project is the standardization of communication from states and IOOs to third-party application providers or OEMs. Direct communication channels between states/IOOs and vehicles exist in the form of vehicle-to-everything (V2X) communication. This project recognizes that this will continue to occur, and in addition there are auxiliary connections to vehicles and smart devices that are enabled through third-party connections. Current communication from states/IOOs to third-party companies is based on an agency-by-agency and third-party-by-third-party arrangement, which is considered to be inefficient and complicated. This is represented in the "before" diagram shown of Figure 2.

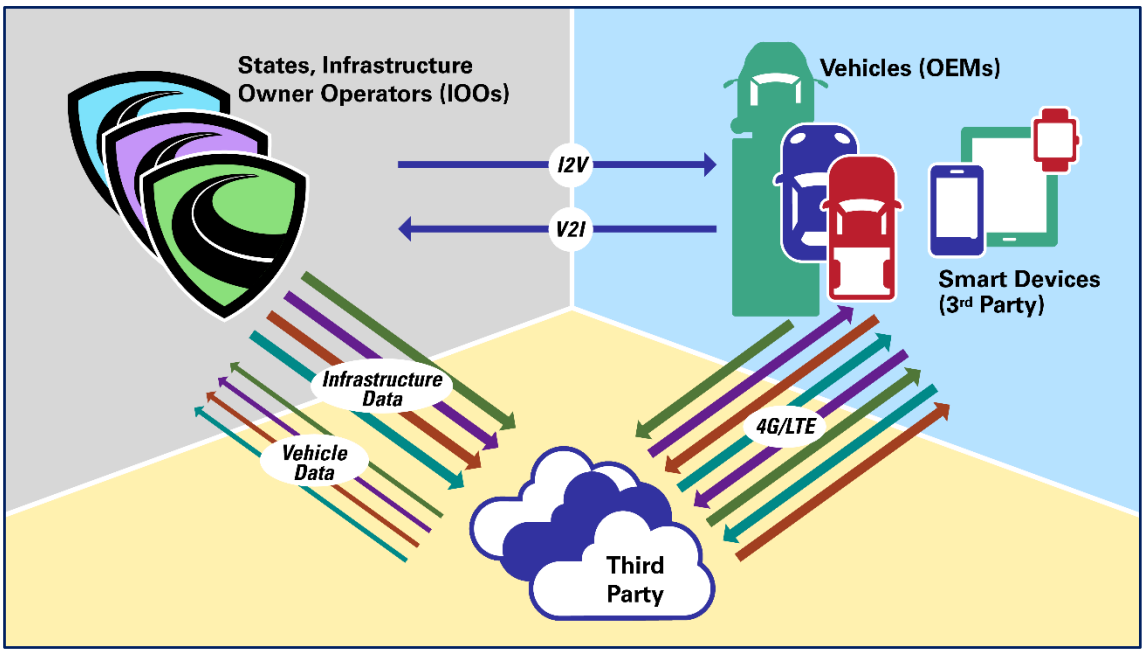

Figure 2: Example Communication Channels Between States/IOOs, Third-Party Companies, Vehicles, and Smart Devices.

This project will attempt to standardize the communication between

states/IOOs and third-party companies. Standardizing this data will allow the multiple streams of data from IOOs and third-parties to be consistent. The data will be provided via implementations that adhere to the CV Data Framework defined through this project. Such implementations will result in the data exchanges shown in Figure 3. Through these efforts, the participants in the CV PFS and others can benefit from the usage of a standardized data distribution strategy.

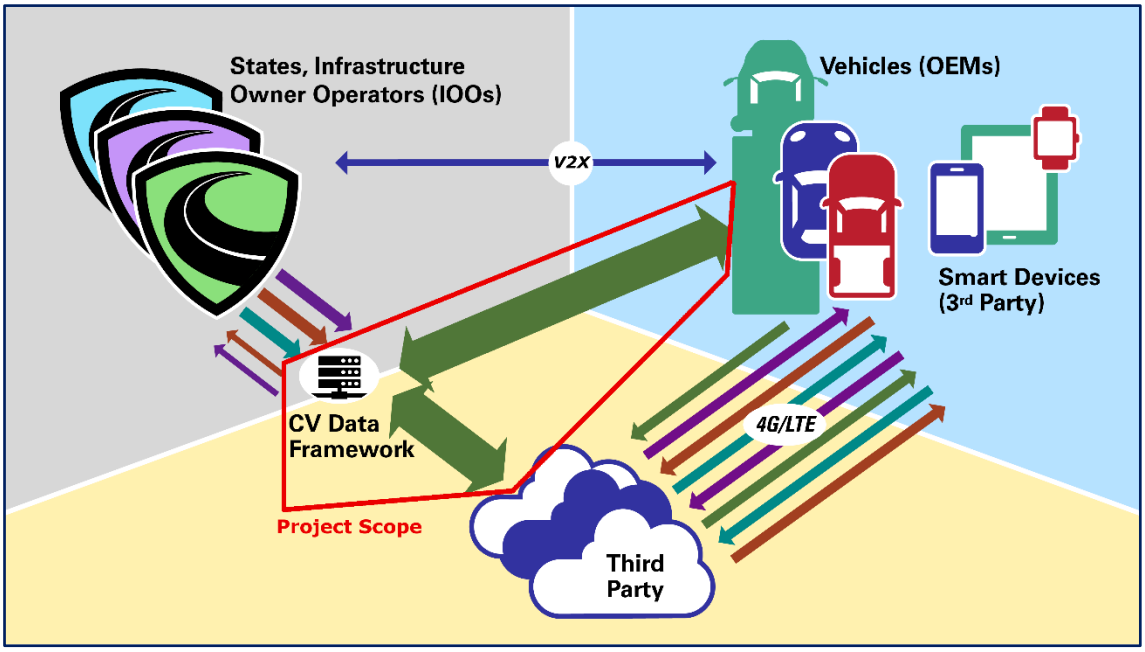

Figure 3: Project scope and interactions between the CV Data Framework and other users.

2 Objectives and Scope

This ConOps document seeks to describe the users, user needs, functions and features, operational scenarios, constraints, and context diagrams that describe the proposed CV Data Framework. These concepts are captured and referenced for additional documentation, including the SysReqs and ICD.

The scope of the ConOps will include the interactions between the data framework and third-parties. The focus will be on the data that will be standardized and provided through the CV Data Framework. Data provided through the CV Data Framework includes but is not limited to signal phase and timing (SPaT), map and data (MAP), basic safety messages (BSMs), signal timing plans, pedestrian call information, signal controller status, and real-time, historic, and predicted queues.

Data that has been considered but not included as required data includes presence detection, splits, signal cycles, work zone information and reduced speed limits.

Interactions between third-parties and vehicles or user devices is considered out of scope for this document. Direct communication between states/IOOs and vehicles or user devices is also considered out of scope. The back-end operation and administration of the data framework is also out of scope.

3 Software Components

Third-parties, states/IOOs, and system integrators will interact with the CV Data Framework through the Data Feed and via a Web Client (each described in subsequent subsections). Each of these communication paths will incorporate an appropriate level of data security. Figure 4 shows the relationships between these components.

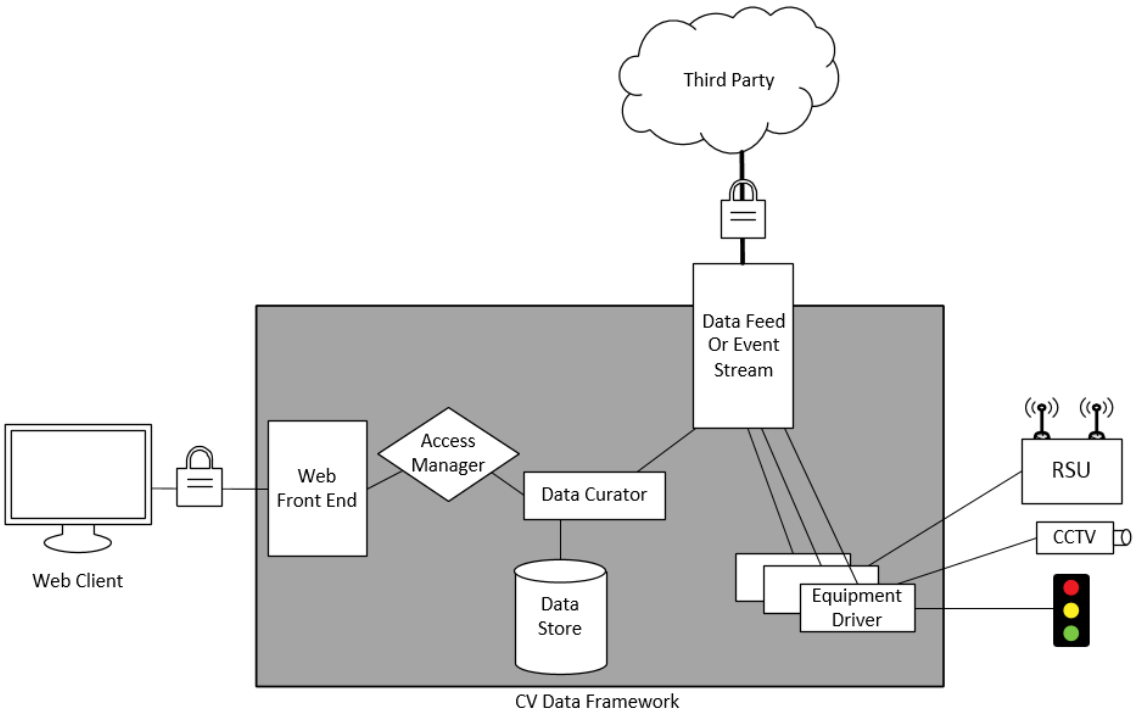

Figure 4: Software Components for the CV Data Framework

The software components for the CV Data Framework include:

3.1 Data Feed

The Data Feed is responsible for managing the communication of data to and from external users, such as third-parties. The Data Feed will serialize and encode all data transmitted from the CV Data Framework. The Data Feed provides appropriate web-based Application Program Interfaces (APIs such as Representational State Transfer [REST] or GraphQL) that define the encoding of all data. Communication is secured using up-to-date security protocols, as appropriate.

3.2 Event Stream

The Event Stream is responsible for providing a direct connection to the data from devices. The Event Stream uses web-based APIs but does not modify the data from the devices prior to providing it to third-party consumers. Communication is secured using up-to-date security protocols, as appropriate.

3.3 Equipment Driver

Equipment Drivers communicate with the field equipment used in a CV deployment. Field equipment is a broad category and includes traffic signal controllers, roadside units (RSUs), closed circuit television cameras (CCTVs), traffic detectors, and other infrastructure equipment. Each type of field equipment would need its own Equipment Driver.

3.4 Data Curator

The Data Curator is responsible for scrubbing data from Equipment Drivers, managing data within the Data Store, and providing data to the Data Feed. The Data Curator modifies data for efficiency and preparation for transfer, which could include de-duplication, normalization (of units and scales), anonymization, prioritization, aggregation, and enrichment of data. As appropriate, the Data Curator would assign metadata to incoming data. The Data Curator will be responsible for preventing Personally Identifiable Information (PII) from being transmitted by the system through a data anonymization process. The Data Curator may archive anonymized data for medium/long term storage via the Data Store. Access to the curated data is provided by the Access Manager (described in a subsequent section), with only approved data being transmitted through the Data Curator.

3.5 Data Store

The Data Store is responsible for storing and retrieving data over medium or long timescales. Only certain classes of properly scrubbed data will be stored. Access to the stored data will be provided through the Data Curator.

3.6 Access Manager

The Access Manager is responsible for registering and managing web users and third-parties. The Access Manager communicates with the Data Curator to define what type of data is provided to third-parties and how it is provided.

3.7 Web Front End

The Web Front End interacts with external web clients via a secured connection and provides a web-formatted interface for configuring and managing access to the data. The Web Front End communicates with the Access Manager in order to grant access and customize the Data Feed provided to each user. Appropriate internet security practices are used to secure this connection.

4 System Considerations

The system considerations include both constraints which need to be addressed and considerations which are optional but valuable for the CV Data Framework.

4.1 Data Timeliness (Constraint)

Some data (noted as low-latency data) needs to be provided to third-party companies with minimum latency from the source (typically a traffic signal controller). This constraint allows third-parties to use this data for effective in-vehicle warnings and information. Low-latency and event-based data will be provided in a streaming format while data that is less time critical will be provided to users through a polling operation.

4.2 Data Reliability (Constraint)

Data from the CV Data Framework needs to be reliable. Reliability is defined as being accurate (at least as accurate as the source device), complete (contains all of the necessary fields with values), and essential data will be provided. The removal of Personally Identifiable Information (PII) is appropriate.

4.3 Time Synchronization (Constraint)

Time synchronization is a critical capability for the CV Data Framework. A common time reference will be selected by implementers of a CV Data Framework. By default, UTC time will be utilized, and any offsets to UTC will be clearly indicated. Any data that is stored or manipulated by the CV Data Framework should be timestamped with the Framework's reception time in the common time reference. Time synchronization at the device is left to the device manufacturer. When possible, details regarding the source of time synchronization should be stored as metadata (such as GPS or Network Time Protocol [NTP]). Any available confidence factors or slew rates should be included when available. Additional details regarding when the last synchronization occurred should also be stored when available.

4.4 GPS Resolution (Consideration)

GPS resolution for devices will be based on the governing standard for that device. For CV on-board units (OBUs), this is dictated as 1.5 meters at 1 sigma by SAE J2945/1[1] (see V2V-BSMTX-DATAACC-012). As RSUs and other infrastructure devices are not required to accurately report their location, an estimate of the location is sufficient.

4.5 Data Rates (Consideration)

The rate at which data will be provided by the CV Data Framework is dependent on the message type. For example, SPaT messages may be provided at a rate of 10 Hz per intersection, while MAP messages may be provided once every 10 seconds, or upon request.

4.6 Security (Consideration)

Data security is a consideration for the CV Data Framework and when identified as a user need, support for data encryption and authentication should be provided. Data authentication and verification for V2X messages is offered through the Security Credential Management System (SCMS). The USDOT has sanctioned the design and development of SCMS solutions, which are currently in the proof-of-concept phase and are offered by a limited number of providers. The usage of an SCMS offers integrity, authenticity, and privacy. An SCMS uses a Public Key Infrastructure (PKI)-based design to authenticate that a message's source can be trusted. There is no personal or equipment-identifying information contained within the certificates, therefore anonymity is still maintained[1]. From the perspective of the CV Data Framework,

[1] https://saemobilus.sae.org/content/j2945/1_201603
[1] https://www.its.dot.gov/resources/scms.htm

incoming CV messages may be authenticated by utilizing the SCMS. The CV Data Framework may be designed to connect to an SCMS and verify the authenticity of messages that are signed by a CV device. When configured to verify SCMS signed messages, it is the CV Data Framework's responsibility to ignore messages that fail to authenticate (optionally these could be stored for future evaluation). When providing data to a third-party, the CV Data Framework should include the SCMS certificate for messages that are requested with no adjustments. Other authentication and security considerations should be supported by the CV Data Framework, such as Transport Layer Security (TLS) to secure and encrypt the communication between the client and the backend.

5 Use Cases

5.1 Users

This section describes users or other actors that have a stake in the proposed CV Data Framework.

5.1.1 OEMs

OEMs are vehicle manufacturers who may have integrated human-machine interaction (HMI) devices into their vehicles, such as heads-up displays, infotainment systems, and haptic feedback.

5.1.2 States/IOOs

States and IOOs are agencies responsible for managing, among other things, I2V data coming from the equipment that they own and manage. CV data shared by states/IOOs may include infrastructure related information (e.g., SPaT messages, MAP messages [including intersection ID, reference point, orientation, lane width, type, etc.]), as well as speed limit information, standard signage, school and/or work zone information, lane closures, messages displayed on dynamic messages signs or messages sent out over highway advisory radios.

5.1.3 Third-Parties

Third-party companies (typically commercial) work with states/IOOs to receive and utilize CV data in order to provide information to OEMs or device users. A company is not considered a third-party if the majority of their operational costs are covered by a state or IOO (these would be considered contractors and would already be following the state or IOO data format). Also, a third-party relies directly on the equipment owned by the state/IOO for the majority of the CV data, but also exchanges data with device users and OEMs.

5.1.4 System Integrators

System integrators are companies (typically commercial) that develop hardware that enables the generation and distribution of data used in this project. System integrators have needs that overlap with both states/IOOs and third-party companies.

5.2 User Needs

This section describes needs for each of the users mentioned in the previous section.

Challenge	Need ID	Need
OEM		
OEMs do not have appropriate channels to receive safety-related and informative data such as signal phase and green speed data to provide to their customers.	UN-1.01	An OEM needs a reliable source of data to support safety-related and informative vehicle applications desired by their customers.
OEMs do not have a means to selectively manage data they receive.	UN-1.02	An OEM needs the ability to adjust the type or quantity of data received to them via the CV Data Framework.
OEMs are not able to verify the contents or security of the data they receive.	UN-1.03	The CV Data Framework needs to verify the contents and security of the data it provides.
State/IOO		
States/IOOs are responsible for addressing congestion, environmental concerns, and crashes in their jurisdiction.	UN-2.01	A state/IOO needs a means to broadly share data with travelers that will enable eco-friendly driving and avoid crashes.
States/IOOs are responsible for managing the storage (or disposal) of data.	UN-2.02	A state/IOO needs support for storing and disposing of data.
Third-Party		
Third-parties do not have direct access to SPaT, MAP, BSM messages, signal timing plans, pedestrian call information, signal controller status, and real-time, historic, and predicted queues.	UN-3.01	A third-party needs access to SPaT, MAP, BSMs, signal timing plans, pedestrian call information, signal controller status, and real-time, historic, and predicted queues via the CV Data Framework to provide relevant data to its users.
Third-parties are vulnerable to security threats.	UN-3.02	A Third-party needs secure connections to the CV Data Framework.
Third-parties do not have a means to selectively manage data they receive.	UN-3.03	A Third-party needs the ability to adjust the type or quantity of data received to them via the CV Data Framework.
Third-parties do not necessarily communicate with other third-parties.	UN-3.04	Third-parties need to use the CV Data Framework to access data from other third-parties.
Third-parties are not able to verify the contents or security of the data they receive.	UN-3.05	The CV Data Framework needs to verify the contents and security of the data it provides.
System Integrator		
System integrators do not have direct access to OEMs or device users.	UN-4.01	A system integrator needs access to OEMs and device users.

5.3 Functions and Features

This section identifies the functions and features of the CV Data Framework. A function is what the system can do and should be an action. A feature is how a function can be accomplished and should be a noun.

5.3.1 Functions

- Provide data directly from devices
    - Data provider: States/IOOs
    - Data consumer: OEMs/Third-parties
    - Needs addressed: UN-1.01, UN-3.01
- Provide enhanced data
    - Data provider: States/IOOs
    - Data consumer: OEMs/Third-parties
    - Needs addressed: UN-1.01, UN-3.01
- Manage access to data
    - Data provider: States/IOOs
    - Data consumer: OEMs/Third-parties
    - Needs addressed: UN-1.02, UN-3.03, UN-2.02
- Verify contents/security of data from devices
    - Data provider: States/IOOs
    - Data consumer: OEMs/Third-parties
    - Needs addressed: UN-1.03, UN-3.05
- Secure the connections to third-parties
    - Data provider: States/IOOs
    - Data consumer: OEMs/Third-parties
    - Needs addressed: UN-3.02
- Provide the ability to archive data
    - Data provider: States/IOOs
    - Data consumer: OEMs/Third-parties
    - Needs addressed: UN-2.02

5.3.2 Features

- Web-based API
- User Interface for configuration and data management
- Internal data store
- Schemas

5.4 Operational Scenarios

This section describes example use cases and operational scenarios associated with data that is exchanged through the CV Data Framework between states/IOOs, third-party application providers, and OEMs.

5.4.1 Use Case 1: CV Data Framework Provides Data

<table>
<tr><th colspan="4">Use Case 1 Scenario 1 (UC1-S1): Direct communication of data from CV devices</th></tr>
<tr><td>Scenario Objective(s)</td><td colspan="3">Provide data directly from CV devices without changing or manipulating the data</td></tr>
<tr><td>Operational Event(s)</td><td colspan="3">• CV Data Framework receives data from CV devices
• CV Data Framework provides the data from CV devices to data consumers</td></tr>
<tr><td>User(s)</td><td colspan="3"><table><tr><th>User</th><th>Role</th></tr><tr><td>States/IOOs</td><td>Data owner</td></tr><tr><td>Third-parties</td><td>Data consumer</td></tr></table></td></tr>
<tr><td>Initial Conditions</td><td colspan="3">• (optional) Third-parties request access to the CV Data Framework
• (optional) Third-parties configure the requested data
• Third-parties have connectivity to the CV Data Framework</td></tr>
<tr><td>Key Actions and Flow of Events</td><td colspan="3"><table><tr><th>Step</th><th>Source</th><th>Key Action</th></tr><tr><td>1</td><td>CV Data Framework</td><td>Receives data from devices</td></tr><tr><td>2</td><td>Third-party</td><td>Initiates a request for direct data</td></tr><tr><td>3</td><td>CV Data Framework</td><td>Provides data directly to the third-party without modification</td></tr><tr><td>4</td><td>Third-party</td><td>Receives and uses the data</td></tr></table></td></tr>
<tr><td>Post-Conditions</td><td colspan="3">• Third-party application users benefit from use of CV Data Framework data</td></tr>
<tr><td>Traceability</td><td colspan="3">UN-3.01</td></tr>
</table>

<table>
<tr><th colspan="4">Use Case 1 Scenario 2 (UC1-S2): Communication of enhanced data</th></tr>
<tr><td>Scenario Objective(s)</td><td colspan="3">• Make enhanced data available to third-parties</td></tr>
<tr><td>Operational Event(s)</td><td colspan="3">• CV Data Framework receives data from devices
• CV Data Framework executes logic that enhances the value of direct data
• CV Data Framework provides enhanced data to data consumers</td></tr>
<tr><td>User(s)</td><td colspan="3"><table><tr><th>User</th><th>Role</th></tr><tr><td>States/IOOs</td><td>Data owner</td></tr></table></td></tr>
</table>

<table>
<tr><th colspan="4">Use Case 1 Scenario 2 (UC1-S2): Communication of enhanced data</th></tr>
<tr><td></td><td colspan="3">Third-party | Data consumer</td></tr>
<tr><td>Initial Conditions</td><td colspan="3">• States/IOOs have configured devices to provide data to CV Data Framework
• CV Data Framework can receive data from devices
• Algorithms have been defined and implemented on the CV Data Framework
• Third parties have connectivity to the CV Data Framework
• Third-parties have indicated which enhanced data is desired</td></tr>
<tr><td>Key Actions and Flow of Events</td><td colspan="3"><table>
<tr><th>Step</th><th>Source</th><th>Key Action</th><th>Comments</th></tr>
<tr><td>1</td><td>CV Data Framework</td><td>Receives data from devices</td><td></td></tr>
<tr><td>2</td><td>CV Data Framework</td><td>Executes algorithms to enhance the data</td><td></td></tr>
<tr><td>3</td><td>Third-party</td><td>Requests enhanced data</td><td></td></tr>
<tr><td>4</td><td>CV Data Framework</td><td>Sends enhanced data to the third-party</td><td></td></tr>
<tr><td>5</td><td>Third-party</td><td>Consumes the enhanced data</td><td></td></tr>
</table></td></tr>
<tr><td>Post-Conditions</td><td colspan="3">• Third-party application users benefit from use of enhanced CV Data Framework data</td></tr>
<tr><td>Traceability</td><td colspan="3">UN-3.01</td></tr>
</table>

5.4.2 Use Case 2: CV Data Framework Receives Data from Third Parties

<table>
<tr><th colspan="3">Use Case 2 Scenario 1 (UC2-S1): Aggregate vehicle data is provided by third-parties</th></tr>
<tr><td>Scenario Objective(s)</td><td colspan="2">• Make aggregated data from third-parties available to states/IOOs or other third-parties
o Aggregated data may include
▪ Insights from predictive analytics such as traffic volume predictions, road surface changes, or water on roadway
o Direct reports may also be provided from vehicles such as a disabled vehicle</td></tr>
<tr><td>Operational Event(s)</td><td colspan="2">• CV Data Framework receives vehicle data from third-parties
• CV Data Framework sends insights from vehicle data to states/IOOs
• (optional) CV Data Framework archives data</td></tr>
<tr><td>User(s)</td><td colspan="2"><table>
<tr><th>User</th><th>Role</th></tr>
<tr><td>Third-party</td><td>Producer of vehicle data</td></tr>
</table></td></tr>
</table>

<table>
<tr><th colspan="4">Use Case 2 Scenario 1 (UC2-S1): Aggregate vehicle data is provided by third-parties</th></tr>
<tr><td></td><td colspan="3"><table>
<tr><td>States/IOOs</td><td>Consumer of vehicle data</td></tr>
<tr><td>CV Data Framework</td><td>Provide access to archived vehicle data</td></tr>
</table></td></tr>
<tr><td>Initial Conditions</td><td colspan="3">• Third-parties capable of sending vehicle data to the CV Data Framework can communicate with the CV Data Framework
• States/IOOs have connectivity to the CV Data Framework
• Data definitions have been established and are followed</td></tr>
<tr><td>Key Actions and Flow of Events</td><td colspan="3"><table>
<tr><th>Step</th><th>Source</th><th>Key Action</th><th>Comments</th></tr>
<tr><td>1</td><td>CV Data Framework</td><td>Receives vehicle data</td><td></td></tr>
<tr><td>2</td><td>CV Data Framework</td><td>(optional) Archives vehicle data</td><td></td></tr>
<tr><td>3</td><td>States/IOOs</td><td>Initiates a request for predictive analytics insights</td><td></td></tr>
<tr><td>4</td><td>CV Data Framework</td><td>Sends requested data to the states/IOOs</td><td></td></tr>
<tr><td>5</td><td>States/IOOs</td><td>Receives and uses the predictive analytics insights</td><td></td></tr>
</table></td></tr>
<tr><td>Post-Conditions</td><td colspan="3">• The states/IOOs benefit from the use of predictive analytics insights
• (optional) Vehicle data are archived</td></tr>
<tr><td>Traceability</td><td colspan="3">UN-2.01
UN-3.01</td></tr>
</table>

5.5 Supported Applications

The supported applications provide real-world examples of applications that would exercise the operational scenarios listed above and would meet some of the needs of the users. This is not expected to be an exhaustive list but will allow for further refinement of the capabilities offered.

5.5.1 Eco-Approach and Departure at Signalized Intersection

This application provides a recommended speed to vehicles that are approaching an intersection or departing an intersection. The recommended speed maximizes some metric that is valuable to the vehicle operator, such as gas mileage or total travel time. The recommended speed is calculated by third-parties based on SPaT, MAP and Speed Limit data.

5.5.1.1 Data Considered

1. Vehicle position (externally available from BSM source)
2. Vehicle speed (externally available from BSM source)
3. Intersection geometry (MAP)
    1. Lane geometry
    2. Speed Limit per approach/roadway
4. Phase time remaining (SPaT)
    1. (Desired) Queue length (see GLOSA)

5.5.2 Extended Eco-Approach at Signalized Intersection

This application is similar to the above application but extends the scope of the applicable intersections to include intersections that are more than one light cycle away. In order to perform the appropriate calculations for a recommended speed, additional information needs to be provided to third-parties through the CV Data Framework. The information allows a third-party to perform long-term predictions on a light's future state.

5.5.2.1 Data Considered (inherited from Eco-Approach)

1. Vehicle position (externally available from BSM source)
2. Vehicle speed (externally available from BSM source)
3. Intersection geometry (MAP)
    1. Lane geometry
    2. Speed Limit per approach/roadway
4. Phase time remaining (SPaT)
    1. (Desired) Queue length (see GLOSA)

5.5.2.2 Additional Data

5. Signal light timing plan
6. Time synchronization
7. (Desired) Device status
8. (Desired) Vehicle call per lane
9. (Desired) Pedestrian call

5.5.3 Red Light Violation Warning

This application provides a warning to vehicles that are approaching an intersection if they would be likely to enter the intersection while the light is red. The warning is calculated based on SPaT and MAP data (provided through the CV Data Framework).

5.5.3.1 Data Considered

1. Vehicle position (externally available from BSM source)
2. Vehicle speed (externally available from BSM source)
    1. Acceleration (negative for deceleration)

3. Vehicle destination (for some intersections)
4. Intersection geometry (MAP)
    1. Location of cross-bar
    2. Roadway geometry
    3. Restricted movement
5. Phase time remaining (SPaT)

5.5.4 Pedestrian and Cyclist Warning

This application provides a warning to vehicles that a pedestrian or cyclist may be in the crosswalk. The broadcasted warning is expressed as an estimation or known detection, based on the data sources provided to the CV Data Framework.

5.5.4.1 Data Considered

1. Push button activation
    a. Real-time
    b. Historic activations
2. Intersection geometry (MAP)
    a. Lane geometry
3. Signal phases (SPaT)
    a. (Desired) Exclusive pedestrian phases
4. Sensor feed (if available)
    a. On the curb
    b. In the crosswalk

5.5.5 Data Sharing by Third-Parties

This application refers to the sharing of aggregated vehicle data (and potentially predictive analytics insights such as traffic prediction, road surface changes, or water on roadway) to states/IOOs or other third-parties. Examples of data sharing include information about system performance (SPM reporting) as well as aggregation of data from different OEMs to provide agencies with meaningful reports and insights. From an operational standpoint, there are automation opportunities for traffic signal systems (transit signal priority, system feedback, etc.) and broadcasting of desirable information (queue length, disabled vehicles, etc.) that could be enabled through data sharing by third-parties.