Connected Intersections –
Consistent Procedures for Operations (CPO)

Cooperative Automated Transportation Coalition

IOO/OEM SPaT/RLVW Working Group

DRAFT Version 1.1

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1 Introduction

This document is being circulated as a dated draft document, with the intent and anticipation that the document will evolve and improve as additional input is received. Future updates will be posted to the CAT Coalition website.

1.1 Definition of Connected Intersections

A connected intersection is defined by ITE as "an infrastructure system that broadcasts signal, phase and timing (SPaT), mapping information and position correction data to On-Board Units and Mobile Units."[1] Connected intersections have the goal of accomplishing communications with vehicles, pedestrians, and other end-user systems (commonly referred to as V2X communications).

Recent activities led by the ITE Connected Intersections (CI) Committee have developed a Concept of Operations (ConOps), System Requirements, and System Design Details (SDDs) for Connected Intersections Implementation Guide. The implementation guide will promote interoperability by defining guidance for implementing connected intersections to avoid ambiguities and differences of interpretation. During the implementation process of a connected intersection, at least two stages of deployment are defined for purposes of reference in this document, including:

- ***Connected Intersections In deployment.*** A term used to describe the period when implementation of the connected intersection has begun, and equipment may be deployed and operational. However, the full deployment, security credentialling, testing, and verification, as defined by the Connected Intersections Implementation Guide, has not been fully completed. These systems may be broadcasting data, and the data may be received and used by in-vehicle systems. However, the full functionality has not been verified.
- ***Fully Operational Connected Intersections.*** A term used to describe connected intersections that have completed all testing and verification steps defined by the Connected Intersections Implementation Guide. These are intersections that in-vehicle applications would understand to be interoperable and consistent with the SDD of the implementation guide.

1.2 Connected Intersections – Role of Operations

The need for consistency does not stop after the implementation phase. Fully operational connected intersections need to be consistently operated after they are deployed in order for in-vehicle applications to rely upon the broadcasts of data. The two primary roles of connected intersections operations are:

- To maintain continuous broadcasts of data; and
- To perform periodic updates to connected intersections as new conditions, technologies, standards, or issues are introduced. These updates will lead to a need for a subset of the initial testing to "re-verify" the connected intersection for operations.

These roles, and the relationships are shown in Figure 1.

[1] Institute of Transportation Engineers. Technical Resources, Connected Intersections. Accessed 23 Feb 2021: https://www.ite.org/technical-resources/standards/connected-intersections

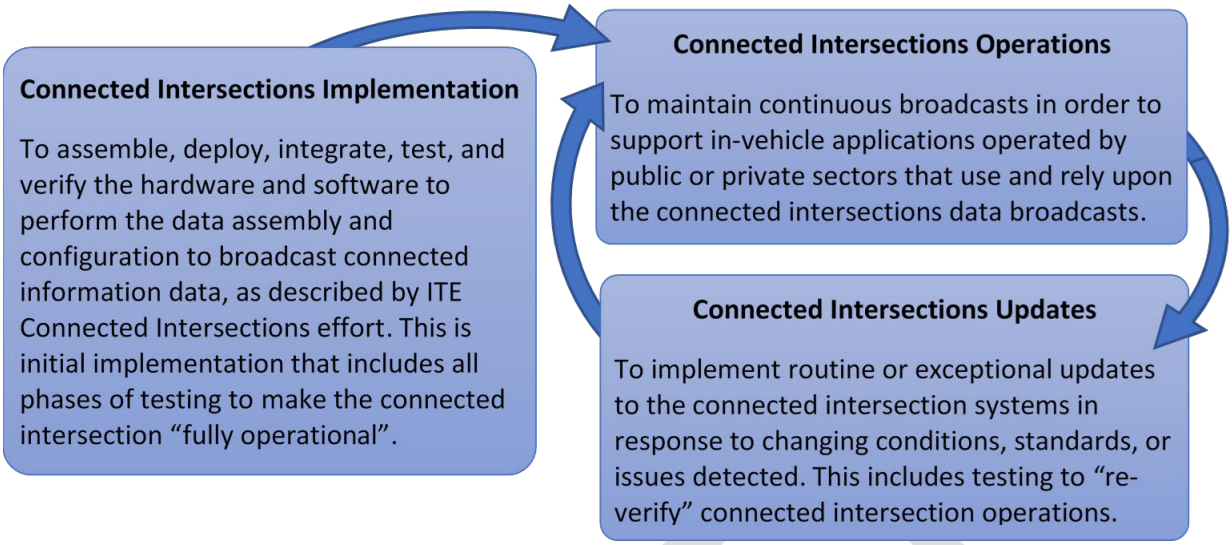

Figure 1. After implementation, connected intersections evolve in a cyclical process of operations and updates.

1.3 Context/Purpose and Structure of this Document

This document benefits from the collaboration of the IOOs and OEMs participating in the IOO/OEM Forum's SPaT/RLVW working group. Working together, the IOOs and OEMs have identified a comprehensive list of operational scenarios and developed context around the anticipated needs of in-vehicle applications expected to be operating in production vehicles. The document describes a series of agreed principles for maintaining operations, but stops short of identifying or prescribing how the principles should be executed. It is envisioned that a broader group of stakeholders (e.g., involving signal control manufacturers and others) will be involved in eventual development of tactics that may include standard operating procedures (SOPs) to accomplish the principles. This document includes a series of scenarios that define situations when operational decisions are needed.

The subsequent chapters of this document are organized to:

2. Describe challenges and the need for consistent connected intersection operations.
3. Define principles for connected intersection operations.
4. Define common procedures for connected intersection operations during normal conditions and during outages, as well as procedures for tracking/reporting connected intersection deployments.
5. Describe the various types of possible disruptions to normal operations.
6. Describe monitoring and maintenance considerations of connected intersections infrastructure.

2 Challenges Facing Operations of Connected Intersections

Beyond the need for clarifications and requirements for the implementation of connected intersections is the need to clarify operational approaches to scenarios that will regularly or periodically occur. These scenarios include such situations as short-term maintenance or road work impacting a connected intersection, power outages, long-term closures, etc. Additionally, conflict monitoring is critical to signal operations and an equivalent approach for connected intersections is also needed. The following challenges summarize the need for consistency in operations of connected intersections:

1. Temporary lane closures for operational activities can alter the intersection geometry, rendering the MAP message inaccurate.
2. Several agencies may close lanes, including utilities, that are outside the DOT. These staff would likely not know if the intersection were connected and manual implementation of messages cannot be accurately guaranteed.
3. Even when outages or disruptions are not occurring, malfunctions may create differences in the signal controller status and the data output and broadcast in the SPaT message.
4. In-vehicle applications have no way of determining if broadcasted messages are correct or incorrect, and therefore assume data is correct.
5. The deployment of connected intersections could be a progressive activity that occurs over an extended timeframe to accomplish the required system integration, testing, verification, and security credentialling. During this time, data may be broadcast, but there is a need for identifying intersections as fully operational once they meet the implementation guidelines established by the ITE/CI effort.
6. Following a disruption or changes made to the MAP, SPaT, and RTCM messages, there is a need to conduct a subset of the testing procedures to re-verify connected intersection operations.
7. Once operational, there is a need to track deployment of connected intersections for overall understanding of OEMs and other third-party applications to understand how many and where connected intersections are operational. This is not a need for real-time tracking, but rather for market understanding.

3 Principles for Connected Intersection Operations

This chapter describes a series of principles that the IOOs and OEMs discussed and identified as appropriate for operating fully operational connected intersections.

Principle #1: No Broadcasts of Incorrect Messages. A broadcast message containing incorrect information has the risk of doing greater harm than if no message were broadcast at all. Any broadcast message should always contain correct information.

- Absent messages are better than incorrect messages. Temporary periods where there are no broadcasts of messages are acceptable.
- Messages that contain information that do not match physical conditions and traffic control in the field should no longer be broadcast or should be identified as "not valid".
- Testing of SPaT and MAP broadcasts should be conducted upon deployment of the connected infrastructure and following changes to deployments, in accordance with the testing and verification procedures and tools defined by the ITE/Connected Intersections project.
- In situations where the current lane configuration no longer matched the MAP message (e.g., during a temporary lane closure), the MAP message should not be broadcast. The exception would be if a supplemental warning message of "No valid MAP message available" is broadcast using a standard data exchange protocol, such as a Traveler Information Message (TIM) or Road Safety Message (RSM).
- IOOs should implement systems capable of monitoring signal controller outputs to detect when SPaT message are not correctly reporting current signal head displays.
- The "Safe State" to support in-vehicle applications is to ***stop broadcasting all messages***.

Principle #2: Restore Correct Broadcasts Progressively as Soon as Practical. Functionality of the connected intersection should be restored in a progressive, gradual, reliable approach that results in messages containing correct information being broadcast as soon as is practical. Rather than hasty restoration of broadcasts that may be valid for a period of time and then not valid again, a gradual restoration process that minimizes the transitions from valid to not valid is preferred when restoring functionality once intersection operations have returned to a normal, operational state.

- This may involve restarting the broadcast of previous messages that are once again valid.
- This may require the creation of new messages to update information (e.g., if re-striping or reconstruction has changed the physical characteristics of the intersection).

Principle #3: Anomalies Must Self-Report to Ensure Accurate Messages. Detection of anomalies (specifically, situations where the connected intersection broadcast does not match the current signal controller mast head displays, the MAP message is incorrect, or the RTCM message is incorrect) should be self-reported by individuals causing the outage (e.g., a utility

company closing an approach lane to the intersection) whenever possible. Self-reporting of anomalies by automated processes or system detection is also a preferred option.

- Infrastructure and vehicle systems will include various forms of monitoring capabilities, however given the variety of types of disruptions, there can be no assurance that automatic monitoring will detect all disruptions.
- Self-reporting by agency staff, law enforcement, construction contractors, or other authorized personnel is required, to the extent possible, so that these disruptions are known.
- Human reporting may not be possible in all circumstances, or may be delayed (e.g,. first responders to an incident must focus their attentions on crash victims). Reliance on human reporting has flaws; but is a necessary stopgap until more sophisticated monitoring approaches can be developed and implemented.

Principle #4: Clearly Identify Fully Operational Connected Intersections. Connected intersections should be considered "in deployment" until they are fulling tested, verified, and secured; upon which they should be considered "fully operational".

- While there are examples of connected intersections "in deployment" that are used for agency operated vehicles (e.g., transit signal priority, snowplow preemption, etc.) production vehicles will require connected intersections to complete all verification activities, as defined by the ITE/CI process, before they can be trusted as interoperable.
- OEMs and private third-party application providers will benefit by data describing deployments of "fully operational" connected intersections. At the highest level, knowledge of the number of intersections per state or metro area will be beneficial. Additional details about locations will be supplemental information.

4 Evolving Tactics for Operating Connected Intersections

This chapter contains sections that describe tactics for operating connected intersections under normal conditions and during outages and disruptions, as well as tracking their deployment.

4.1 Evolving Tactics for Normal Operations

Normal operations of connected intersections would be all times when the intersection is not experiencing roadwork, temporary lane closures or restrictions, or any other human interaction with traffic control within or around the intersection.

Once implemented, a connected intersection's normal operations would typically include:

- ***SPaT Operations.*** Operating and maintaining the connection between the signal controller and the RSU to ensure content is continuously generated for broadcast to connected vehicles.
- ***MAP Updates.*** Creating and implementing an approach that any time the intersection geometry is altered or the assignment of signal groups changes, the MAP message is updated, tested, verified, secured, and uploaded to be broadcast by the RSU.
- ***Position Correction Operations.*** Operating the selected approach to generate and secure location position correction messages (e.g., RTCM messages) continuously without interruption.
- ***Malfunction Monitoring.*** Operating malfunction monitors to detect situations when the signal controller data does not match SPaT broadcasts. Emerging approaches are expected to be developed and tested in the coming years. These could include:
    - Expansions of existing malfunction monitoring equipment and systems that monitor traffic signals today.
    - Deployment of new approaches, such as comparisons of basic safety message (BSM) data received from connected vehicles in an around the intersection against current signals (e.g., a series of BSMs that shows vehicles are turning left from lane 7 to lane 10, may indicate a left-turn for Signal Group B. a check of whether Signal Group B is reported as left turn protected could determine if the SPaT message is matching the signal head).
- ***Security Operations***. Operating security credentialling business practices to ensure credentials are being created on a continuous basis, as needed.

4.2 Evolving Tactics for Operations during Outages and Disruptions

In 2021, it is likely not practical for an IOO to immediately respond to all types of outages that may impact the quality of connected intersection broadcasts, nor does the number of production vehicles operating in-vehicle applications justify prioritization of resources to such a response. However, over the coming 10-20 years, several things are likely to occur:

- More intersections are likely to become connected, with increasing numbers of products to support easier more efficient management of the broadcasts;
- More vehicles are likely to be equipped with in-vehicle applications;

- The role of in-vehicle applications is likely to change, possibly beyond supplemental warning systems to supporting partial or automated driving functions, increasing the reliance on the data broadcast by the infrastructure; and
- The operations that IOOs perform will evolve with potentially an increased emphasis on maintaining the operational status of infrastructure broadcast.

While the principles defined above may remain intact, the tactics that IOOs implement to accomplish the principles may evolve as these and other changes occur over the coming decades. The industry is only beginning to initiate discussions involving these topics. Sustained collaboration is needed to understand what is possible from current technologies and capabilities, what is possible as supporting technologies evolve, and the penetration rate of connected vehicles and reliance upon the data.

Possible tactical approaches that may be chosen by an agency for various types of disruptions, include:

- ***Take no action.*** Wait for the temporary disruption to end. In situations where a lane is closed temporarily, the lane may reopen shortly after and no action may have been performed in response to the outage.
- ***Pause Broadcasts.*** Implement a temporary stop/pause in broadcasting the messages. In situations where a physical activity impacts the intersection, the RSU broadcast may be paused while either the MAP or SPaT messages are not valid.
- ***Supplemental warning***. It may be more efficient to continue to broadcast SPaT/MAP messages while adding an indication in either the SAE J2735 message or the security WSA message to indicate the messages are not valid;
- ***Broadcast Road Safety Messages (RSMs).*** RSMs describing the maintenance or construction work zone event could be broadcast to help indicate to passing vehicles that the intersection operations may be disrupted.
- ***On-site Responder Broadcasts***. Alerts could be broadcasts by vehicles (e.g., law enforcement or first responder vehicles) at the intersection (e.g., stationary location, flashing beacons activated) that would help indicate to passing vehicles that intersection operations may be disrupted.

As noted above, the selection of appropriate tactics will evolve over time, as in-vehicle application use and reliance on the broadcasts increases.

4.3 Evolving Tactics for Restoring Operations After Updates or Disruptions

Testing will be required to restore connected intersection operations following any disruption or updates that are made. This testing is expected to be only a subset of the full test procedures that are used for initial implementation. Specifically, agencies will be required to conduct Phases 2a & 2b testing on the connected intersections following any disruption or update to “re-verify” intersection functionality and operations, as shown in Figure 2 below.

4.4 The Role of Testing and Verification in Connected Intersections Operations

Connected intersections operations will inherently have a close relationship to the testing procedures adopted to ensure functionality and interoperability. A separate effort, the “Connected Intersections

Overall Testing Approach" (insert link when posted) includes additional details describing five phases to testing and verifying connected intersections. Figure 2 provides a high-level summary of the five testing phases that will apply to implementation, operations, and updates for connected intersections.

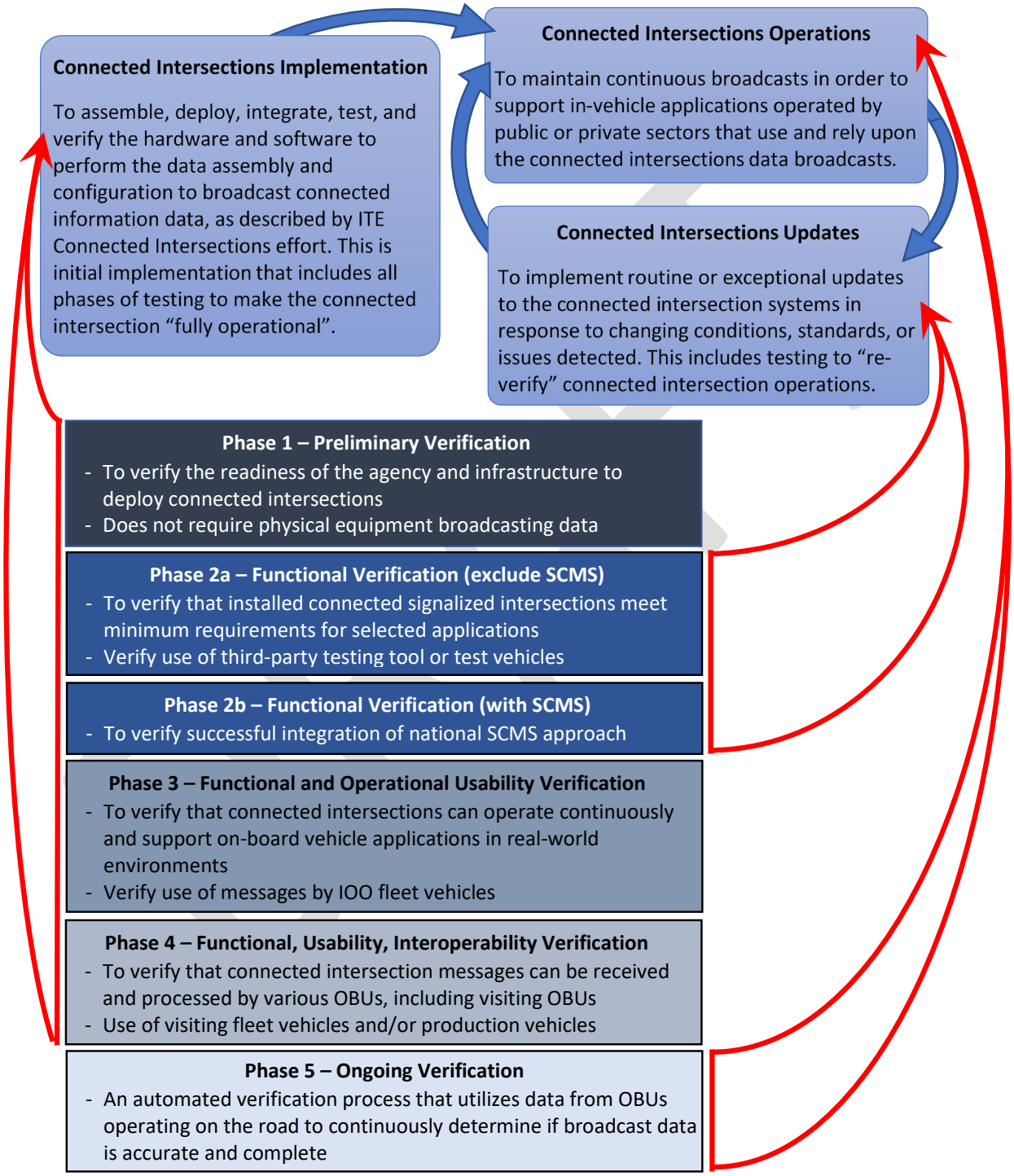

Figure 2. Testing approaches for connected intersection implementation, operations, and updates

4.5 Evolving Tactics for Tracking Connected Intersections

As Connected Intersections are implemented, industry and the broader community of stakeholders need to have a general understanding of the number and location of "fully operational" connected intersections. Tracking operational connected intersection is currently envisioned to have the following characteristics:

1. A self-reporting process coupled with a web-enabled platform to support reporting and viewing is needed for tracking deployments of Connected Intersections that are "fully operational".
   a. The tracking is not intended to be a real-time depiction of which intersections are fully functioning vs. those that may be experiencing a temporary malfunction, but rather a representation of the number of sites "fully operational" as connected intersections.
2. As a minimum, the self-reporting process would result in a high-level count of Connected Intersections by state and/or metro area.
3. Tracking may also consider relative number of Connected Intersections that are operating at different thresholds of standards or capabilities. Examples may include:
   a. To distinguish connected intersections using the latest standards versus those that use earlier standards;
   b. To distinguish intersections with additional capabilities (beyond basic SPaT, MAP, RTCM) such as queue length detection and green window reporting (required for TOSCo and other cooperative driving automation applications).
   c. IOOs may also track and report connected intersections that are "in deployment" but require additional testing to be "fully operational", however this information is likely less valuable to OEMs.

5 Use Cases Describing Possible Disruptions to Normal Operations

This section describes the following examples of planned or unplanned disruptions at Connected Intersections that are expected to be most common:

- Complete unplanned malfunction such as a loss of power (e.g., to everything versus specific elements like RSU and/or controller);
- Partial malfunction where the RSU is operational but data is not guaranteed;
- Maintenance or construction; and
- A geometry change at the intersection.

Note that these disruptions may overlap as the event evolves over time. Additionally, the durations of these disruptions will vary, and may result in different operational changes to the Connected Intersection from the IOO, such as:

- Unknown duration (e.g., SPaT data not properly configured or other situations where manual or actuated control is preventing a known end time. Even if a disruption may end in 5 seconds when the phase changes, for example, it is a disruption of "unknown duration".)

- Duration of less than one day (e.g., crash, planned special event, or short duration maintenance in the intersection when one or more lanes is closed and/or signal timings are modified or manually overridden)
- Duration of multiple days (e.g., construction activity in the intersection, possibly involving multiple phases with different lane closures)

5.1 Complete Unplanned Malfunction like Loss of Power

<table>
<tr><td rowspan="2">Activity:
• There is no power to the signal controller or RSU
• Duration is not known</td><td rowspan="2">Signal Controller Status:
• Flashing mode is either automatically activated or manually activated
• Signals may be in Dark Mode if no battery backup is available, or battery life is exhausted</td><td>SPaT Message:
No SPaT message would be generated or broadcast</td></tr>
<tr><td>MAP Message:
MAP message exists but is not broadcast</td></tr>
<tr><td colspan="3">Considerations and Possible Solutions:
• Implement remote detection to identify loss of power and other malfunctions
• Use network communications to broadcast RSM or TIM messages to supplement information
• During times when the RSU is not broadcasting, the safe system status of not broadcasting inaccurate data is met. It is acceptable for there to be no RSU broadcast as it minimizes the risks of the in-vehicle application receiving bad data.
• In this use case, once power is restored, there is not a need to retest and verify the intersection.</td></tr>
</table>

5.2 Minor Unplanned Malfunction where RSU is Operational But Data Not Guaranteed

<table>
<tr><td rowspan="2">Activity:
• There is a malfunction at the signal controller.
• Output data may not match display.
• Duration is <u>not known.</u></td><td rowspan="2">Signal Controller Status:
• Signal is not providing valid data such that output to RSU does not match display
o Flashing mode may be automatically activated or manually activated.
o Signal may be operating, displaying interval status as red, green, yellow</td><td>SPaT Message:
SPaT Message is still derived from the output controller data</td></tr>
<tr><td>MAP Message:
MAP message exists and is broadcast</td></tr>
<tr><td colspan="3">Considerations and Possible Solutions:
• These disruptions introduce the highest-level risk to in-vehicle applications as the data may be inaccurate and the application has no mechanism to test it. Under the principles described above, IOOs should have a mechanism in place to pause the data broadcast by the RSU.
• SAE J2735 allows for intersection status of “Off” when the signal controller is not providing valid data. This may automatically be output by the signal controller.
• Situations may occur where the RSU output is not providing valid data but the IOO is not aware of this.
• A malfunction monitor may detect this disruption, and could be tied to processes to automatically pause broadcasts.
• This situation may resolve itself within seconds.
• It would be valuable to detect and log instances of this malfunction to understand how frequent they are, if at all.
• In this use case, once service is restored, there is not a need to retest and verify the intersection.</td></tr>
</table>

5.3 Maintenance, Construction, Incident, or Special Event

<table>
<tr><td rowspan="2">Activity:
• Intersection operations have changed due to law enforcement, crash, or work zone blocking one or more lanes of an intersection and/or manually directing traffic.
• Duration is generally known and last up to several hours, or may extend to many months.</td><td rowspan="2">Signal Controller Status:
• Assumes flashing mode is not activated, signals are operating per timing plans (timing plans may be altered to reflect temporary change).
• Flashing mode may be manually activated or flagging operations may be present for some or all of the activity.</td><td>SPaT Message:
Message is describing current phase timings.</td></tr>
<tr><td>MAP Message:
MAP message is no longer accurate because of temporary lane closures or restrictions.</td></tr>
<tr><td colspan="3">Considerations and Possible Solutions:
• If the MAP message is no longer accurate, these disruptions introduce the highest-level risk to in-vehicle applications as the MAP data is inaccurate (depending upon the work being performed) and the application has no mechanism to test it. Under the principles described above, IOOs should have a mechanism in place to pause the data broadcast by the RSU as soon as practical.
• Alternatively, a broadcast of “No valid MAP message” may be used to alert in-vehicle applications of the disruption. This may be accomplished through a J2735 SPaT message or a Wave Service Announcement (WSA) in the security message.
• Under the principles described above, workers in the intersection could self-report the outage and (if systems allow) pause broadcasts or activate “No valid MAP message” broadcasts.
• With the signals not in flashing mode, human drivers would visually observe temporary traffic control including signage and channelizing devices like barrels and cones, but OBU applications would not have any notice of the activity.
• Construction or maintenance activities may be described in other, supplemental messages (e.g., RSM)
• In this use case, once that activity is completed, there would not be a need to retest and verify the intersection unless the activity resulted in a change in intersection geometry, allowed movements, or assignment of signal groups.</td></tr>
</table>

5.4 Geometry Change at the Intersection

<table>
<tr>
<td>Activity:
• An additional turn lane is added to the intersection. Signal timing (and signal groups) are adjusted to reflect the change.
• There is a construction period and a period where the MAP message is updated.</td>
<td>Signal Controller Status:
• Signal may continue to operate as timed during construction, with flaggers directing traffic when needed.
• Signal timing changes will be implemented just prior to the opening of the new lane.</td>
<td>SPaT Message:
SPaT Message is still derived from the controller data. When the new timing plan is implemented, SPaT data will immediately be output.

MAP Message:
MAP message (initial geometry) will exist and may be broadcast and valid during the construction period.
A new MAP message will be needed to reflect the additional lane and connections.</td>
</tr>
<tr>
<td colspan="3">Considerations and Possible Solutions:
• This represents a combination of several use cases above:
  • There will likely be times when intersection work is active, that the original MAP message is inaccurate and the broadcast should be paused.
  • There will likely be times when intersection work is inactive and all lanes are open (e.g., evenings) when the broadcast of SPaT/MAP is appropriate.
• There will be a need to test the newly configured intersection to verify the SPaT/MAP are properly represented upon reopening the intersection.</td>
</tr>
</table>

6 Monitoring and Maintenance Considerations of Connected Intersections Infrastructure

There is need for IOOs to have processes in place for ongoing monitoring of connected intersections in order to identify unplanned disruptions and proactively maintain infrastructure to prevent disruptions. These are needs for connected intersections to enable vehicle and application functionality, as identified by OEMs and fleet operators, such that:

- OEMs may operate apps like RLVW
- Transit agencies may rely on data for priority
- EMS may rely on data for preemption
- Snow plows may rely on data for priority

These needs may require IOOs to develop operational procedures that consider the following:

- Built-in alarms at the signal controller / RSU for errors in communications / broadcasts / data availability
- Inserting a notification within the WSA when a MAP message is not accurate (e.g., for short-duration planned events, potentially lasting for multiple weeks)
- Periodically updating the MAP message date stamp (e.g., every 30 days) to demonstrate to OEMs and users that information is not stale
- Software upgrades
- Ongoing data verification
- Infrastructure inspection and maintenance
- Monitor changes to standards and make updates to infrastructure, messages, and other items, when needed