Updating NTCIP 1202 (Actuated Signal Controllers) to Support a Connected Vehicle Environment

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Summary

USDOT *connected vehicle* research indicates that connected vehicle applications and technologies show great promise in improving safety, mobility and environment on the US surface transportation network. One specific area where connected vehicles may have a large beneficial impact is at signalized intersections, where connected vehicle applications related to signal timing operations may greatly reduce crashes. The development of NTCIP 1202 v03 began in Summer 2014 and quickly identified support for the connected vehicle environment as a user need. This paper introduces the user needs and requirements that have been expressed in draft NTCIP 1202 v03, at this stage, in support of connected vehicle applications for signalized intersections. The paper also introduces candidate architectures that draft NTCIP 1202 v03 anticipates supporting, and provides an overview of conformance provisions for draft NTCIP 1202 v03.

Keywords

Connected vehicles, standards, NTCIP, traffic signals, signalized intersection, MAP message, SPAT message, signal priority, actuated signal control

Introduction to NTCIP 1202 v03 (Actuated Signal Control Object Definitions)

NTCIP 1202 v02 (Object Definitions for Actuated Signal Controllers) is currently supported by all the vendors supplying traffic signal controllers for traffic signal control systems in the United States. NTCIP 1202 standardizes the communications interface between a management station (such as a central traffic signal system software) and an actuated traffic signal controller (ASC). In 1992, the NEMA 3-TS Transportation Management Systems and Associated Control Devices Section, in response to user needs, began the development of a communications standard for the NEMA TS 2 standard. The NEMA TS 2 standardized the functions of a US traffic signal (phase based) controllers. That communications standard was originally designated NEMA TS 3.5-1996, and was subsequently re-designated NTCIP 1202 v01 in 2005. NTCIP 1202 is a data dictionary that supports the functional requirements of a (phase based) NEMA TS 2. Version 2 of the standard was published in 2005.

Many new user needs and requirements have been identified since NTCIP 1202 v02, resulting in many manufacturer-specific proprietary objects. Though consistent with and permitted by NTCIP 1202 v02, the use of so many proprietary objects is a challenge to interoperability. Thus, in October 2014, work started on updating NTCIP 1202 v02 to NTCIP 1202 v03.

One of the major changes in the development of NTCIP 1202 v03 is the addition of systems engineering content. By applying a systems engineering process, the standard defines the user needs that are supported. With the incorporation of systems engineering content, the standard is designed to allow a user to quickly and easily select the user needs that are desired by the agency. The standard then provides the user with the functional requirements that satisfy each user need selected. The user is then allowed to select the requirements that are applicable for a specific project. The standard goes on to define the (single) design that fulfills each requirement. By defining a single design, the standard is able to support interoperability. Interoperability is the ability to use components from different vendors to exchange information and to use the information that has been exchanged the way it was intended. Interoperability is a key objective and benefit for using the standards. Interoperability reduces risks, and by extension, costs.

At this time, NTCIP 1202 v03 is still in development, and subject to significant change, with a scheduled publication date at the end of 2016.

Connected Vehicle-Related User Needs

Some of user needs identified for NTCIP 1202 v03 are directly related to supporting a connected vehicle environment. But before reviewing those user needs, it is important to understand the scope of NTCIP 1202 v03. NTCIP 1202 v03 is an interface standard, describing the specific information exchanges between two components of an ASC system. Figure 1 presents an overview of what a complete ASC system may look like for a transportation agency, and identifies the interfaces addressed by NTCIP 1202 v03.

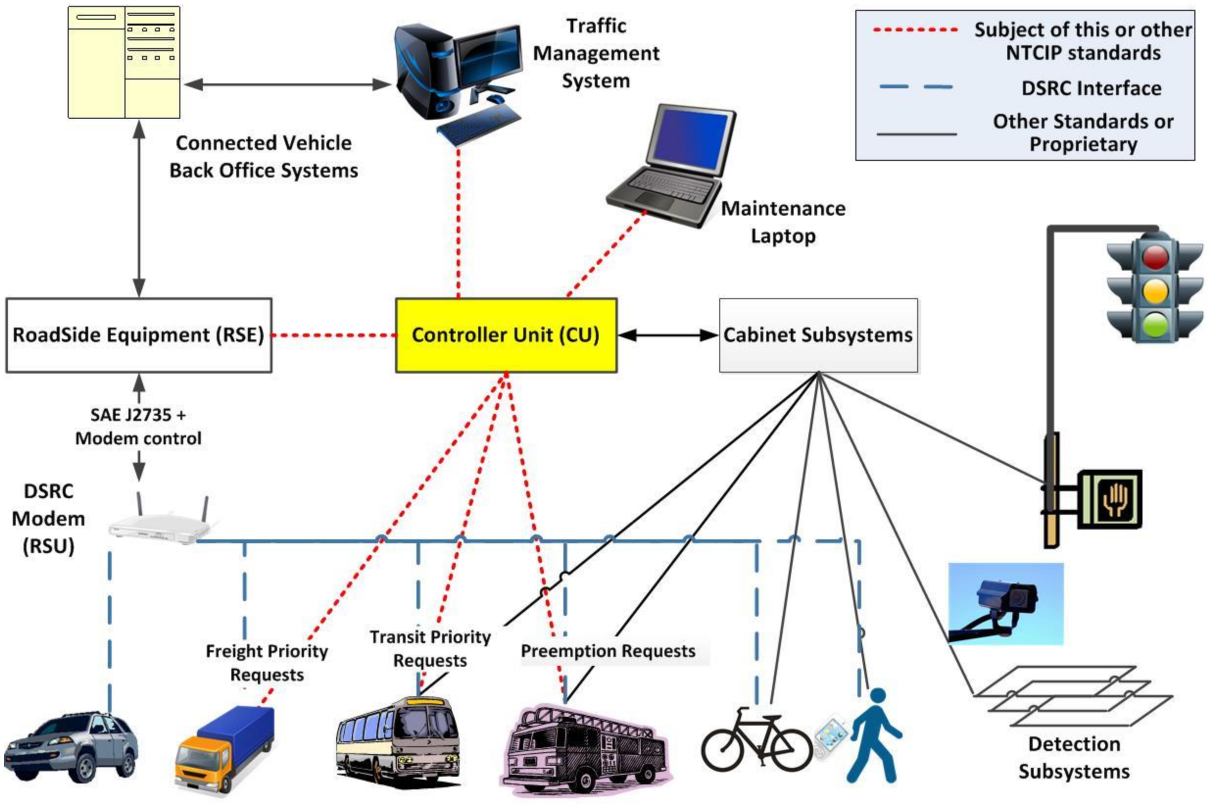

Figure 1. NTCIP 1202 v03 Reference Physical Architecture

Interfaces in red and dotted are supported by NTCIP 1202 and other NTCIP standards. Interfaces in blue and dashed are supported by other connected vehicle standards, such as SAE J2735. Black, solid lines are either proprietary or might be supported by other standards.

The components of the ASC system include:

a) **Controller Unit (CU):** A host computing platform that is used to manage the traffic signals at an intersection. The CU is responsible for ensuring that the proper signal indications are present on traffic signals and that these signal indications are not in conflict.
b) **Traffic Management System:** A management station typically located in some type of management center (e.g., a Traffic Management Center) and may be a considerable distance from the ASC.
c) **Maintenance Laptop:** A computer that a field technician may use on a trip to visit the ASC or a field processor that may be used to access the ASC.
d) **RoadSide Equipment (RSE):** A connected vehicle field device that includes a computing platform running applications and that supports secure communications with connected devices. The RSE receives messages from and transmits message to nearby connected devices (vehicles or mobile devices) using Dedicated Short Range Communications (DSRC)/ IEEE 802.11/1609.x. In an ASC System, it may also act as a management station responsible for configuring, monitoring and controlling the ASC.
e) **Detection Subsystems:** The units that provide inputs for traffic-actuated control, surveillance, or data collection systems.
f) **Cabinet Subsystems:** The controller assembly that consists of the electrical devices in the cabinet for controlling the operation of a traffic control signal display(s).
g) **Connected Vehicle Back Office Systems:** Represent centers that manage and support the connected vehicle environment.

Connected vehicle applications for improving traffic operations at signalized intersections was one of the areas identified as having high benefits by the connected vehicle research. Improved traffic signal control operations included using connected vehicle technologies to inform travelers what intersection movements are currently permitted, to inform travelers when a permitted movement is expected to end, providing priority to fleet vehicles (such as transit or public safety vehicles); and using the current location and heading of vehicles around the intersection to improve safety, mobility and the environment. Note that although the term 'connected vehicles' is used, any traveler with a connected device, such as a pedestrian or bicyclist with a smartphone, can benefit from connected vehicle applications.

The support in the proposed NTCIP 1202 v03 for the connected vehicle environment is based on supporting specific messages defined in SAE J2735_201603. SAE J2735_201603, Dedicated Short Range Communications (DSRC) Message Set Dictionary, is a message set dictionary defining messages and data elements for use by connected vehicle applications. The user needs identified in support of these messages in NTCIP 1202 v03 are summarized as:

- Managing the RSE Interface. A TMC operator needs to retrieve and configure the interface between an ASC and a RSE. This feature allows a manager to configure how and when information is exchanged between an ASC and a RSE.
- Provide Signal Phase and Timing Data. To promote safety at signalized intersections, an ASC needs to broadcast signal timing information, such as the status of the ASC. This signal timing information would be broadcasted by a RSE in the form of a Signal Phase and Timing (SPAT) message.
- Manage Roadway Geometry Information. To assist travelers through an intersection, an ASC needs to broadcast geographic information about the intersection. This roadway geometry information would be broadcasted by a RSE in the form of a MAP data message.
- Receive Service Requests. An ASC needs to receive requests from travelers for signal service. These requests may be for signal preemption, signal priority, or authorized pedestrians or bicyclists requesting service. This feature includes support for Signal Request Messages (SRM) broadcasted by connected devices and received by a RSE.
- Provide Service Request Status. In response to requests for signal service, an ASC needs to provide the status of the signal service request back to the requestor. This feature includes support for a RSE to broadcast a Signal Status Message (SSM).
- Manage Collection of Connected Devices Data. A TMC operator needs to retrieve information about connected devices on the roadway around the ASC. This information can be used as a call for actuated movements or to monitor the travel demand on the roadway. This feature includes support for retrieving data from the Basic Safety Messages (BSMs) and Personal Safety Messages (PSMs) received by a RSE.

Requirements

With the user needs related to connected vehicles identified, the proposed NTCIP 1202 v03 then documented the functional requirements to satisfy those user needs. The first step was to identify the interfaces that NTCIP 1202 v03 supports and what information needs to be exchanged across those interfaces. Figure 2 is a system context diagram for an ASC system's interaction with the connected vehicle environment. The connected vehicle environment includes the broadcast of MAP data messages, SPAT messages and SSM messages, as defined in SAE J2735, from an RSE to connected vehicles (or devices), using IEEE 802.11 and IEEE 1609 family of standards.

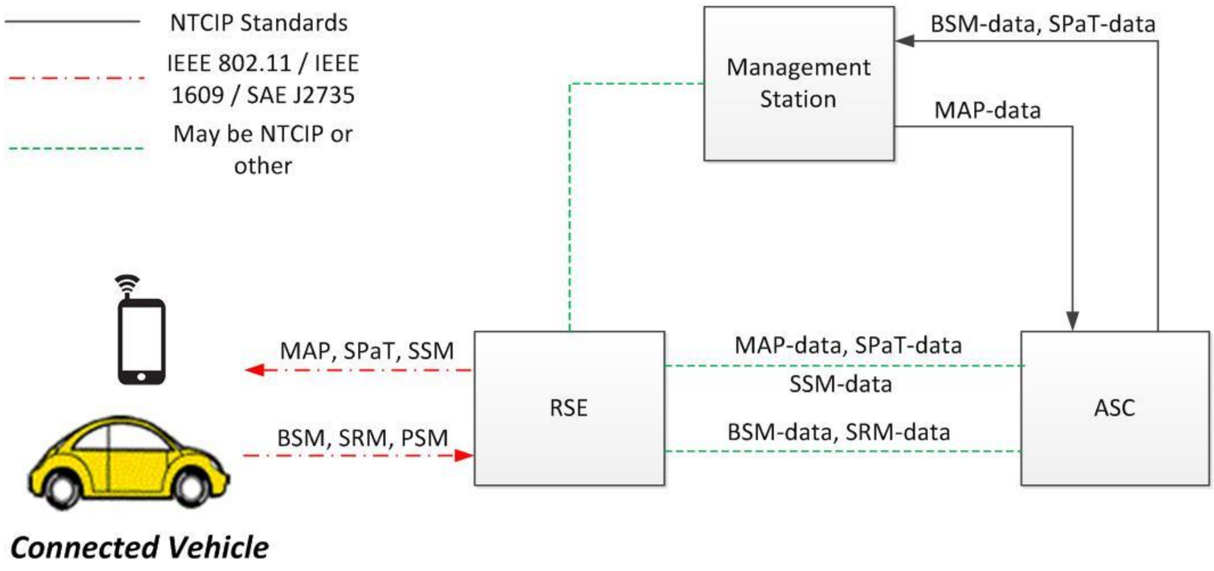

Figure 2. System Context Diagram

The connected vehicle environment also includes the RSE receiving BSMs, SRMs and PSMs from connected devices.

NTCIP 1202 v03 provides a set of requirements to address the interface between management station and the ASC to exchange the MAP, SPAT and BSM-related data, allowing the ASC to provide this information to the RSE or to allow a TMC operator to monitor the information being broadcasted.

Across the ASC-RSE interface is the data that allows a RSE to broadcast MAP, SPAT and SSM; and the data that allows an ASC to receive and process the data in the BSM, SRM, and PSM messages received by the RSE. However, the exact requirements to support the exchange of this data depend on the relationship between the RSE and the ASC. The nature of this relationship depends on which component (RSE or ASC) is retrieving/delivering the information and what standard(s) are used to exchange the data between these components.

Three scenarios are considered by the proposed NTCIP 1202 v03.

a) The RSE retrieves MAP-, SPAT- and SSM- related data from the ASC using NTCIP standards. The RSE also delivers BSM- and SRM- related data to the ASC using NTCIP standards. From an SNMP standpoint, the RSE is the SNMP manager (or management station) and the ASC is the agent.
b) The ASC retrieves BSM- and SRM- related data from the RSE using NTCIP standards. The ASC also delivers MAP-, SPAT- and SSM- related data to the RSE using NTCIP standards. From an SNMP standpoint, the ASC is the SNMP manager and the RSE is the agent.
c) The exchange of information between the ASC and the RSE using non-NTCIP standards, such as IEEE 802.11, IEEE 1609.x and SAE J2735. This option is outside the scope of NTCIP 1202 v03.

Each scenario, or architecture, has its benefits and deficiencies. For example, specifying the ASC to be the SNMP agent decreases the complexity of the ASC as it does not have to be a SNMP agent for one interface (TMC - ASC interface) while simultaneously being a SNMP manager for another interface (ASC - RSE). However, there may be increased security concerns because this interface, with the ASC as the SNMP agent, is a gateway into the ASC via a wireless modem.

Scenario c recognizes that there are many potential architectures that may be valid without using NTCIP across this interface. For example, some vendors have proposed an architecture where the functions of the RSE is performed by the traffic signal controller itself, thus the DSRC modem, which may be an external device or a board on the traffic signal controller, is just a "dumb" modem with that transmits and receives DSRC messages. In such a scenario, the user needs and requirements, and thus the design content, for the interface between the ASC and RSE would not apply.

Ultimately, the procuring agency needs to select which architecture it wishes to implement for its system based on its particular needs and policies.

Thus, NTCIP 1202 v03 provides two sets of requirements, one for each architecture supported by NTCIP 1202 v03, because the component (ASC or RSE) that initiates the information exchange across the ASC - RSE interface is different for each architecture. The two sets of requirements also results in two sets of design, one for each architecture. Although the object definitions used to fulfill similar requirements are the same, the dialogs used for each architecture is different.

Finally, Figure 2 also shows an interface between the management station and the RSE. This interface may be needed to allow a management station to configure the RSE, but is outside the scope of NTCIP 1202 v03. NTCIP standards or non-NTCIP standards may be used across this interface.

Design

SNMP Traps

One important change addressed in NTCIP 1202 v03 and enabled by the draft NTCIP 1103 v03, which is currently under ballot, is the use of SNMP traps. NTCIP currently relies on a request - response model. An NTCIP device can provide information to another device, such as a traffic management center system, only when requested or "polled". While this model has worked in the past, this model has potential deficiencies in a more mobile and high-speed, high-bandwidth environment. This request-response model requires that the management station poll the device frequently to determine if any information, such as the status of the ASC, has changed. For critical pieces of information, this may be an issue when a few hundred milliseconds delay may compromise safety. While a management station may poll the device more frequently, this may cause congestion on the limited bandwidth that is available.

With SNMP traps, a NTCIP device can be configured to send data to another device when specified conditions are satisfied, without requiring a request. For example, with SNMP traps enabled, an ASC can report back to a TMC when its status has changed, without waiting for a poll (request) from the TMC. SNMP traps is particularly useful for mobile devices so data is transmitted only when needed. In a connected vehicle environment, SNMP traps can be useful so devices process information only when needed (such as when data has changed). NTCIP 1202 v03 does support, but does not require the implementation of SNMP traps for a connected vehicle environment.

SPAT Message

As designed, a RSE is expected to broadcast a SPAT message to the surrounding connected devices at regular intervals. Each SPAT message contains the status of one or more traffic signal controller. For each traffic signal controller, a SPAT message minimally contains an identifier for the signalized intersection, the general status of the controller, a mapping between a lane at the signalized intersection and a movement, and the status of each movement.

For the RSE to generate a SPAT message, the information for the general status of controller and the status of each movement must be from the ASC. The information for other mandatory data, such as identifier of the signalized intersection or the mapping between a lane and a movement, may be from the ASC or another source, such as a laptop or a TMC.

Optional information that may be broadcasted in a SPAT message include when a movement is expected to begin and end, advisory speeds for a movement, the allowed maneuvers (left turn, right turn, straight through) for a movement, information about other travelers wishing to perform the same movement and if pedestrians or bicyclist are detected that conflicts with the movement.

New objects and tables have been added in the proposed NTCIP 1202 v03 to support all the mandatory and optional components of the SPAT message as defined in SAE J2735_201603, except for region specific information. This includes support for specific classes of users. SAE J2735 allows agencies to define classes of users when a movement at an intersection is restricted to or permitted for specific user types, such as transit vehicles, eco-vehicles, or non over-weight vehicles. Each class of users may be users that meet a specific criteria, or a combination of criteria. The specific class of users defined may vary for each intersection. If no specific user class is defined, it is assumed that the allowed movement (or advisory speed) is valid for all users.

MAP Message

In a connected vehicle environment, MAP data messages were designed to be broadcasted to assist travelers in safely traversing a section of roadway that may otherwise have characteristics that make it unsafe, such as complex intersections (intersections other than a typical cross-section of intersecting streets), or a highway section with a sharp curvature. While a MAP data message may be broadcasted to connected devices by other means than a RSE, the focus of NTCIP 1202 v03 assumes that the MAP data message is broadcasted by a RSE in conjunction with a SPAT message, and that the ASC is a conduit for providing the information necessary for the RSE to generate the MAP message. The MAP data message may contain roadway geometric information for more than one intersection.

While it is certainly possible for agencies to load the information necessary to generate a MAP message directly into the RSE (for example, via an direct interface between a TMC and the RSE), there are situations when it is necessary for the ASC to know if the contents of what the RSE is broadcasting in the MAP message has changed. One example is if the intersection includes a reversible lane. A RSE may be programmed to reverse the lane between 6 AM and 9 AM every weekday and the ASC has been programmed to provide signal timing operations assuming a reversible lane during the same period. But if the reversible lane operation is extended for 30 minutes, the RSE may have its database updated so the MAP message reflects the extension, but the ASC must also have its database updated so the signal timing matches the MAP message (and the reversible lane).

Two paths are supported by NTCIP 1202 v03. A RSE may have the most current MAP information so it updates the ASC with that information, or a management station may download the information to the ASC, and the ASC updates the RSE with the most current information.

Each MAP data message broadcasted minimally contains a message sequence identifier, the identifier for each intersection, the geographic position of a reference point for each intersection, identifiers for each lane to be broadcasted, the attributes of each lane, and node points describing the spatial pathway of each lane.

Optional information that also may be included in a MAP data message includes the allowed maneuvers for each lane along with any user class restrictions, the identifier of destination lane for each allowed maneuver, and the signal timing phase or channel that allows that maneuver. Other optional information includes the regulatory speed limits for a lane, the width of a lane, computed lanes and metadata about the MAP data. Computed lanes are lanes that have similar properties, attributes and paths as another lane in the MAP data message. Computed lane are supported by SAE J2735_201603 to reduce the bandwidth needed to broadcast a MAP data message.

All the mandatory and optional information for an intersection in the MAP message, as defined in SAE J2735_201603, is supported by NTCIP 1202 v03, except for regional MAP information.

Signal Request Message

In a connected vehicle environment, a connected device approaching a signalized intersection may wish to request signal service for the intersection using a Signal Request Message (SRM). The connected device may be any authorized equipped vehicle, or pedestrian or bicyclist with a smartphone, and the signal service request may include a priority level. An authorized pedestrian or bicyclist may request service for a pedestrian or bicycle phase, while a transit vehicle or freight vehicle may request transit or freight signal priority. The equipped vehicle may also be a tracked vehicle (such as a train) or a public safety vehicle responding to an incident requesting signal preemption. Although there are different means for the connected device to send a service request, for the purposes of NTCIP 1202 v03, it is assumed that the connected device broadcasts a SRM and it is received by a RSE.

Each SRM minimally consists of an identifier for the requestor, an identifier for the signal service request, the identifier of the intersection that signal service is being requested from, the signal request type, and the identifier of the lane, approach, or connection that the requestor is requesting signal service for. The identifier of the requestor may be a temporary vehicle identifier, or a permanent identifier, such as a Vehicle Identification Number (VIN).

If the identifier is temporary, it is expected that the identifier will remain the same until the signal service request is serviced or the requestor has traversed through the intersection. The signal service request identifier is generated by the requestor and is used to distinguish that signal service request from other signal service requests that may be generated by the requestor for other signalized intersections. The requestor shall "learn" the identifier of the intersection from a broadcasted SPAT message. The signal request types are used to indicate if the signal service request is a new request, an update to an existing request, or a cancelled request.

Optional information that may be included in a SRM include the identifier of the lane or movement to egress the intersection, the estimated time of arrival, and estimated duration for the signal service. The estimated duration can be used as a time to live, defining the amount of time the signal service request is requested to remain active after the time of service. This time-to-live may be used to provide a buffer to account for any uncertainty to the estimated time of arrival. This uncertainty may be due to non-recurring congestion, or the variability for boarding and alighting times at a transit stop for transit vehicles.

The SRM may also include optional information about the requestor. This includes identifying the role of the requestor while making the signal service request (e.g., a transit vehicle in service or a public safety vehicle responding to an incident), the type of vehicle, and a priority level for the request. Other optional information about the requestor that may be included in the SRM includes the location and heading of the requestor, and for transit vehicles, its status, relative occupancy and its schedule adherence (the amount of time the transit vehicle has deviated from its schedule).

All the mandatory and optional information in the SRM message, as defined in SAE J2735_201603 is supported by NTCIP 1202 v03, except for regional SRM information. However, what information is needed by the ASC depends on the functions of the RSE.
For some implementations, the RSE simply processes the SRMs and forwards the information to the ASC. The ASC then processes all the signal service requests it has received and selects the appropriate signal timing plan for implementation. Note that the source of the signal service requests received by the ASC does not have to be via a SRM, it may be through a pedestrian-activated pushbutton, or some other detector at the ASC.

For other implementations, the RSE may function as a Priority Request Server (PRS), receiving and processing all the signal service requests. The RSE may also receive additional information about the current signal timing operation and based on the information available, send a service request to the ASC. The functions of a PRS and the contents of a service request are defined in NTCIP 1211 v02.

Both implementations are mentioned and discussed in NTCIP 1202 v03. If the latter architecture is used, NTCIP 1202 v03 refers the user to the appropriate dialogs and objects in NTCIP 1211 v02. If the former architecture is used, NTCIP 1202 v03 refers the user to the new dialogs and objects created (in NTCIP 1202 v03).

Signal Status Message

Upon transmitting a signal service request, a requestor needs an acknowledgement that its signal service request has been received and an indication about the status of its request. In the connected vehicle environment, the Signal Status Message (SSM) is used to provide the acknowledgement and status from the ASC back to the requestor. Although there are different means for a connected device to receive a service request, for the purposes of NTCIP 1202 v03, it is assumed that a RSE broadcasts the SSM and that SSM is received by the requestor.

The SSM consists of the status of all active signal service requests that the RSE is aware of. A signal service request is considered active by the ASC until the requestor exits the intersection or until the signal service request's time-to-live is exceeded. Note that a RSE may interface with more than one ASC, so the SSM generated by the RSE may contain the status of signal service requests for more than signalized intersection.

For each signal service request, the SSM minimally contains the identifier of the intersection the request is for, a sequence number for the signal service requests for an intersection, the status of the signal service request and the identifier of the lane, approach, or connection that the requestor is requesting signal service. The SSM also includes a partial timestamp indicating when the SSM was generated. The sequence number for the signal service request for an intersection is used to indicate if the status for any of the signal service requests for the intersection has changed.

Optional information that may be included in a SSM include a message sequence number indicating if there is a change in any of the contents of the SSM, a sequence number for each signal service request, the identifier of the requestor, the identifier of the signal service request, the role of the requestor in making the signal service request, the priority of the signal service request, the estimated time of arrival, and the identifier of the lane, approach, or connection that the requestor would like to egress out of the intersection.

All the mandatory and optional information except for regional SSM information are supported by NTCIP 1202 v03.

Basic Safety Messages

The proposed Notice of Proposed Rulemaking (NPRM) for vehicle-to-vehicle (V2V) communications technology is expected to require that light vehicles support the broadcast and reception of Basic Safety Message (BSMs). BSMs are broadcasted by connected vehicles nominally at ten times per second to provide its location, heading, speed and status to other nearby connected vehicles for use by V2V safety applications. However, once the BSMs are broadcasted, other connected devices near the connected vehicle may also receive these BSMs.

The data in the BSMs can be received by RSEs on the roadside and either forwarded to the ASC and the traffic management center for its use, respectively. An ASC may use the data as a call for an actuated movement, or to determine the demand for specific movements. The ASC may also use the data to produce performance metrics related to intersection demand, safety and operations.

NTCIP 1202 v02 already allows vehicle and pedestrian detectors to be defined as inputs for signal operations and for data collection. NTCIP 1202 v03 extends that capability to connected vehicles by allowing a user to define sensor zones for BSMs and also the Personal Safety Messages (PSMs). PSMs are similar to a BSM, but are expected to be broadcasted by a mobile device on a pedestrian, bicyclist, or a work zone worker. If a BSM or PSM is detected within the sensor zone, NTCIP 1202 v03 can use the data from in the BSM or PSM as an input.

Conformance

As is true of NTCIP standards generally, to claim conformance to NTCIP 1202 v03 (once published), while supporting the user needs for a connected vehicle environment, the conformant device shall minimally fulfill the mandatory requirements identified in the NTCIP 1202 v03 for the interface between the management station and the ASC. A conformant device may offer additional (optional) features supported in the standard, as long as they are conformant with the requirements of NTCIP 1202 v03 and the standards it references (e.g., NTCIP 1201 v03 and NTCIP 2301 v02).

However, an implementation is currently NOT required to exchange information between the RSE and the ASC as defined in NTCIP 1202 v03 to claim conformance to NTCIP 1202 v03. NTCIP 1202 v03 does define (standard) information exchanges for the ASC - RSE interface, and a device may claim that its ASC - RSE interface is conformant to NTCIP 1202 v03 if it minimally fulfills the mandatory requirements identified for this interface. But it is recognized that there are different methods and communications protocols that can be used to exchange information across this interface and is highly dependent on the relationship between the ASC and the RSE and the functions that each component performs.

As mentioned earlier, one possibility is that the "functions" of the RSE are integral to and performed by the ASC, with an external DSRC modem or a DSRC modem on a board for communicating with connected devices. In this situation, no ASC - RSE interface exists from the perspective of NTCIP 1202 v03 because the functions of the ASC and the RSE are not considered to be separate.

There are other valid reasons why a RSE vendor or a procuring agency may not wish to support NTCIP 1202 v03 for its ASC - RSE interface. For example, for a RSE to claim its ASC - RSE interface is conformant to NTCIP 1202 v03, the RSE is required to support SNMP (as defined in NTCIP 1103 v03, a normative reference) and use the SNMP objects as defined in NTCIP 1202 v03. However, a vendor may wish to design its RSE to use different protocols or different encoding schemes for exchanging information with the ASC because of efficiency gains and security concerns. However, a procuring agency is cautioned that if NTCIP 1202 v03 is not used for the ASC - RSE interface, interoperability may be endangered and the overall lifecycle costs for the ASC system (ASC and RSE) may be higher.

Summary

The proposed NTCIP 1202 v03 (actuated signal control) is being updated to support the connected vehicle environment while promoting interoperability. Specific messages addressed by NTCIP 1202 v03 include the SPAT message, the MAP data message, Signal Request Message, Signal Status Message, and the use and collection of Basic Safety Messages.