SPaT Challenge

SPaT Infrastructure System

Model Concept of Operations

Draft Version 1.6

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Contents

1. Introduction

1.1 Background

The American Association of State Highway Transportation Officials (AASHTO), the Institute of Traffic Engineers (ITE), and ITS America (ITSA) working together through the Vehicle to Infrastructure Deployment Coalition (V2I DC) have challenged state and local public sector transportation infrastructure owners and operators (IOOs) to work together to achieve deployment of roadside Dedicated Short Range Communications (DSRC) 5.9 GHz broadcast radio infrastructure to broadcast signal phase and timing (SPaT) in real-time at signalized intersections on at least one road corridor or street network (approximately 20 signalized intersections) in each of the 50 states by January 2020. This is commonly called the SPaT Challenge. In 2017, the National Highway Traffic Safety Administration (NHTSA) released a notice of proposed rulemaking (NPRM) (inviting industry comments) that, if enacted, would require all new light vehicles sold in the US to be equipped with DSRC radios which can continuously and anonymously transmit basic information about the location, speed and critical operation of the vehicles. These radios may also be able to receive agency transmitted data, such as SPaT, with the intent to support safer, more efficient operations.

1.2 Purpose

While the primary goal of the SPaT Challenge is to deploy DSRC broadcasts of the SPaT messages, the long term objective is sustained operation of connected vehicle applications that utilize the SPaT messages. For this reason, agencies accepting the SPaT Challenge are encouraged to consider a systems engineering approach towards planning and implementing the SPaT Challenge. The initial steps in the systems engineering approach include development of a Concept of Operations (ConOps) document and related system requirements.

This ***Model Concept of Operations*** document is intended for use by those agencies accepting the SPaT Challenge as they prepare for their deployments.

1.3 Document Overview

This ***Model Concept of Operations*** document provides a summary of stakeholder groups, system types, stakeholder needs, and operational concepts that describe the sequence of operational events and activities carried out by each stakeholder group. The companion document to this is the ***SPaT Challenge Model Functional Requirements,*** in which model requirements are defined and traced back to the operational concepts and ultimately to the user needs.

The intent of this document is to be utilized by state, city, and county Departments of Transportation (DOTs) as they begin to plan their SPaT Challenge deployment. ***This Model Concept of Operations document is written to be circulated as a working draft, with the intent that readers will benefit from the text in the document as they prepare their own individual ConOps to address local specific needs.*** Further, the accompanying Functional Requirements contain industry input to define the minimal requirements that will be required to maintain compatibility between the SPaT messages being broadcast and the vehicle on-board units planned for deployment by the automobile industry.

1.4 Scope

SPaT is a supporting function that supports several V2I connected vehicle applications. This ConOps assumes that SPaT is being deployed to support applications such as Red Light Violation Warning (RLVW), Pedestrian in Signalized Crosswalk Warning, and Eco-Approach and Departure at Signalized Intersections (Eco A/D) within the vehicle. Additionally, SPaT deployments will support the Mobile Accessible Pedestrian Signal System (PED-SIG) application on a mobile Personal Information Device (PID). These applications are discussed throughout this ConOps. These applications generally have been more widely researched, documented, and deployed. Many other V2I connected vehicle applications may be developed and deployed locally that are closely related to SPaT broadcasts and, based on specifics of the local deployment, may use the SPaT data. Examples of these applications include Signal Priority (transit, freight, other fleet vehicles), Emergency Vehicle Preemption (PREEMPT), and Probe-enabled Traffic Monitoring. These other V2I connected vehicle applications are not addressed in this version of this document, but may be covered in updates to this model ConOps. Figure 1 illustrates these applications and provides brief descriptions of each. The SPaT implementation will need to provide message and network security, and should provide a means to manage and monitor the configuration, operation and data associated with the connected vehicle system. The implementation should also provide support for maintenance staff to help with diagnosing and repairing problems. ***To meet the SPaT Challenge, an agency need only deploy a basic set of functions of the SPaT Infrastructure System, and are encouraged to tailor this document to fit their specific needs.***

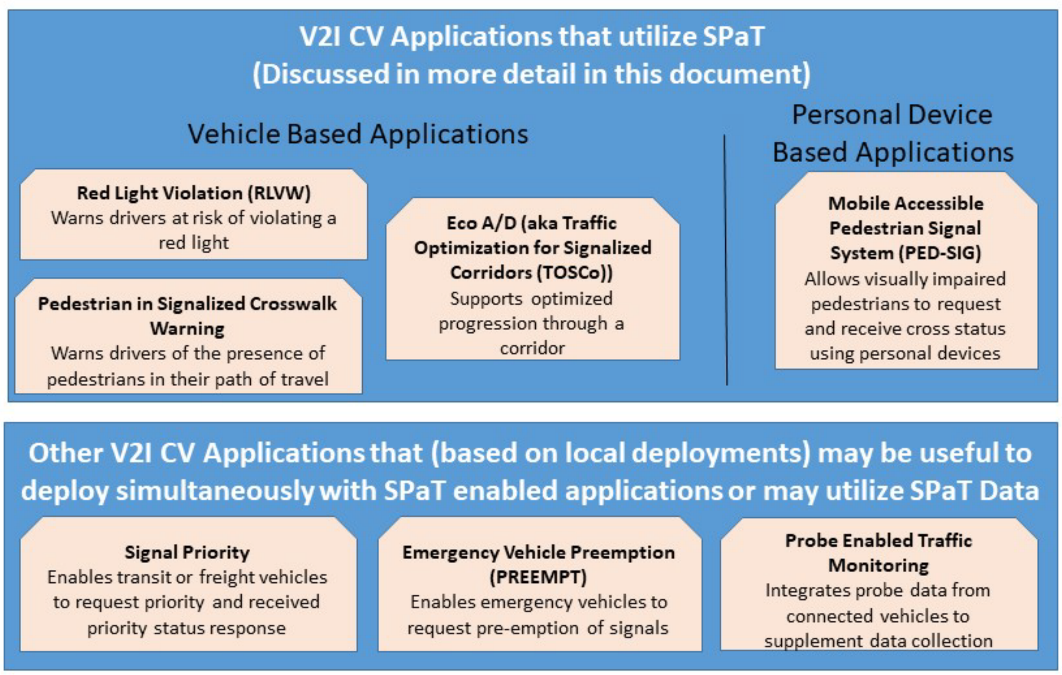

Figure 1 V2I Applications Related to SPaT Broadcasts

1.5 System Boundary

The SPaT Infrastructure System exists in a larger context of other functional components that make up the SPaT Enabled V2I Connected Vehicle System. The main user of the SPaT applications is the vehicle driver. However, the vehicle driver does not interact directly with the SPaT Infrastructure System, but instead interacts with the SPaT Vehicle System and therefore is considered an 'indirect user'. With the exception of the priority and preemption applications, transportation agencies are typically not the entities providing the SPaT Vehicle System. Therefore, from the point of view of the SPaT Infrastructure System, the SPaT Vehicle System, not the driver, is considered to be the user stakeholder for the in-vehicle applications. A second indirect user group is the pedestrians crossing the intersection, specifically the visually impaired or vulnerable pedestrians. Like the drivers, they will not interact with the SPaT Infrastructure System, but rather with Personal Information Devices (PIDs), typically hand-held devices that receive and transmit data and provide user information.

Other users of the SPaT Infrastructure System include the individuals and systems that will interact with the SPaT Infrastructure System in some way.

Figure 2 illustrates the relationship of the SPaT Infrastructure System, the SPaT Vehicle System, the Personal Information Devices and the other direct and indirect users.

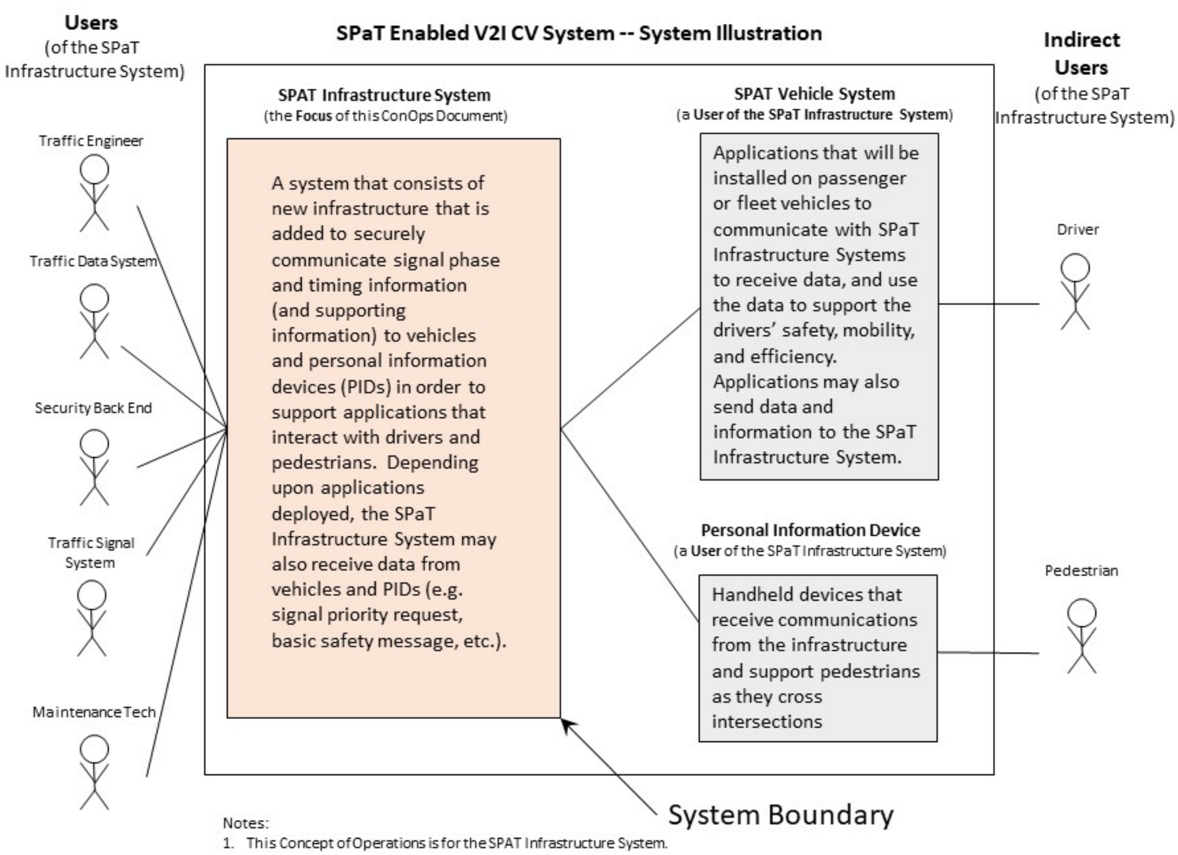

Figure 2 SPaT Enabled V2I Connected Vehicle System

2. Current Situation and Needs

2.1 Current System Overview

It is important to document the transportation infrastructure currently in place in the location where SPaT Broadcasts are to be deployed. Existing traffic signal systems provide visual indications to drivers and do not communicate electronically with the vehicle. Countdown pedestrian indications are commonly used and may provide the driver with some basis for anticipating when the associated green indication may end, although they are not intended for that purpose. A small number of international traffic signals provide either a countdown to red/green or a simultaneous yellow/red or flashing green to provide advance notice to drivers of imminent change in signal indications.

When tailoring this model document to meet local needs, agencies should assemble and document details about the following components that make up the current system that will be affected by the SPaT Challenge deployment.

- ***Signal Controller*** - Most existing traffic signal controllers are not capable of outputting the real time data needed to generate a SPaT message. At a minimum, the controllers may need a software upgrade to provide this function. Older controllers may not possess the processing power to support the function, and would need a hardware upgrade or complete replacement in order to provide the function. Standards governing the signal controller interface for SPaT related data are still evolving, and so even a controller that is currently outputting real time data supporting SPaT may need to be upgraded in order to interoperate with other roadside equipment and vehicles that utilize newer versions of the standards. Room in the signal controller cabinet for any additional equipment that will be needed for SPaT is also necessary.

- ***Backhaul Communications*** - Having backhaul communications that will allow for monitoring and configuring the SPaT system from a central location will save a lot of staff time and vehicle use in operating and maintaining the SPaT system. The agency may also desire to utilize the real time SPaT data from the controller for other purposes in addition to broadcasting it over DSRC. Vehicles will not accept SPaT messages sent via DSRC to the vehicle unless the messages are digitally signed. The security credentials used to digitally sign the messages are normally supported by a security credentials management system (SCMS) at a remote location accessible over the Internet. A backhaul communications system enables these functions. If a traffic signal is not currently connected via a backhaul communications system, the agency will want to provide one as part of implementing SPaT. A wide range of communications approaches, from cellular data to a cable or phone company Internet drop to an agency-owned fiber optic communications system would all be options.

2.2 Stakeholders

Many stakeholders will interact with and/or be impacted by the deployment of SPaT Broadcasts. Some will be travelers that will experience increased mobility or safety as a result of connected vehicle (CV) applications deployed to utilize the SPaT broadcasts, while other stakeholders will be responsible for operating and maintaining the new equipment and systems. Following is a list of the primary stakeholder groups who will most directly interact with the equipment deployed or the applications supported by the SPaT broadcast. Their needs will serve as the basis for developing functional requirements for the SPaT broadcasts.

2.2.1 Indirect User Stakeholders

As illustrated in Figure 1, the SPaT Infrastructure System has two indirect users identified. These users are identified as indirect because they do not interface with the SPaT Infrastructure System directly (rather they interface with SPaT Vehicle Systems and Personal Information Devices). The indirect users include:

- **Drivers**. This includes a range of roadway users – passenger vehicle drivers, commercial drivers, and transit vehicle operators who travel through the intersections where SPaT broadcasts will be deployed. Drivers will not directly interact with SPaT Infrastructure System, but rather with the SPaT Vehicle System that is outside of the SPaT Infrastructure System, and in most cases will be provided by others rather than by infrastructure owners & operators (IOOs). Therefore, the SPaT Vehicle System is considered to be the user, rather than the driver being the user.

- **Pedestrians.** This includes pedestrians, including pedestrians with disabilities, who are authorized to use a PID to request a walk indication at the traffic signal, to indicate they are crossing the intersection, or to receive information about when a pedestrian cross is allowed.

2.2.2 User Stakeholders

User stakeholders describe those ***individuals or systems*** that will interact directly with the SPaT Infrastructure System. These include the following:

- **SPaT Vehicle System.** This includes vehicles equipped with Red Light Violation Warning, Pedestrian in Crosswalk, Eco Arrival Departure and/or Traffic Signal Priority or Preemption applications.

- **Pedestrian Personal Information Devices (PIDs).** This includes the systems/devices that authorized pedestrians will use to receive information or send crossing requests, as identified in the updated version of the National Intelligent Transportation System (ITS) Architecture entitled Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) version 8.0.

- **Traffic Signal System.** This includes the system controlling the traffic signals at the intersection.

- **Traffic Data System.** This includes traffic conditions databases, central signal control systems (CSCS), Advanced Traffic Management Systems (ATMS), and other applications and distribution systems the IOO uses to collect, store, process and distribute real time and archived traffic flow data.

- **Security Back End.** This includes the Security Credentials Management System for connected vehicle message security and any agency network security systems.

- **Traffic Engineering Staff.** This includes the individuals that provide engineering services for traffic control performed by the agency with operating authority over the signalized intersections included in the SPaT broadcasts. They are responsible for the design, construction and operation of the traffic signal systems, including the signal controller, signal control box, mast arms and signal heads, as well as any equipment attached to the mast arm or added to the signal control box.

- **Maintenance Staff.** This includes staff that performs routine maintenance of field equipment and also monitors and responds to maintenance issues impacting the signalized intersections selected for the project.

2.2.3 Other Stakeholders

- **Project Sponsors.** This includes entities that fund the project. Project sponsors may have additional requirements or constraints beyond what users need. For example, if the project is funded under a program intended to deploy DSRC, this may impact the requirements and design of the system, even if the same user needs could be met using a non-DSRC design approach.

- **Fleet Operators**. This includes operators and managers of fleets that may be equipped with on-board units and CV applications that interact with the SPaT broadcasts. For example, in situations where a transit fleet is equipped with transit signal priority functionality, the SPaT broadcast will be one aspect of the two-way communications between the transit vehicle and the intersection. A SPaT Vehicle System may have interfaces to the fleet management system, which is outside of this SPaT Infrastructure System. For these situations, fleet operators are identified as a stakeholder.

- **Mapping / GIS staff.** This includes the individuals or groups within the DOT that are responsible for maintaining the mapping and/or GIS data for the agency. During initial pilots, map data for intersections may be created by selected members of the team. However, long term operations are likely to involve the mapping / GIS group and therefore they are identified as a possible stakeholder.

The primary goal of the SPaT Challenge deployments is to deploy SPaT broadcasts that can serve as supporting infrastructure to the eventual CV Applications to be deployed in passenger and fleet vehicles and PIDs to ‘connect’ vehicles and pedestrians to the infrastructure in order to promote safety, mobility, and efficiency.

2.3 Stakeholders Use of the SPaT Infrastructure System

In order to define the stakeholder needs, operational concepts, and ultimately the requirements for the SPaT Infrastructure System, a use case diagram was used to illustrate how each stakeholder will use the SPaT Infrastructure System, and ultimately to derive the stakeholder needs presented in Section 2.4. ***When tailoring this model document to meet local needs, agencies may decide to review and edit the stakeholder needs to meet local needs and intended uses. As part of this process, agencies may decide to step through the use case diagram exercise.*** Appendix A presents information about the use case exercise, as well as the overall use case diagram for this ConOps and a use case diagram for the most basic SPaT deployment.

2.4 Stakeholder Needs

This section presents model stakeholder needs based on input and feedback from agencies pursuing the SPaT Challenge and the use cases illustrated in the previous section's use case diagram. It should be noted that deploying SPaT broadcasts alone does not address stakeholder needs, however the SPaT broadcasts are supporting infrastructure to multiple possible CV application that could address the needs. The needs are identified by first describing a challenge facing one or more of the stakeholders (column 1). Based on each challenge, one or more needs (column 3) are described and will serve as the basis for SPaT Challenge operational concepts, requirements, and design. Each need is also numbered (column 2) for identification and traceability purposes. The need identification allows each subsequent reference to be traced back to an original need and corresponding challenge.

In order to distinguish the needs for a basic functioning SPaT Infrastructure System capable of broadcasting the minimum SPaT related messages, requirements that are beyond the SPaT related requirements are shown in italics, and should be considered optional by agencies using this model document. These needs would depend upon the intended deployments at each intersection.

2.4.1 Indirect User Functional Needs

The needs of these indirect users are captured in Table 1 below, and presented before the needs of other user groups because they represent the underlying needs for ultimately deploying the SPaT Infrastructure System and related systems.

Table 1 Indirect User Needs for SPaT Broadcasts to Support CV Applications

Challenge	Need ID	Need
Indirect User Stakeholder Needs		
Driver Needs		
Vehicles running red lights and entering signalized intersections is a safety concern, with an average of 700 fatalities each year, 90,000 injuries related to an average of 100,000 red light running related crashes.[i]	1.1	Drivers need a red light violation warning (RLVW) to help them avoid unintended red light violations.
Commercial vehicles, transit vehicles, and emergency vehicles encounter delays at traffic signals, costing time and money and reducing safety.	1.2	*Commercial, transit and emergency vehicle drivers need preference over other vehicles when passing through signalized intersections (Signal Priority and Preemption).*
Vehicle time spent idling, accelerating or decelerating in relation to signalized intersections increased fuel consumption, emissions, and reduces traffic flow.	1.3	*Drivers need supporting information that will help them drive the appropriate speed through a signalized intersection or series of coordinated signalized intersections in a manner that will minimize delay, fuel consumption and emissions (Eco Approach and Departure).*
Vehicles occasionally hit pedestrians lawfully using a crosswalk in conflict with the vehicle's intended movement, particularly when the vehicle is turning right on red. In 2015, the 5,376 pedestrian fatalities were 15% of all traffic fatalities nationally. 18% of the pedestrian fatalities occurred at intersections. From NHTSA Traffic Safety Facts February 2017.	1.4	*Drivers need a warning when pedestrians are in the crosswalk in conflict with the intended vehicle movement.*

[i] https://safety.fhwa.dot.gov/intersection/conventional/signalized/rlr/

Challenge	Need ID	Need
Pedestrian Needs		
Pedestrians with visual impairments may have difficulty placing a call for a walk indication.	2.1	*In order to enable all pedestrians to safely and efficiently cross intersections where passive pedestrian detection is not present, pedestrians who are not able to activate a pedestrian pushbutton need a mechanism to request to cross.*
Pedestrians with visual impairments may have difficulty discerning the current state of the walk/don't walk indications.	2.2	In order to know when it is safe to enter the crosswalk, pedestrians with visual impairments need a personal notification when the walk sign is activated.
Pedestrians in the crosswalk during a permitted crossing time may still be vulnerable to drivers who do not see them.	2.3	*In order to help avoid being hit by vehicles, pedestrians need their presence in the crosswalk to be communicated to drivers approaching the crosswalk.*
Pedestrians with visual impairments may have difficulty determining their location with respect to a signalized crosswalk.	2.4	*In order to ensure they stay within the boundaries of crosswalks, pedestrians with visual impairment need to be alerted when they are not in the crosswalk.*

Table 2 User Stakeholder Needs for SPaT Broadcasts to Support CV Applications

Challenge	Need ID	Need
User Stakeholder Needs		
SPaT Vehicle System Needs		
Providing Red Light Violation Warning (RLVW), Pedestrian in Crosswalk and Eco Arrival / Departure (Eco A/D), applications requires information from the SPaT Infrastructure System.	3.1	In order to support Red Light Violation Warning (RLVW) and Eco Arrival / Departure (Eco A/D) applications, the SPaT Vehicle System needs the SPaT Infrastructure System to communicate current signal phase and timing information about the intersection so that the vehicle applications can determine the current control active on their approach to the intersection.
	3.2	In order to support Pedestrian in Crosswalk Warning applications, the SPaT Vehicle System needs the SPaT Infrastructure System to communicate the presence of pedestrian crossing requests for crosswalks in conflict with the intended vehicle movement.
	3.3	In order to support Red Light Violation Warning (RLVW), Pedestrian in Crosswalk and Eco Arrival / Departure (Eco A/D) applications, the SPaT Vehicle System needs the SPaT Infrastructure to communicate map data so that the vehicle can determine which lanes and crosswalks are related to the signal phase and timing data.
	3.4	In order to support Red Light Violation Warning (RLVW), Pedestrian in Crosswalk and Eco Arrival / Departure (Eco A/D) applications, the SPaT Vehicle System sometimes needs the SPaT Infrastructure System to communicate position correction data so that the vehicle can determine which lane it is in.
In order to provide preference to a commercial, transit or emergency vehicle at an intersection the traffic signal needs to know information about the approaching vehicle.	3.5	*In order to support preemption and priority, the SPaT Vehicle System needs the SPaT Infrastructure System to accept priority and preemption requests and cancellations.*
The driver of a commercial, transit or emergency vehicle approaching a traffic signal does not know if the signal will be green when the vehicle reaches the intersection, and so does not know if they need to prepare to stop at the intersection.	3.6	*In order to inform the driver of priority / preemption status, the SPaT Vehicle System needs the SPaT Infrastructure System to communicate the priority and preemption status of the traffic signal.*

Challenge	Need ID	Need
Creating Arterial Traffic Signal Performance Measures and arterial traveler information, such as arterial travel times, requires information about individual vehicle trajectories.	3.7	*In order to support traffic signal operations and arterial traveler information, the SPaT Vehicle System needs the SPaT Infrastructure System to accept BSM and Probe Vehicle Data.*
Traffic Signal System's Needs		
The Traffic Signal Systems has no way to communicate the needed data describing signal phase and timing directly to the SPaT Vehicle Systems, and therefore relies on the SPaT Infrastructure System.	3.7	*In order for the SPaT Infrastructure System to communicate current SPaT data to vehicles to support in-vehicle applications, the Traffic Signal System needs the SPaT Infrastructure System to accept current signal phase and timing information.*
In order for Traffic Signal Systems to process priority or preemption requests, they must receive real-time requests from vehicles.	3.8	*In order for the Traffic Signal Systems to consider and process all requests for signal preemption & priority, Traffic Signal Systems need the SPaT Infrastructure System to communicate connected vehicle enabled Preemption/Priority requests received from SPaT Vehicle Systems.*
Commercial, transit and emergency vehicle drivers will benefit if they are informed of the preemption and priority status of the signal they are approaching.	3.9	*In order to enable signal preemption/priority information to reach commercial, transit and emergency vehicle drivers, Traffic Signal Systems need the SPaT Infrastructure System to accept signal preemption/priority status information, so that the SPaT Infrastructure System can communicate it to the SPaT Vehicle Systems.*
In order to perform dynamic signal control changes, Traffic Signal Systems need to know information about the approaching vehicles.	3.10	*In order to respond to vehicle traffic, Traffic Signal Systems need the SPaT Infrastructure System to communicate the presence of SPaT Vehicle Systems within a geo-fenced area to supplement other data collected at the intersection.*
Pedestrians rely on visual or audible displays of cross walk status to know when it is safe to cross the street, and there are visually impaired pedestrians who are not able to receive these messages.	3.11	In order to support visually impaired pedestrian crossing the intersection, the Traffic Signal System needs the SPaT Infrastructure System to accept current pedestrian signal phase and timing information in order that it may communicate whether or not a cross walk light is activated to the Personal Information Devices (PIDs) used by visually impaired pedestrians.
Traffic Signal Systems may not provide a mechanism for pedestrians that are unable to use the traditional pedestrian pushbutton to request a walk phase.	3.12	*In order to activate pedestrian crossing to support vulnerable pedestrians who are not able to push traditional cross request buttons, Traffic Signal Systems need the SPaT Infrastructure System to communicate pedestrian crossing requests received from Personal Information Devices (PIDs).*

Challenge	Need ID	Need
Personal Information Device (PID) System Needs		
There is no mechanism for PIDs to send messages directly to Traffic Signal Systems to communicate cross requests.	3.13	*In order to support pedestrians who are not able to activate the pushbuttons to request a cross phase, PIDs need the SPaT Infrastructure System to accept personal crossing requests from PIDs such that they can be communicated to the Traffic Signal System.*
There is no mechanism for PIDs to receive data or information directly from Traffic Signal Systems.	3.14	*In order to be able to inform visually impaired pedestrians when it is safe to enter the crosswalk, PIDs need the SPaT Infrastructure System to communicate current pedestrian signal phase and timing information so that the PID can determine the status of the crosswalk signals.*
	3.15	*In order to warn pedestrians that are crossing the street and have wandered outside the boundaries of the crosswalk and to determine which signal phase and timing data are related to the crosswalk, PIDs need the SPaT Infrastructure System to communicate MAP data describing crosswalk geometries.*
In order to accurately determine if pedestrians are outside the designated crosswalk, their position must be accurately determined.	3.16	*In order to support Pedestrian in Crosswalk applications, the PID sometimes needs the SPaT Infrastructure System to communicate position correction data so that the PID can determine if it is within the crosswalk.*
Traffic Data Systems Needs		
Arterial Traffic Signal Performance Measures and arterial traveler information would benefit from increased information about vehicles.	4.1	*In order to support Arterial Traffic Signal Performance measures and arterial traveler information, Traffic Data Systems need the SPaT Infrastructure System to communicate Basic Safety Messages and probe vehicle data (PVD) received from vehicles.*
Security Back End Needs		
There is a risk of unauthorized systems imitating vehicles and sending data to the road side equipment.	5.1	In order to protect the security of the SPaT related messages, Security Back End Systems need the SPaT Infrastructure System to verify the authenticity of security credentials received from SPaT Vehicle Systems and PIDs.
There is a risk of unauthorized systems imitating the infrastructure	5.2	Security back end systems need the SPaT Infrastructure System to accept security credentials so that they can be attached to messages sent to SPaT Vehicle Systems.

Challenge	Need ID	Need
and sending inappropriate data to vehicles.	5.3	Security back end systems need the SPaT Infrastructure System to accept certificate revocation lists identifying security credentials that should be considered invalid if received from SPaT Vehicle Systems or PIDs.
There is a risk of unauthorized access to devices on the agency network.	5.4	Security back end systems need the SPaT Infrastructure System to provide control of access.
The agency must protect the signal controller, network, and central system that interfaces with the SPaT Infrastructure System from unwanted access or malicious intents.	5.5	To manage network security and configuration, the security back end needs the SPaT Infrastructure System to provide a means to configure address, access limitations, [etc.]
Traffic Engineering Staff Needs		
Traffic engineering staff will be responsible for managing, configuring, and monitoring the overall operations of SPaT broadcasts at intersections.	6.1	Traffic engineering staff need the SPaT Infrastructure System to provide a mechanism for them to manage, and configure the system so that it performs the functions as designed.
	6.2	Traffic Engineering staff need the SPaT Infrastructure System to provide a mechanism to define and configure the MAP data that describes the intersection geometry and approaches in a format that is ready for communication to other systems.
Traffic engineering staff are ultimately responsible for the data communicated through the SPaT Infrastructure System, and therefore must have access to understand the data.	6.3	In order to assess and maintain the quality of data being shared with Connected Vehicles and PIDs, the Traffic Engineering staff need the SPaT Infrastructure System to provide a mechanism for them to monitor and receive reports of the data being sent and received.
Maintenance Staff Needs		
Vehicle and pedestrian based safety applications will rely on communications from SPaT Infrastructure Systems on a continuous 24/7 basis.	7.1	Maintenance staff need the SPaT Infrastructure System to provide local and remote diagnostic information and logs to help them diagnose and repair malfunctions.
	7.2	Maintenance staff need the SPaT Infrastructure System to provide a mechanism for locally and remotely resetting the system and updating software and firmware.

Challenge	Need ID	Need
Without any notification, maintenance staff will not be able to detect and respond to SPaT Infrastructure System malfunctions or outages.	7.3	Maintenance staff need the SPaT Infrastructure System to provide configurable alerts when it detects improper system operation.
Performance Needs		
Improperly deployed radios and supporting equipment will diminish the communications capabilities with vehicles.	8.1	While not every intersection will be equipped with V2I communications, for those intersections that are equipped, SPaT Vehicle Systems and PIDs need the SPaT Infrastructure System to be configured to enable DSRC communications to vehicles as they approach the intersection.
Drivers do not limit their driving to geographic areas or specific agency operated intersections.	8.2	SPaT Vehicle Systems and PIDs need the SPaT Infrastructure Systems to send and accept data by following common standards wherever they are deployed, in order to allow SPaT Vehicle Systems to work universally with all SPaT Infrastructure System equipped intersections.
Safety or mobility applications that are not reliable or functionally sound will not be accepted by drivers.	8.3	SPaT Vehicle Systems need SPaT Infrastructure Systems to communicate data so that it is received at upstream locations frequently enough, timely enough and accurately enough that will allow them to act on them.
SPaT Vehicle Systems that incorrectly assign a vehicle to a lane could not provide adequate information to drivers	8.4	SPaT Vehicle Systems need MAP data to be accurate enough to be able to reliably determine the lane of travel and distance of the vehicle from the stop bar.
Any systems interfacing with a traffic signal controller introduce a risk that signal control could be exposed to accidental or intentional interference.	8.5	Traffic engineering staff need SPaT Infrastructure Systems to not interfere with the operations of the signal controller, except in ways that are intended and approved (e.g. priority requests, pedestrian activations).
	8.6	All users of the SPaT Infrastructure System need the SPaT Infrastructure System to operate properly in the traffic signal roadside physical, electrical, radio frequency and support environment.
Project Sponsors Needs		

Challenge	Need ID	Need
Deployment of two-way DSRC based V2I communications between vehicles and the infrastructure is facing a 'chicken and egg' problem where functional operation of either relies on deployment of the other.	9.1	In order to overcome the DSRC 'chicken and egg' problem, Project Sponsors need the SPaT Infrastructure Systems to utilize (as a minimum) DSRC communications to SPaT Vehicle systems, even if options exist to meet the application needs using other communication approaches.

3. Operational Concept for the SPaT Infrastructure System

This section presents the operational concept for the SPaT Infrastructure System to broadly support RLVW, Eco A/D, Pedestrian in Crosswalk Warning, PED-SIG, and signal preemption/priority applications. The operational concept is presented from the perspective of each stakeholder group and references back to the original needs and challenges are noted in parentheses.

This section will be the primary source for functional requirements defined later in this document. For this reason, paragraphs are numbered to allow each requirement to reference the operational concept that is the source of the requirement.

3.1 Drivers' Perspective

3.1.1 Drivers will **not visually or audibly receive any direct communications from the SPaT Infrastructure System.** All V2I communications will occur between the SPaT Infrastructure System and the SPaT Vehicle Systems. Therefore, no operational concepts are described in this document for drivers, rather they would be described by the agencies building the SPaT Vehicle Systems and in-vehicle applications.

3.2 Pedestrians' Perspective

3.2.1 Pedestrians **will not receive any direct communications from the SPaT Infrastructure System**. All communications will be between the SPaT Infrastructure System and the PID. Therefore, no operational concepts are described in this document for pedestrians, rather they would be described in documents describing the PID Concept of Operations.

3.3 SPaT Vehicle Systems' Perspective

3.3.1 SPaT Vehicle Systems will receive current signal phase and timing (SPaT Data) from the SPaT Infrastructure System for the approaching intersection. **(Need 3.1)**

3.3.1.1 For intersections equipped with SPaT Infrastructure Systems, SPaT Vehicle Systems will receive the SPaT Data upstream of the intersection, beginning at a distance that enables the SPaT Vehicle System to perform needed calculations and information display to drivers. **(Need 8.3)**

3.3.1.2 For intersections equipped with SPaT Infrastructure Systems, SPaT Vehicle Systems will receive the SPaT Data regardless of the lane they are in when approaching the intersection. **(Need 8.1)**

3.3.1.3 SPaT Vehicle systems will receive standardized messages describing the current SPAT Data from all SPaT Infrastructure Systems. This consistency and standardization will enable vehicles to receive SPaT Data in the same consistent manner from any intersection broadcasting SPaT. **(Need 8.2)**

3.3.1.4 The SPaT messages communicated by SPaT Infrastructure Systems will contain the current status of each traffic control phase at the intersection. **(Need 3.1)**

3.3.1.5 SPaT Vehicle Systems will receive SPaT messages frequently enough to perform near real-time calculations and determine messages to display to drivers. **(Need 8.3)**

3.3.1.6 For intersections supporting the Pedestrian in Signalized Crosswalk Warning application, the signal phase and timing information received by the SPaT Vehicle System will include information describing whether the traffic signal system has received a call for a walk signal on pedestrian phases that conflict with specified vehicle movements at the intersection. For intersections supporting Eco A/D, the signal phase and timing information will also include an estimate of queue length. **(Need 3.2 and NTCIP 1202)**

3.3.2 The SPaT Vehicle Systems will receive geographic information about the intersection and approach geometry (MAP Data) from the SPaT Infrastructure System that provides geospatial descriptions of node points along each intersection ingress and egress lane in order to enable the SPaT Vehicle System to relate the vehicle's position to the lanes, possible maneuvers, and signal phase and timing information using on-board GPS data. **(3.3)**

3.3.2.1 The source of the MAP Data will be the agency responsible for the intersection or a map provider, who will load the MAP Data into the SPaT Infrastructure System for broadcasting. In general, the MAP Data will change only when the intersection geometry or lane control changes. In situations where approaches change by time of day/day of week (e.g. if a Protected Left Turn Lane becomes a through lane during peak periods) the SPaT Infrastructure System will accommodate these dynamic changes using revocable lanes which are dynamically indicated in the SPaT message as being enabled. **(NTCIP 1202 and SAE J2735)**

3.3.2.2 SPaT Vehicle Systems will receive Map Data that is accurate enough to enable the vehicle to compare the current vehicle position to coordinates in the Map Data and determine the lane of travel. **(8.4)**

3.3.2.3 SPaT Vehicle Systems will receive Map Data frequent enough and current enough such that the data can be processed and compared with current vehicle position in time to present information to the drivers in advance of the intersection. **(8.3)**

3.3.2.4 SPaT Vehicle Systems will receive Map Data in a format that is standardized such that the SPaT Vehicle System can expect the same format from any intersection that is operating a SPaT Infrastructure System. **(8.2)**

3.3.3 Because on-board GPS devices function by receiving precisely timed transmissions from GPS satellites in order to calculate absolute position, in some locations the atmospheric conditions may cause localized delays in data transmitted from the GPS satellites and create local inaccuracies in GPS calculations. In these situations, SPaT Vehicle Systems will rely upon vehicle position correction data communicated by the SPaT Infrastructure System to enable the vehicle to correct the GPS position determined by the vehicle. **(3.4)**

3.3.3.1 SPaT Vehicle Systems will receive vehicle position corrections in a standard way from every intersection broadcasting corrections. **(8.2)**

3.3.3.1.1 The Radio Technical Commission for Maritime (RTCM) is a message standard and data format for communicating position correction data.

3.3.4 In situations where the vehicle has implemented signal preemption/priority, the SPaT Vehicle System will send and receive messages to support preemption/priority systems with the SPaT Infrastructure System.

3.3.4.1 SPaT Vehicle Systems will send preemption/priority requests when appropriate. The determination of when preemption/priority requests are sent would be defined by the SPaT Vehicle System Concept of Operations and are not defined here. ***(3.5)***

3.3.4.2 SPaT Vehicle Systems may also send preemption/priority cancellation messages. ***(3.5)***

3.3.4.3 SPaT Vehicle Systems will receive messages from the SPaT Infrastructure System describing if the preemption/priority message was received. ***(3.6)***

3.3.4.4 SPaT Vehicle Systems will receive messages from the SPaT Infrastructure System describing the current status of preemption/priority (e.g. which approaches have been granted preemption/priority if any). ***(3.6)***

3.3.5 SPaT Vehicle Systems will communicate data describing the vehicle trajectory and status to the SPaT Infrastructure System.

3.3.5.1 SPaT Vehicle Systems will communicate current vehicle data formatted as the standardized Basic Safety Message (BSM) that may be received by the SPaT Infrastructure System (or any other system configured to receive BSM data). ***(3.7)***

3.3.5.2 SPaT Vehicle Systems will communicate Probe Vehicle Data (PVD) that may be received by the SPaT Infrastructure System. ***(3.7)***

3.3.6 SPaT Vehicle Systems will only accept digitally signed and credentialed messages, generated by SPaT Infrastructure Systems with support from Security Back End Systems and a National Security Credentials Management System (SCMS). **(5.3)**

3.3.7 In situations where SPaT Vehicle Systems communicate data to SPaT Infrastructure Systems, they will send messages that meet minimum credentialing requirements. **(5.1)**

3.4 Traffic Signal System's Perspective

3.4.1 The Traffic Signal System will provide SPaT Data to the SPaT Infrastructure System. **(3.7)**

3.4.1.1 For deployments supporting RLVW, the Traffic Signal System will output the data elements from the SAE J2735 Mar2016 standard that support the RLVW application

3.4.1.2 In deployments supporting the Pedestrian in Crosswalk Warning application, the Traffic Signal System will output the data elements from the SAE J2735 Mar2016 standard that support the Pedestrian in Crosswalk Warning application. ***(3.11)***

3.4.1.3 *For intersections also supporting Eco A/D applications, the Traffic Signal System will output the data elements from the SAE J2735 Mar2016 standard that support the Eco A/D applications.*

3.4.1.4 The Traffic Signal System will generate messages containing the SPaT Data using the approach defined in the NTCIP 1202 V3 standard.

3.4.1.5 Traffic Signal Systems that are operating NTCIP 1202 v03 will be able to output the mandatory and optional data needed to populate the SPaT Data. Traffic Signal Systems operating earlier versions of NTCIP 1202 may need proprietary objects to complete the full SPaT Data set. **(NTCIP 1202)**

3.4.2 In deployments supporting Connected Vehicle enabled pedestrian and vehicle detection and PED-SIG applications, the Traffic Signal System will receive messages from the SPaT Infrastructure System describing pedestrian and vehicle detection.

3.4.2.1 The Traffic Signal System may receive detector calls indicating if pedestrians have requested a crossing indication and the crosswalk they are crossing. ***(3.12)***

3.4.2.2 The Traffic Signal System may receive detector calls indicating if vehicles are approaching the intersection within a geo-fenced region. ***(3.10)***

3.4.2.3 Detector calls will be assigned to the appropriate phase based on the vehicle location and trajectory.

3.4.2.4 The detector calls received by the Traffic Signal System from the SPaT Infrastructure System will follow NTCIP1202v3 standards.

3.4.3 In deployments supporting signal preemption/priority, the Traffic Signal System will include CV generated preemption/priority requests when managing the signal timing. Preemption/priority requests may be processed at the Traffic Signal System or the SPaT Infrastructure System.

3.4.3.1 The SPaT Infrastructure System will process preemption/priority requests and control this function for the Traffic Signal System.

3.4.3.2 The Traffic Signal System will process preemption/priority requests and control this function.

3.4.3.2.1 The Traffic Signal System will receive signal preemption and priority requests for specific paths of ingress from the SPaT Infrastructure System. ***(3.8)***

3.4.3.2.2 The Traffic Signal System will process preemption/priority requests received from the SPaT Infrastructure System, together with other requests, according to the current algorithms for signal control (e.g. in some locations, the SPaT Infrastructure System may manage multiple preemption/priority requests and pass only the most appropriate request to the Traffic Signal System; while other *locations the SPaT Infrastructure System may pass all preemption/priority requests to the Traffic Signal System and defer management to the Traffic Signal System.*

3.4.3.2.3 The Traffic Signal System will communicate the status of preemption/priority to the SPaT Infrastructure System. ***(3.9)***

3.4.4 In locations with dynamic maps (i.e. maps change periodically such as a reversible lane that changes during the day) the Traffic Signal System will output an indication of the status of these lanes such that the SPaT Vehicle System will be aware of the currently enabled lanes. Note: the configuration of which system produces the appropriate map is a local design decision, however the indication of the lane status is the role of the Traffic Signal System.

3.5 Traffic Data Systems Perspective

3.5.1 Traffic Data Systems will typically be central signal control systems (CSCS) or Advanced Traffic Management Systems (ATMS) or a combination of both. Typically, they will be housed at a TMC connected to the SPaT Infrastructure System through backhaul communications.

3.5.1.1 Connections to Traffic Data Systems are not mandatory for SPaT Infrastructure Systems. Their interaction with SPaT Infrastructure Systems will primarily be obtaining probe vehicle data (PVD) and/or Basic Safety Message (BSM) data sent to the SPaT Infrastructure System from the SPaT Vehicle Systems. **(4.1)**

3.5.1.2 If Traffic Data Systems receive PVD or BSM data, the system might use the data to calculate queue length at the intersection, delay at the intersection, or to archive the data for future use. In situations where the Traffic Data System is the CSCS, it might assist in retiming the signal, either in real-time or in analysis mode. **(4.1)**

3.5.1.3 Due to the large amount of data as number of equipped SPaT Vehicle Systems increases, each broadcasting a BSM 10 times per second, the Traffic Data System may receive data from the SPaT Infrastructure System that the SPaT Infrastructure System has aggregated or processed before sending it to the Traffic Data System.

3.6 Traffic Engineering Staff Perspective

3.6.1 Traffic engineering staff will use the user interface to the SPaT Infrastructure System to configure a MAP message for each intersection. For example, this will typically be the creation of an XML file that contains the MAP data for each intersection. **(6.2)**

3.6.2 Traffic Engineering Staff will use a user interface to interact with the Traffic Signal System to configure the SPaT message to be communicated from the Signal Control System to the SPaT Infrastructure System, depending upon the applications to be supported at the intersection. **(6.1)**

3.6.3 Traffic Engineering Staff will use the user interface to interact with the SPaT Infrastructure System to configure the SPaT message to be communicated to the SPaT Vehicle System and PID. **(6.1)**

3.6.3.1 SPaT message configuration will include the number of broadcasts per second.

3.6.4 Traffic engineering staff will use the user interface to interact with the SPaT Infrastructure System to monitor the data being communicated by the system. **(6.3)**

3.6.5 Traffic engineering staff will use the user interface to interact with the SPaT Infrastructure System to configure the connection(s) between the SPaT Infrastructure System and the Security Back End System.

3.6.6 Traffic engineering staff will use the user interface to configure the Security Back-End System, including connections to one or more National Security Credentialing Systems.

3.7 Maintenance Staff's Perspective

3.7.1 Maintenance staff will perform troubleshooting and repairs to restore operations when any portion of the SPaT Infrastructure System is not working.

3.7.1.1 Maintenance staff will receive alerts and reports indicating a malfunction. **(7.1)**

3.7.1.2 Maintenance staff will view logs and reports to help diagnose malfunctions. **(7.2)**

3.7.1.3 Maintenance staff will be able to reset hardware and software portions of the system and to update software and firmware. **(7.3)**

3.8 Security Back End's Perspective

3.8.1 Security Back End Systems will operate somewhere within the agency responsible for the signalized intersection, within a partner agency, or be a commercially-provided service. The Security Back End System will be or be compatible with the National SCMS to enable it to issue digital signatures and verify the credentials of digitally signed messages. The Security Back End System will typically be connected through backhaul communications to each SPaT Infrastructure System. Additionally, the Security Back End will include any agency network configuration or monitoring equipment supporting network security of the SPaT Infrastructure System and backhaul communications system.

3.8.1.1 The Security Back End System will interact with the SPaT Infrastructure System to enable the SPaT Infrastructure System to verify if messages received from SPaT Vehicle Systems are digitally signed with current credentials. **(5.2)**

3.8.1.1.1 The Security Back End System may communicate to the SPaT Infrastructure System the revoked security credentials to enable the SPaT Infrastructure System to process security credentials received from vehicles.

3.8.1.2 The Security Back End System will interact with the SPaT Infrastructure System to communicate security credentials to be attached to SPaT messages in the form of digital signatures such that vehicles can validate that the message is authentic and secure. **(5.3)**

3.8.1.3 The SPaT Infrastructure System will be enrolled in and maintain current security credential certifications required for the applications supported at the location of the SPaT Infrastructure System (e.g. if the SPaT Infrastructure system is only broadcasting SPaT data and not receiving vehicle data, the Security Back End would not need to validate vehicles' credentials).

3.9 PID's Perspective

3.9.1 PIDs will be handheld devices carried by visually impaired or otherwise vulnerable pedestrians that have difficulty interacting with pedestrian pushbuttons or viewing pedestrian cross indicators or crosswalks. Each PID used by authorized pedestrians will interact with the SPaT Infrastructure System to send and receive messages. The communications between the SPaT Infrastructure System and the PID will typically be Wi-Fi or cellular based to work with off-the-shelf mobile devices running applications.

3.9.2 *In deployments supporting PED-SIG applications, PIDs will communicate messages to the SPaT Infrastructure System using Personal Safety Messages.*

3.9.2.1 PIDs will communicate Personal Safety Messages to the SPaT Infrastructure System to indicate when an authorized pedestrian has requested a walk indicator and the crosswalk impacted. ***(3.13)***

3.9.3 In deployments supporting PED-SIG applications, PIDs will receive SPaT and MAP messages from the SPaT Infrastructure System that contain data needed to support pedestrians.

3.9.3.1 PIDs will receive current cross walk status from the SPaT Infrastructure System, enabling the PID to be used by pedestrians to understand if they have walk status. These status reports will be included in the SPaT Data. ***(3.15)***

3.9.3.2 PIDs will receive MAP data from the SPaT Infrastructure System describing the geometry of the crosswalk. ***(3.16)***

3.9.4 *In deployments supporting PED-SIG applications, PIDs will receive support from the SPaT Infrastructure System to correct the position determined by the PID in order to determine if the PID is within the crosswalk.*

4. Operational Concept for SPaT, MAP, RTCM, and Traffic Data

4.1 SPaT Data Overview

In order for the SPaT Vehicle System to provide the driver with SPaT enable applications, the SPaT Vehicle System needs to know where it is in relation to the intersection, which signal indications are pertinent to the vehicle's intended movement through the intersection, and the state of those signal indications. This is accomplished by wireless data exchange between the SPaT Infrastructure System and the SPaT Vehicle System using 5.9 GHz DSRC communications. The SPAT, MAP, and RTCM messages defined in the SAE J2735 standard provide the SPaT Vehicle System with the needed information, and the SPAT message is populated with data from the Traffic Signal System, typically the signal controller.

4.2 SAE J2735 MAP Message

The SAE J2735 MAP message focuses on information about lanes. It can provide lane information for up to 32 intersections and 32 non-intersection road segments. For the purposes of SPaT enabled applications using DSRC, it would typically contain the lane information for a single intersection.

4.2.1 Intersections and Lanes

4.2.1.1 The intersection has a unique integer ID within a unique integer road regulator ID. The message provides for up to 65,535 road regulator IDs, each of which can have up to 65,535 intersection IDs. Each intersection can have up to 255 lane IDs. Note that efforts are currently underway to define a process for assigning unique road regulator IDs.

4.2.1.2 The intersection is located by a reference point at the center of the intersection. The lanes are described by node points along the center of the lane, starting with a node at the stop line and ending with a node as far back from the intersection as is needed for the SPaT enabled application to function properly. The first node, at the stop line, is located as an X,Y offset from the reference point. Subsequent nodes are located by an X,Y offset from the previous node. Alternatively, nodes may be identified by latitude and longitude; however, as more bits are required in a message for this approach, it may be difficult to fit the MAP message into a WAVE Short Message for a DSRC broadcast.

4.2.1.2.1 SPaT enabled applications assume the lane is a straight line connecting the node points. Therefore, a straight approach lane having no curves only needs 2 nodes, one at the stop line and one at the furthest point from the intersection.

4.2.1.2.2 A curved approach lane would need sufficient nodes such that straight lines connecting the nodes do not deviate from the actual center line of the lane by an excessive amount.

4.2.2 Lane Types and Attributes

4.2.2.1 The MAP message can describe several types of lanes. SPaT enabled applications will need information about vehicle lane types, crosswalk lane types and potentially sidewalk lane types.

4.2.2.2 The MAP message describes lanes both approaching (ingress) and departing from (egress) the intersection (the first node of the lane). The message can identify the maneuvers allowed at the stop line, including left/right/through, U turns and turns on red. These allowed maneuvers can in addition or instead be defined as part of the connection, described below.

4.2.2.3 Pedestrian crosswalks are configured like other lanes.

4.2.3 Connections and Signal Groups

4.2.3.1 The MAP message identifies each egress lane ID that an ingress lane connects to, and can identify the maneuver required to reach that egress lane lane (left/right/through/U turn).

4.2.3.1.1 Each ingress lane in the MAP message can have up to 16 connecting egress lanes. Each connection can be provided with an optional connection ID, which is required if it is desired to convey maneuver assistance as part of the SPAT message. One relevant example of maneuver assistance is an indication if a bicycle or pedestrian is detected crossing the lane, which the Pedestrian in Crosswalk Warning application needs.

4.2.3.2 The lane connections in the MAP message are what identify to the SPaT Vehicle System which signal indications are associated with the intended movement at the intersection.

4.2.3.2.1 Each egress lane connection from an ingress lane is associated with one of up to 254 possible signal group IDs per intersection. A signal group is associated with a traffic signal phase, which consists of traffic movements separately controlled by signal indications at the intersection. If a single movement of traffic can be controlled by more than one signal group (phase), such as a protected permissive left turn that can turn left with a green left turn arrow or with a green circular indication, then the MAP message will indicate the connection for the protected permissive turn to the signal group for the protected signal indication. That is, when the related permissive signal indication is green, the signal group for the protected signal indication should indicate a status of permissive green.

4.2.3.2.2 The SPAT message provides signal indication and timing information for signal groups at the intersection.

4.2.3.3 To provide pedestrian signal timing information for pedestrian crosswalks, the crosswalk lanes must have connections to other lanes. The SAE J2735 standard suggests that the crosswalks connect with each other at the corners of the intersection. Alternatively, sidewalk lanes could be created in the MAP message for the crosswalks to connect to.

4.2.4 Dynamic Map Information

4.2.4.1 The MAP message includes a revision number that increments any time the contents of the MAP message have changed. This will allow the SPaT Vehicle System to forego processing map data that has not changed since a previous time the SPaT Vehicle System received the MAP message for that intersection.

4.2.4.2 The MAP message allows designating a lane as being revocable. Lanes designated as being revocable are not considered to be available for use unless the SPAT message identifies them as being enabled. This could apply to a parking lane, for example, that is available for vehicle traffic during peak periods but is reserved for parking during off peak periods. It could be used for reversible lanes, where the MAP message would define two lanes in the same place, one an ingress lane and one an egress lane.

4.2.4.2.1 The SPAT message would identify the appropriate lane as being enabled. It could apply for time of day turn restrictions, such as not permitting right turn on red during certain time periods. Similar to the reversible lanes, the MAP message would define two lanes in the same place, one allowing turn on red and the other not allowing it. SPaT enabled applications would only use revocable lanes from the MAP message if the SPAT message has identified the lane as being enabled.

4.3 SAE J2735 SPAT Message

The SAE J2735 SPAT message provides status information about a signalized intersection as a whole and dynamic signal indication and timing state information for the individual signal groups at the intersection. It can provide information for up to 32 intersections. For the purposes of SPaT enabled applications using DSRC, it would typically contain signal state information for a single intersection.

The SPAT message uses the same intersection ID that the MAP message uses. For each intersection, the message can provide information for up to 254 signal groups, which relate to signal phases. Like the MAP message, the SPAT message has a revision indicator.

4.3.1 Intersection State

4.3.1.1 The status information the SPAT message provides about the intersection as a whole includes information such as whether the intersection is currently in preemption or priority, whether the intersection is in failure flash, whether it is fixed time or traffic actuated, and indicators that the MAP message has been updated, among other things. It also includes a list of which revocable lanes are currently enabled, if the MAP message had indicated any revocable lanes.

4.3.2 Signal Group State

4.3.2.1 For each active signal group in use at the intersection, the SPAT message describes the current state (which is the current interval for that phase), provides the best estimate for when that interval may end, and potentially describes future interval states and times also.

4.3.2.2 In order for the SPAT message to be applicable across regions and countries, the state of the signal group is described in the message by its meaning, rather than how it is displayed at the intersection. For example, a state may be "protected-Movement-Allowed", displayed in the United States as a green arrow, or "stop-Then-Proceed" displayed as a flashing red indication. Comments in the standard help clarify what these normally mean in the United States. The states enumerated in the standard do not mention pedestrian indications, and so they will need to be applied based on the description. For example, a flashing Don't Walk would use the "permissive-clearance" state, indicating it is a clearance interval and that conflicting traffic may be present.

4.3.2.3 The SPAT message is capable of including the state for every signal group each time the message is sent.

4.3.3 Signal Group Timing

4.3.3.1 The SPAT message uses a point in time, called a time mark, to indicate when an interval will change rather than a countdown to when the interval will change.

4.3.3.1.1 The SPAT message can identify the time when the interval started, when is the earliest time it could end assuming there are no preemption or priority calls, when is the latest time it could end, what is the most likely time it will end, how confident are we of the likely end time and when is the next time this signal group may be in a green state.

4.3.3.1.2 A traffic actuated signal controller will often know the earliest time the interval could end, but often will not know the other values.

4.3.3.1.3 The controller usually will know the exact duration of a yellow clearance interval and should only provide an earliest end time.

4.3.3.2 For a traffic actuated traffic signal system, the SPAT message for a green interval may start with an earliest end time being a time in the future when the minimum green will expire.

4.3.3.2.1 If a vehicle extends the green beyond the minimum green before the green interval ends, the new SPAT message will have a new earliest end time reflecting the extension of the green.

4.3.3.2.2 The earliest end time will continue to get revised as the green gets extended until there are no more vehicles extending the green or until the maximum green time is reached, at which time the interval will change to yellow.

4.3.3.2.3 The maximum green time or the coordination timing parameters may allow the traffic signal system to know the latest end of the green interval, which can be included in the SPAT message.

4.3.3.3 Using time marks rather than countdowns minimizes the SPAT message updates needed and can help mitigate the impact of latency in transmitting the message. For example, if a signal group just started its minimum green time, the earliest end time for the green interval may stay constant for many seconds, whereas a countdown time would need to be updated every tenth of a second. Also, a delay (latency) in receiving the SPAT message would often not impact the validity of the earliest end time, but it would impact the validity of a countdown time.

4.3.3.3.1 One challenge with using time marks is the need to ensure that the traffic signal system and the SPaT Vehicle System clocks are synchronized.

4.3.4 Future Intervals

4.3.4.1 The SPAT message can provide information about the future states and times of signal group intervals in addition to the current interval with its end times.

4.3.4.1.1 A pre-timed signal, such as in a downtown grid, could provide information on the green, yellow and red intervals of multiple future cycles. This information about future intervals could be useful to the Eco Approach / Departure application, for example, that could inform the driver of a recommended speed that would avoid stopping at multiple intersections.

4.3.5 Connection Maneuver Assistance

4.3.5.1 The SPAT message can include connection maneuver assistance. The traffic signal system knows if a pedestrian has activated the pedestrian pushbutton to request a walk indication.

4.3.5.1.1 If there is a pedestrian pushbutton actuation, the traffic signal system can provide information for the SPAT message to indicate the presence of a pedestrian in the crosswalk that conflicts with a specific connection, using the connection ID that was set in the MAP message. This information would be associated with the signal group controlling the movement that will be in conflict with the pedestrian.

4.3.5.2 In addition to the presence of a pedestrian pushbutton actuation, the intersection may include detection equipment specifically designed to detect pedestrians in the crosswalk.

4.3.5.2.1 The SPaT Infrastructure System may be able to directly include this information in the SPAT message separately from the traffic signal system data if the traffic signal system is not aware of the information.

4.4 Traffic Signal System

Traffic control in a traffic signal system is often structured by traffic phases. Eight vehicle phases provide for separate control of left turns and through movements for four roadway approaches. Four pedestrian phases provide separate control for pedestrians crossing four roadway approaches, and are often associated with the adjacent vehicle phase, as illustrated in Figure 3. Complex intersections may require additional phases. Overlaps provide control for movements that are dependent on what is happening with other movements, such as a right turn arrow that turns green whenever the crossing street has a green protected left turn arrow displayed. Many controllers assign these vehicle, pedestrian and overlap phases to separate controller channels. The channel outputs, whether physical outputs or time slots in a communication channel, interface with equipment in the traffic signal control cabinet to operate the signal indications displayed at the intersection. The traffic signal system will associate each MAP and SPAT message signal group with a controller channel in order to create the data needed for the SPAT message.

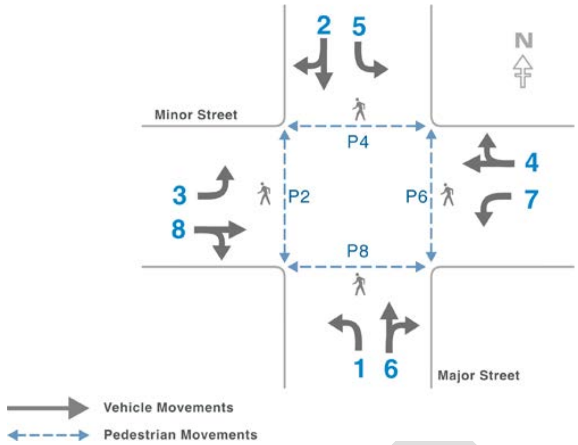

Figure 3 Traffic Signal Phasing Source: USDOT

4.4.1 Pre-timed Traffic Signal Systems

4.4.1.1 A pre-timed traffic signal system has the timing for all of the intervals for all of its phases programmed in advance. Different sets of pre-programmed timing values may be selected based on time of day, or based on overall traffic levels, but the signal then utilizes the selected timing values regardless of individual vehicle movements.

4.4.1.2 Fully pre-timed traffic signals systems usually only exist in central downtown grids, where maintaining coordination in all traffic directions simultaneously requires setting the timing to fixed values. This type of traffic signal system knows all the information needed to create a SPAT message.

4.4.2 Semi-actuated Traffic Signal Systems

4.4.2.1 A semi-actuated traffic signal system uses detection to determine the presence of traffic for left turns and/or cross streets and/or for pedestrians, but not for the main road through movement.

4.4.2.2 The signal provides green indications on the main roadway through movements unless there are vehicles on the left turns and/or cross streets or pedestrians requesting to cross the main roadway.

4.4.2.3 Semi-actuated traffic signal systems may not know all the timing information that a SPAT message provides for, because they may change the time of the end of green based on actual traffic detected. Even less than one second before the green ends, the traffic signal system may not have known when it would end, since it may have extended the green if another vehicle had been detected during that one second.

4.4.2.4 Most of these types of traffic signal systems do know the earliest time that the green could end. They may also know the latest time it could end.

4.4.3 Fully Actuated Traffic Signal Systems

4.4.3.1 A fully actuated traffic signal system uses detection on all approach movements and adjusts the lengths of the green intervals on all movements in response to the actual traffic present.

4.4.3.2 Fully actuated traffic signal systems may not know all the timing information that a SPAT message provides for, because they may change the time of the end of green based on actual traffic detected. Even less than one second before the green ends, the traffic signal system may not have known when it would end, since it may have extended the green if another vehicle had been detected during that one second.

4.4.3.3 Most of these types of traffic signal systems do know the earliest time that the green could end. They may also know the latest time it could end.

4.4.4 Coordinated Traffic Signal Systems

4.4.4.1 A coordinated traffic signal system coordinates the timing of the signals at multiple adjacent traffic signals by linking the timing at the individual intersections to a common cycle length and cycle start time shared among the multiple signals to improve the movement of traffic through the multiple signalized intersections. Pre-timed, semi-actuated and fully actuated traffic signals can all be coordinated.

4.4.4.2 A coordinated traffic signal system may know more about the possible time windows when a green indication could end than an uncoordinated traffic signal system does, because the coordination or adaptive system forces each signalized intersection to start the green indication for its coordinated movement by a certain point in time and will not let it leave the green interval until a certain point in time.

4.4.5 Traffic Adaptive Traffic Signal System

4.4.5.1 A traffic adaptive traffic signal system adjusts the coordination between multiple intersections and the lengths of green intervals based on overall traffic, without being constrained to selecting from pre-programmed values.

4.4.5.2 A traffic adaptive traffic signal system may know more about the possible time windows when a green indication could end than an uncoordinated traffic signal system does, because the coordination or adaptive system forces each signalized intersection to start the green indication for its coordinated movement by a certain point in time and will not let it leave the green interval until a certain point in time.

4.5 RTCM Messages

4.4.5.1 In order for the vehicle to accurately identify the ingress lane of travel using the MAP message, it is critical that the location of the vehicle (determined by the on-board GPS) is accurate. This can be accomplished by a broadcast of GPS correction information as standardized in messages by the RTCM (RTCM Message) as a method for minimizing the effects of GPS error caused by atmospheric conditions.

4.4.5.2 The general concept of RTCM is that a base station with a known location (the location may be known by either by surveying in the station location or operating a GPS receiver for a long continuous period of time) continuously receives satellite signals and determines a current latitude/longitude position given the current atmospheric conditions. The base station then compares the position determined with the current atmospheric conditions to the known location and computes a correction factor that corrects the current calculated position to the known position. This correction factor is the RTCM message that can be sent out to vehicles.

4.4.5.3 Depending upon the vehicle and the GPS system on board, the vehicle may or may not be able to apply the correction factor.

4.4.5.4 Creation of the RTCM message may either be done by operating a base station at the intersection, or by retrieving the RTCM from an on-line source, or by a central calculation at the TMC.

4.4.5.5 Determining which intersections should include position correction broadcasts would be a site specific decision.

4.4.5.5.1 Vehicles approaching simple intersections where lane delineation is not required may not benefit from broadcast corrections.

4.4.5.5.2 Vehicles approaching intersections with separated left-turn lanes (and therefore require the vehicle to process the MAP data and determine the lane of travel) would likely benefit from receiving broadcast corrections.

4.4.5.5.3 Vehicles approaching intersections in locations with low or poor satellite visibility (e.g. urban canyons) would not benefit significantly from the broadcast corrections to overcome the poor satellite visibility.

5. SPaT Infrastructure System Operational Scenario

This scenario illustrates the expected operation of a SPaT Infrastructure System communicating to vehicles and PIDs using DSRC communications that utilize the SAE J2735 MAP and SPAT messages, and interfacing with local Traffic Signal Systems.

5.1 Initial Conditions

The following conditions must be in place before the scenario starts:

The SPaT Vehicle System:

- Is approaching the signalized intersection.
- Knows the intended maneuver the driver intends to make at the intersection (Left/Right/Through/U-turn).
- Continuously knows its current position.
- Is configured to receive SPAT and MAP messages, including supporting standard message security features.
- Is configured with SPaT enabled applications to support the driver.
- Is configured to receive position correction information and to apply it to its current position, as needed to support enabled applications.
- Is equipped with a clock that is synchronized with the SPaT Infrastructure System.

The Traffic Signal System:

- Is operating normally, there are no preemption or priority currently in effect, and no failure mode flashing operation in effect.
- Has been configured and is sending data to the SPaT Infrastructure System to support a proper SPaT message.
    - Traffic signal vehicle, pedestrian and overlap phases are assigned to channels.
    - Channels are assigned to signal group IDs.
    - Overall signal status information is being provided to the SPaT Infrastructure System.
    - Movement states and timing for active signal groups are being provided to the SPaT Infrastructure System.
    - Pedestrian pushbutton actuations or pedestrian detections from separate pedestrian detectors associated with any signal group are indicated to the SPaT Infrastructure System.

The SPaT Infrastructure System:

- Is configured and broadcasting a proper MAP message.
- Is configured and is receiving SPaT supporting data from the traffic signal system.

- Is configured and broadcasting a proper SPAT message.
- Supports standard message security features.

5.2 Sequence of events

Map Message:

1. The SPaT Vehicle System receives the MAP message and validates the security credentials.
2. The SPaT Vehicle System checks the message revision number and determines it has never received this revision of the MAP message (alternate - the SPaT Vehicle System determines it has already received this revision of the MAP message and skips step 3.)
3. The SPaT Vehicle System decodes the MAP message and determines
    a. Intersection location.
    b. Ingress and egress lane geometry and location.
    c. Connections from ingress lanes to egress lanes via specific maneuvers.
    d. The signal group IDs related to the connections.
4. The SPaT Vehicle System may receive position correction information and use it to more accurately determine its current position.
5. Based upon its current location and the lane geometry, the SPaT Vehicle System determines which lane it is in.
6. Based upon which lane it is in and the maneuver the driver intends to make at the intersection, the SPaT Vehicle System determines which connection to an egress lane in the map message represents the intended maneuver, and, knowing the connection, determines which signal group ID conveys information about the signal state and timing for that maneuver.

SPAT Message:

A. The SPaT Vehicle System receives the SPAT message and verifies the security credentials.

B. The SPaT Vehicle System checks the message revision number and determines it has never received this revision of the SPAT message (alternate - the SPaT Vehicle System determines it has already received this revision of the SPAT message and skips steps C and D.)

C. The SPaT Vehicle System decodes the SPAT message and determines

    a. The overall intersection status does not indicate failure flash, preemption or priority or other status which could call into question any interval end times contained in the SPAT message.
    b. Determines from the overall intersection status that the traffic signal operation is traffic dependent, such that the SPAT message may not contain an exact end time of the intervals.

D. Based upon the relevant signal group ID that the SPaT Vehicle System determined from the MAP message, the SPaT Vehicle System determines

a. What the current signal indication is for the intended maneuver. If the SPAT message contains no information for the relevant signal group, the SPaT Vehicle System assumes the indication is red.

b. How much time is left at a minimum, for the current signal indication.

c. Whether any pedestrians or bicyclists are crossing in conflict with the intended maneuver.

E. Based upon the position of the SPaT Vehicle System, upon the current signal indication for the intended maneuver, upon the minimum time left for the signal indication and upon the presence of any conflicting pedestrians or bicyclists, the SPaT enabled application provides the intended service to the vehicle driver.

F. Repeat the scenario until the SPaT Vehicle System has passed through the intersection.

Appendix A – SPaT Infrastructure System - Use Case Diagrams

Use case diagrams do not define the functions of the system or data flows, but rather how each stakeholder uses the primary system. For purposes of this ConOps, the SPaT Infrastructure System is the focus, and the use case diagram illustrates how each stakeholder (both human and system stakeholders) will interact with the system. Figure A-1 below illustrates the overall use case diagram for all aspects of the SPaT Infrastructure System. In reading the figure below, it is important to read the connections as use cases, for example:

- The Traffic Engineer ***will use*** the SPaT Infrastructure System to Monitor CV Operations & Data
- The SPaT Vehicle System ***will use*** the SPaT Infrastructure System to Receive SPAT Data
- The Traffic Signal System ***will use*** the SPaT Infrastructure System to receive signal preemption/priority requests.

These and other use cases are illustrated below:

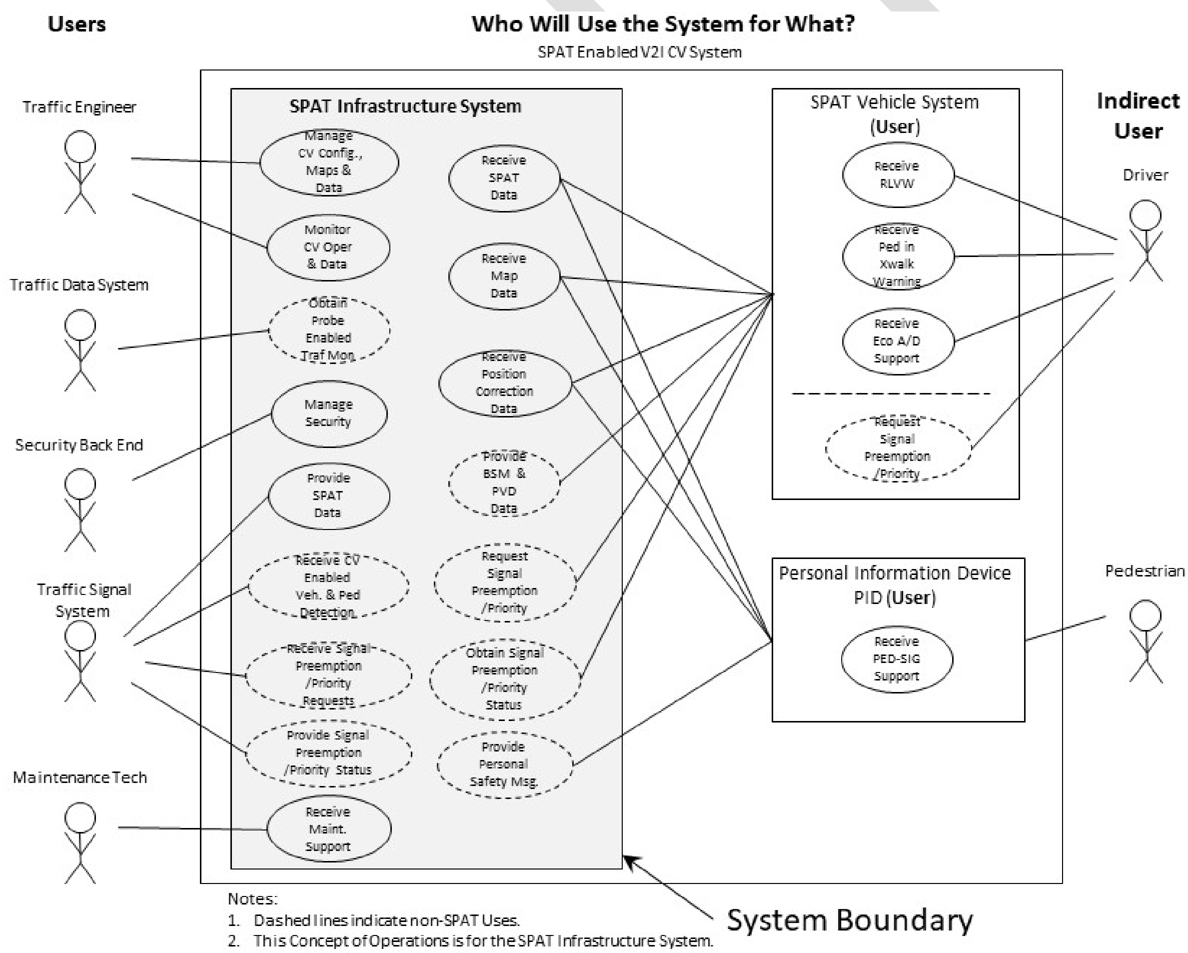

Figure A-1 Use Case Diagram for the SPaT Infrastructure System

As indicated above, for deployments with an emphasis solely on one or more of the applications that relies upon the SPaT broadcast (as described in Section 1.4), the following use case diagram depicts the uses of the SPaT Infrastructure System. This is a provided as a reference for agencies wishing to deploy the basic components of a SPaT Infrastructure System.

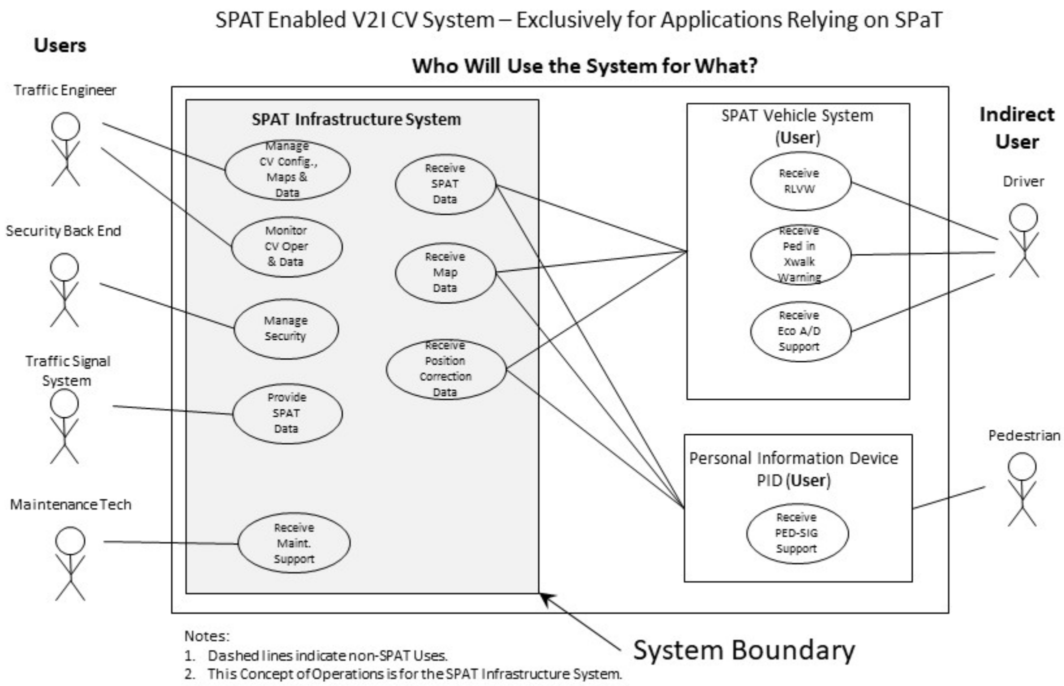

Figure A-2 V2I Use Case Diagram for the SPaT Infrastructure System Specific to SPaT Dependent Applications