NCDOT Multimodal Connected Vehicle Pilot

Concept of Operations

June 9, 2021

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Version History

Version	Date	Summary of Changes
1.0	2/17/21	Draft for NCDOT Review
2.0	3/31/21	Updated by KH per NCDOT Review
3.0	6/9/21	Updated by KH per NCDOT Review

Acronym/Abbreviation	Definition
ATMS	Advanced Traffic Management System
ATSPM	Automated Traffic Signal Performance Measures
ConOps	Concept of Operations
CV	Connected Vehicle
DSRC	Dedicated Short Range Communication
CED	Connected Eco Driving
GMS	Governor Morehead School
HRD	High Resolution Data
ITRE	Institution for Transportation Research and Education
I-SIG	Intelligent Signal System
MUTCD	Manual on Uniform Traffic Control Devices
NCDOT	North Carolina Department of Transportation
NCSU	North Carolina State University
OBU	On-Board Unit
PSCW	Pedestrian in Signalized Crosswalk Warning
PED-SIG	Mobile Accessible Pedestrian Signal System
RLVW	Red Light Violation Warning
RSE	Roadside Equipment
RSU	Roadside Unit
ROI	Return on Investment
SOP	Standard Operating Procedure
SPaT	Signal Phase and Timing
SRM	Signal Request Message
SSM	Signal Status Message
SW	Speed Warning
TIM	Traveler Information Message
TMC	Traffic Management Center
TOC	Traffic Operations Center
TSMO	Transportation Systems Management and Operations
TSP	Transit Signal Priority
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
WZW	Work Zone Warning

1 INTRODUCTION

In 2019, North Carolina Department of Transportation was awarded the Advanced Transportation and Congestion Management Technologies Deployment grant to support a connected vehicle pilot project. The project will develop, deploy, and evaluate the impacts of several Connected Vehicle (CV) applications and the necessary supporting infrastructure.

1.1 PURPOSE OF DOCUMENT

This document describes the Concept of Operations (ConOps) for the North Carolina Department of Transportation's (NCDOT) Multimodal Connected Vehicle Pilot (MMCVP) Project including the scope, vision, and operational scenarios for the system.

The ConOps is one component of the Systems Engineering process, providing a conceptual understanding of how the system is intended to function. This high-level description of the proposed system directs the development of a concept that meets stakeholder needs for the project. The key stakeholders in the project are NCDOT, City of Raleigh, North Carolina State University (NCSU) supported by Institute for Transportation Research and Education (ITRE) and Governor Morehead School (GMS).

The NCDOT MMCVP aims to create and test a connected environment to measure the safety impact of CV technology for pedestrians, cyclists, motorists, and other road users as well as improving the efficiency and mobility of the Wolfline bus system. The pilot will deploy CV technology on the roadside and in the Wolfline bus fleet. Where possible, existing infrastructure will be utilized, including existing traffic signal cabinets and communication backbone fibers. To support the new system, new traffic signal controller units will be deployed along with upgrades to the local controller software and central software. Pedestrian assist applications will be deployed on portable personal information devices (e.g., smartphones). Motorists will be able to use the same applications to receive alerts, notifications, and warnings about pedestrians in the crosswalk, traveler information messages, speed violations, red light violations, work zones, and eco-driving opportunities. Security will be implemented to ensure the integrity and authenticity of the messages while maintaining privacy. The system will also collect high resolution data and implement signal performance measures to help evaluate the effects of pedestrian and transit priority as well as optimize system performance.

1.2 EXISTING CONDITIONS

The current location for the system is in an urban environment between NCSU's Central and South campuses. The project area consists of seven signals owned and operated by the City of Raleigh, and twenty-five signals owned and operated by NCDOT. The current signal software for the signals is Siemens SEPAC, running Tactics without smart corridor technology. Existing infrastructure will be utilized for the pilot where possible.

Along this route, NCSU operates its Wolfline bus system to serve students, faculty, and visitors. The buses do not have any connectivity to the infrastructure, operating as standalone vehicles.

The corridors for the pilot project will include up to thirty-two intersections around campus, strategically placed in areas with multimodal urban use including pedestrian, cyclist, transit, and motorist traffic. This dense location will allow the pilot to test a multitude of applications with various users to evaluate the impact of CV technology. The project area is shown in Figure 1.

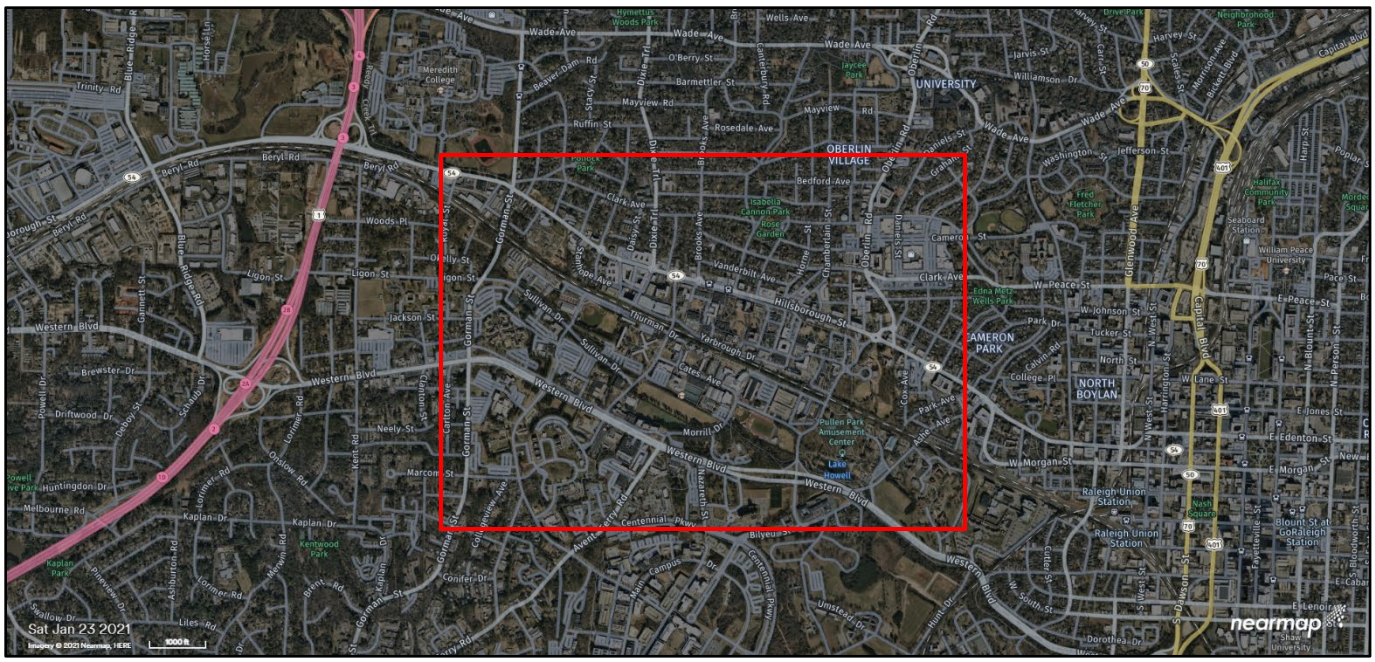

Figure 1 Project Area

2 PROJECT AREA IMPROVEMENT OPPORTUNITIES

2.1 PEDESTRIAN SAFETY OPPORTUNITY

Between 2010 and 2018, there were 104 crashes involving a pedestrian or cyclist along three of the major roads surrounding the North Carolina State University (NCSU) campus. North Carolina had 198 pedestrian fatalities in 2017, accounting for 14 percent of the total traffic fatalities. The national average for pedestrian fatality rate in 2017 was 1.84 per 100,000 population. North Carolina's average was 1.93 per 100,000, or 4.8% higher than the national average.

In response to the safety concerns of the corridor, the partner agencies identified an opportunity to leverage a pilot project that could assess integrated connected vehicle applications and infrastructure to safety, mobility, and environmental impacts of the existing performance.

2.2 GEOGRAPHIC OPPORTUNITY

There is a unique opportunity to assist the students at Governor Morehead School by improving the safety at the intersections for the particular needs of the vision impaired. Since the school is located within the project area, the pilot can explore ways to assist with safe crossing at signalized intersections. In addition, NCSU's existing bus system allows the project team to pilot transit improvements on the campus routes.

3 PROJECT DEVELOPMENT

3.1 PROJECT VISION AND GOALS

It is envisioned that this pilot will improve safety, increase mobility, and help reduce environmental impact. The valuable data this pilot project provides will help the NCDOT to further deploy CV technology within the state, enhancing safety and mobility for all citizens while simultaneously protecting the environment.

The goals and objectives for the MMCVP are:

Goal: Improve mobility within the pilot area for motorists

- Improve travel times
- Improve travel speeds
- Reduce travel delay

Goal: Improve mobility within the pilot area for transit

- Increase schedule adherence for transit buses
- Increase arrival on green
- Increase transit ridership rates
- Improve rider experience
- Improve transit vehicle operator experience

Goal: Improve safety for all users of the pilot area

- Reduce the number of crashes
- Reduce the crash severity in the study area
- Reduce the number of red-light violations
- Reduce the number of crashes involving cyclist and pedestrians
- Improve the road users' safety impression of the pilot area
- Improve the experience of vision impaired pedestrians in the pilot area

Goal: Reduce environmental impacts in the pilot area

- Reduce transportation-related emissions
- Reduce idle times and therefore fuel use

Goal: Reduce costs/Improve ROI

- Demonstrate the benefits outweigh the costs
- Provide cost savings to transportation agencies
- Reduce resources needed from first responders
- Reduce resources needed for data collection

3.2 INTERSECTION LOCATIONS

Table 1 lists the intersections that are anticipated to be a part of this pilot. These intersections, located on and around NCSU's campus were selected based on the proposed Transit Signal Priority application, bus routes, and other key intersections where specific connected applications can be tested.

Table 1: Pilot Intersection Locations

#	Sig Inv. No.	Location	Software	Cabinet
1	05-0023	Hillsborough St at Meredith College Dr	SEPAC	332
2	05-0028	Hillsborough St at Gardner St	SEPAC	332
3	05-0029	Hillsborough St at Horne St	SEPAC	332
4	05-0047	Western Blvd at Dan Allen Dr	SEPAC	332
5	05-0048	Western Blvd at Avent Ferry Rd/Morrill Dr	SEPAC	332 w/Aux
6	05-0186	Western Blvd at Gorman St	SEPAC	332
7	05-0442	Hillsborough St at Enterprise St	SEPAC	332
8	05-0804	Hillsborough St Pogue St	SEPAC	332
9	05-0913	Avent Ferry Rd at Gorman St	SEPAC	332
10	05-0258	Hillsborough St at Faircloth St/Gorman St	SEPAC	332
11	05-1050	Hillsborough St at Logan Ct	SEPAC	332
12	05-1098	Hillsborough St at Beryl Rd	SEPAC	332
13	05-1521	Avent Ferry Rd at Varsity Dr	SEPAC	332 w/Aux
14	05-1586	Hillsborough St at I-440 WB/US 1 SB Ramps	SEPAC	332
15	05-1603	Hillsborough St at I-440 EB/US 1 NB Ramps	SEPAC	332
16	05-1657	Avent Ferry Rd at Centennial Pkwy/Champion Ct	SEPAC	332
17	05-2007	Centennial Pkwy at Oval Dr/Bilyeu St	SEPAC	332
18	05-2146	Avent Ferry Rd at Trailwood Dr	SEPAC	332 w/Aux
19	05-2199	Western Blvd at Varsity Dr	SEPAC	332 w/Aux
20	05-2329	Hillsborough St at Chamberlain St	SEPAC	332
21	R-????	Cates Ave at Morrill Dr*	SEPAC?	NEMA TS-2
22	R-????	Dan Allen Dr at Yarbrough Dr*	SEPAC	332
23	R-????	Method Rd at Ligon St*	Flasher	Flasher
24	R-????	Gorman St at Ligon St/Sullivan Dr*	SEPAC	336
25	R-????	Dan Allen Dr at Thurman Dr*	SEPAC	336
26	R-????	Pullen Rd at Cates Ave*	SEPAC	332
27	R-????	Gorman St at Kaplan Dr*	SEPAC	332
28	05-0032	Hillsborough at Oberlin	SEPAC	332
29	05-0033	Hillsborough at Woodburn/Cox	SEPAC	336
30	05-2127	Western at Canton	SEPAC	332 w/Aux
31	05-0046	Western at Kent/Method	SEPAC	332
32	05-2128	Western at Pullen	SEPAC	332

3.3 STAKEHOLDERS

There are many stakeholders identified for the pilot. Core team stakeholders are the members of the project team. Key agency partners are those agencies that are directly affected by the pilot. Key stakeholder agencies are those agencies/organizations that may interact with the pilot.

Core Team Members

- NCDOT
- City of Raleigh
- NCSU Transportation

Key Agency Partners

- Institute for Transportation Research and Education (ITRE)
- Governor Morehead School
- NCDOT – Division 5, Integrated Mobility, Traffic Safety

3.4 SYSTEM USERS

Some of the users that were identified for this pilot are listed below.

Infrastructure Owners/Operators - users who own and are responsible for operating and maintaining different parts of the system

- NCDOT
- City of Raleigh
- NCSU

Roadway Users - a broad group of users who will utilize the system on a regular basis

- Wolfline Bus Drivers
- Wolfline Passengers
- NCSU Students, Faculty, Visitors
- Governor Morehead Students, Faculty, Visitors
- Meredith College Students, Faculty, Visitors
- Motorists
- Non-Motorized Vehicle Users
- Pedestrians
- Cyclists

Data Users - users who will provide guidance, oversight, and monitor the data for performance measurements

- NCDOT
- ITRE
- City of Raleigh

3.5 POLICIES

The following policies, documents, standards, and guidelines will be referenced during the development, implementation, testing, operations, and maintenance of the project:

- Manual for Uniform Traffic Control Devices (MUTCD)
- IEEE Standards and Practices and other communication protocols
- SAE J2735 - Dedicated Short-Range Communications (DSRC) Message Set Dictionary
- AASHTO Green Book
- NCDOT 2018 Standard Specifications for Roads and Structures
- NCDOT 2018 Roadway Standard Drawings
- NCDOT Signals and ITS Project Special Provisions
- Wolfline SOPs
- City of Raleigh Transportation Operations Division SOP
- NCDOT Signal System Timing Philosophy Manual

4 PROPOSED SYSTEM COMPONENTS AND FUNCTIONS

The following applications will be tested as part of the pilot project. Each subsection describes the application and its use in the scope of the MMCVP.

4.1 SIGNAL PHASE AND TIMING (SPAT)

Signal Phase and Timing (SPaT) broadcasts will enable the development of numerous applications in this pilot. This system broadcasts the current phase and residual time in that phase for each approach and movement in a signalized intersection. It can be used for Transit Signal Priority, Red Light Violation Warning, Pedestrian Signal Application, and others being tested in this pilot.

4.2 TRANSIT SIGNAL PRIORITY (TSP)

The Wolfline bus system serves the student population of NCSU as well as the general public. Riders need to be able to rely on the bus system to arrive and depart on time. Traffic conditions and traffic signal inefficiencies can delay buses, causing a ripple effect throughout the day, resulting in unreliable schedules. Buses stuck idle at an intersection with a red light uses more fuel and release additional carbon dioxide emissions. There is a need to ensure buses arrive and depart on time to promote use and safety and reduce their impact to the environment.

4.3 PEDESTRIAN IN SIGNALIZED CROSSWALK WARNING (PSCW)

Centering around NCSU, an urban college campus, the corridors that comprise this system experience heavy volumes of pedestrian traffic. Distracted pedestrians or those hurrying to class may not pay full attention to vehicles or buses in the area. Furthermore, visitors to campus may be unfamiliar with the area causing a complex dynamic resulting in safety concerns for vulnerable road users including distracted and vision impaired pedestrians.

4.4 MOBILE ACCESSIBLE PEDESTRIAN SIGNAL SYSTEM (PED-SIG)

With the heavy volume of pedestrian traffic along this system, clarity on pedestrian or cyclist priority for crossing is essential. Without receiving confirmations that it is safe to cross, it can be dangerous for visually impaired pedestrians to attempt to cross the street. Because the pilot project is inclusive of several signals near Governor Morehead School, the flagship school in North Carolina for students who

are visually impaired, there is an opportunity to improve the safety of these students as they cross at signalized intersections.

4.5 INTELLIGENT TRAFFIC SIGNAL SYSTEM (I-SIG)

The pilot corridors present the typical challenges associated with moving vehicles, buses, bicyclists, and pedestrians safely and efficiently. This complete Intelligent Signal System will capture and monitor data and optimize system performance while accommodating transit priority, preemption, and pedestrian movements.

4.6 RED LIGHT VIOLATION WARNING (RLVW)

Drivers will run red lights for various reasons which is a safety hazard for pedestrians and other motorists. The Red Light Violation Warning will calculate the vehicle's speed and trajectory as it associates it to the signal system status, to alert the driver of a risk to run the red light if current speed is maintained.

4.7 SPEED WARNING (SW)

The pilot corridors are often heavily congested with vehicles, buses, pedestrians, and cyclists. Drivers speeding through these corridors present a safety hazard to all users of the corridor. There is a need to alert drivers when their speed exceeds the given threshold so that they will reduce their speeds, improving the safety of the road users.

4.8 HIGH RESOLUTION DATA (HRD)

High resolution data is data provided every one tenth of a second. This granularity is vital to ensure the system stays optimized. High resolution data will be used to evaluate the effectiveness of various applications, methods, and technologies within the pilot project.

4.9 AUTOMATED TRAFFIC SIGNAL PERFORMANCE MEASURES (ATSPM)

Automated Traffic Signal Performance Measures (ATSPM) is an objective-based solution to gather data on the actual performance of signal systems. This automated process reduces the level of effort for the agency, provides cost savings, and allows signal retiming efforts to be based on actual data. Different techniques and applications can be used to monitor the overall effect on different aspects of the system. These signal performance measures are needed to ensure the system is optimized.

4.10 WORK ZONE WARNING (WZW)

Reduced speed limits, lane closures, and information on delays associated with work zones can be communicated to drivers, pedestrians, and cyclists. With this information, the user can alter their route or take the appropriate steps necessary to ensure they continue to travel safely through the system. The increased awareness by the users will result in increased safety for workers in the work zone.

4.11 CONNECTED ECO-DRIVING (CED)

This application will use the on board mobile app to collect and process vehicle data. Through real-time information and feedback on driving behavior, optimal driving speeds, optimal acceleration, and optimal deceleration profiles, users can reduce their fuel usage and emissions.

4.12 CONSTRAINTS/CHALLENGES

Operational constraints and challenges include:

- Ensuring potential users are aware of the applications and are using them in their everyday life to capture enough data and evaluate the efficacy of the applications
- Integrating a pedestrian detection system to ensure pedestrians are accurately detected and located within or near the crosswalk
- Ensuring the alerts, warnings, and notifications do not create a layer of distraction to vehicle and transit operators
- Ensuring security is in place to ensure the integrity and authenticity of the data
- Ensuring privacy concerns are addressed
- Training NCDOT, City of Raleigh, and Wolfline staff to support, operate, and maintain this system
- Educating students at the Governor Morehead School in the use of the mobile accessible pedestrian signal application
- Timely troubleshooting and repair of roadside equipment, on-board equipment, and personal portable connectivity devices
- Upgrading traffic signal equipment to be compatible with connected vehicle technology
- Coordination with local projects including Bus Rapid Transit

5 USER-ORIENTED OPERATIONAL NEEDS

A user is defined as anyone who interacts with a system. These user needs describe the objectives of the applications based on the potential users of each system. The table below includes an Identification Value for each need, the application it is associated with, and a description of the general need identified for each user. This section is not intended to list specific requirements, but basic opportunities for the system to improve the experience of the system users.

Table 2 User Needs

Identification	Application	User Need
SPAT-UN-01	SPaT	Drivers need to be able to receive information concerning the signal status of the intersection and how long this status will persist for each approach and lane that is active
SPAT-UN-02	SPaT	Drivers need to be able to receive information concerning the geographical layout of the intersection through MAP broadcasts as well as receive GPS correction data
SPAT-UN-03	SPaT	NCDOT needs to be able to test and deploy emerging CV technology and applications through supporting infrastructure
TSP-UN-01	Transit Signal Priority	Transit drivers need to be able to maintain published arrival and departure times according to the transit schedule
TSP-UN-02	Transit Signal Priority	Transit drivers need to receive a notification when they are given priority
TSP-UN-03	Transit Signal Priority	Transit drivers need to receive notification they do not have priority or priority has been revoked due to a higher priority request
TSP-UN-04	Transit Signal Priority	Transit riders need to be able to rely on consistent travel, departure, and arrival times
TSP-UN-05	Transit Signal Priority	The system needs to be secure to ensure the authenticity and integrity of the data as well as maintain the privacy of the users

Identification	Application	User Need
PSCW-UN-01	Pedestrian in Signalized Crosswalk Warning	Drivers need to receive warnings about pedestrians in the crosswalk
PSCW-UN-02	Pedestrian in Signalized Crosswalk Warning	Drivers need to receive alerts about pedestrians approaching the crosswalk
PSCW-UN-03	Pedestrian in Signalized Crosswalk Warning	Drivers approaching a crosswalk need to receive notification as to whether they have priority, or an approaching pedestrian has priority to enter the crosswalk
PSCW-UN-04	Pedestrian in Signalized Crosswalk Warning	The system needs the ability to detect pedestrians in marked and unmarked crossing areas
PSCW-UN-05	Pedestrian in Signalized Crosswalk Warning	The system needs the ability to detect vehicles encroaching on pedestrians
PED-SIG-UN-01	PED-SIG	Pedestrians approaching the crosswalk need to receive a priority status notification
PED-SIG-UN-02	PED-SIG	Pedestrians in the crosswalk need to receive notification if they have travelled outside the designated crosswalk area
PED-SIG-UN-03	PED-SIG	Pedestrians in the crosswalk need to receive warnings about vehicles encroaching on the crosswalk
PED-SIG-UN-04	PED-SIG	Pedestrians approaching the crosswalk need to receive alerts about vehicles encroaching on the crosswalk
PED-SIG-UN-05	PED-SIG	Pedestrians crossing in non-crosswalk areas need to receive a warning about vehicles in the vicinity of where the pedestrian is crossing
PED-SIG-UN-06	PED-SIG	The system needs to detect pedestrians in marked crossing areas
PED-SIG-UN-07	PED-SIG	The system needs to detect pedestrians not in marked crossing area
PED-SIG-UN-08	PED-SIG	The system needs to detect vehicles encroaching on pedestrians
I-SIG-UN-01	I-SIG	The system needs to log and analyze transit priority requests and their effect on the overall system
I-SIG-UN-02	I-SIG	The system needs to log and analyze pedestrian requests and their effect on the overall system
I-SIG-UN-03	I-SIG	The system needs to optimize performance under changing circumstances
I-SIG-UN-04	I-SIG	Drivers, transit, cyclists, and pedestrians need to have access to an optimized system corridor
I-SIG-UN-05	I-SIG	Transit drivers and riders need to be able to rely on consistent travel, departure, and arrival times
RLVW-UN-01	RLVW	Drivers need to receive warnings when they are violating a red light
RLVW-UN-02	RLVW	Drivers need to receive an alert when they are likely to violate a red light
RLVW-UN-03	RLVW	Pedestrians need to receive warnings if a red light violation is occurring while they are in or near the crosswalk
SW-UN-01	Speed Warning	Drivers to need receive alerts when their speed exceeds a threshold
SW-UN-02	Speed Warning	The system needs to issue alerts when the detected speed of a vehicle is exceeding a threshold
SW-UN-03	Speed Warning	The system needs to be able to identify a necessary change to the speed threshold that triggers a violation alert

Identification	Application	User Need
HRD-UN-01	High Resolution Data	The system needs for the signal controller to send high resolution data every one tenth of a second
HRD-UN-02	High Resolution Data	The system needs to collect and store high resolution data to control and monitor signals within the pilot corridors.
HRD-UN-03	High Resolution Data	The system needs for traffic signal controller software to support high resolution data, NTCIP communications, and connected vehicle applications.
HRD-UN-04	High Resolution Data	The system needs to securely store and manage high resolution data in a way that ensures the integrity and authenticity of the data.
HRD-UN-05	High Resolution Data	Transportation engineers need the ability to analyze this data to quantify the effectiveness of different parts of the system
HRD-UN-06	High Resolution Data	Transportation engineers need the ability to analyze this data to optimize the performance of the system
ATSPM-UN-01	ATSPM	The system needs to display charts and graphs that highlight specific measures of performance
ATSPM-UN-02	ATSPM	Transportation engineers need the ability to analyze data to quantify the effectiveness of different parts of the system
ATSPM-UN-03	ATSPM	Transportation engineers need the ability to analyze this data to optimize the performance of the system
WZW-UN-01	Work Zone Warning	Drivers need to get alerts when their speed exceeds a threshold in a work zone
WZW-UN-02	Work Zone Warning	The system needs to issue alerts and notifications associated with a work zone
WZW-UN-03	Work Zone Warning	The system needs to change and customize the alerts and notifications broadcast for a work zone
CED-UN-01	Connected Eco-Driving	Motorists need to receive notifications and feedback regarding driving efficiency including recommended driving speeds, optimal acceleration, and optimal deceleration
CED-UN-02	Connected Eco-Driving	The system needs to issue notifications and feedback regarding driving efficiency including recommended driving speeds, optimal acceleration, and optimal deceleration
TMC-UN-01	Traffic Management Center	Operators at the traffic management center will need to be trained on new trained on new features implemented within the central ATMS software
TMC-UN-02	Traffic Management Center	Operators at the traffic operations center will need to be trained on how to recognize, record, and handle new alerts and warnings that are provided by the connected vehicle technology
MN-UN-01	Maintenance	Maintenance requirements will need to be defined for roadside units as well as any additional hardware installed along the corridor
MN-UN-02	Maintenance	Maintenance technicians will need to be trained in the operation, configuration, and maintenance of the hardware and software installed
MN-UN-03	Maintenance	Maintenance tools, software, and spare replacement parts will need to be specified and provided.

6 OPERATIONAL SCENARIOS

This section defines the operational scenarios for each Use Case associated with this project. These scenarios establish the what, where, when, why, who, and how for each Use Case operational state. For each Use Case, two modes of operation are defined:

Table 3: Scenario Operation Modes

Mode	Definition
Mode 1: Normal Operations	The system is functioning normally without a failure; CV Applications are active
Mode 2: Failure Conditions	Situations that require temporarily “turning off” the CV technology/system/device, such as “false” warnings and any “fail-safe” mode that the system would revert to.

6.1 USE CASE 1: SIGNAL PHASE AND TIMING (SPAT)

UC1-S1: Normal Operations	**Signal Phase and Timing (SPaT)**	
Scenario Objective	Allow a vehicle to utilize SPaT data and MAP data to enhance safety and mobility for the vehicle operator	
Operational Event(s)	• SPaT and MAP messages are broadcast from the roadside unit (RSU) to vehicles approaching the intersection • The vehicle uses the SPaT and MAP data along with various applications to enhance safety and increase mobility	
User(s)	User	Role
	Vehicle Operator	Safely and efficient travel through an intersection
Key Actions and Flow of Events	Source	Key Action (Comments)
	Vehicle Operator	Approaches intersection
	RSU	Broadcasts SPaT and MAP messages
	Vehicle OBU	Receives SPaT and MAP messages, processes them, and determines that an alert, notification, or warning should be issued (Issuance of warning is based on data contained in the SPaT and MAP messages, as well as vehicle location and motion data obtained via GPS)
	Vehicle Operator	Use the information provided concerning the signal phase timing to maintain speed, decelerate, or otherwise change the operation of the vehicle to limit stops and waiting times at the intersection
	Vehicle Operator	Continues safely through the intersection with reduced delay
Post-Conditions	• The vehicle operator is more aware of conditions at the intersection • The vehicle operator experiences less delay, saves fuel, reduces carbon dioxide emissions, and increases their overall satisfaction with their commute • CV applications are supported on vehicles that are capable of receiving SPaT data	
Inputs Summary	The vehicle OBU receives SPaT and MAP broadcasts from an RSU located at the intersection	
Output Summary	The vehicle OBU provides an audible/visual notification, alert, or warning to the vehicle driver under certain conditions	

UC1-S2: Failure Conditions	Signal Phase and Timing (SPaT)	
Scenario Objective	Demonstrate the failure of the system to provide SPaT and MAP data at an intersection	
Operational Event(s)	• SPaT and MAP messages are not broadcast from the roadside unit (RSU) to vehicles approaching the intersection • SPaT and MAP messages are not received by the vehicle OBU or are not processed properly	
User(s)	User	Role
	Vehicle Operator	Safely and efficient travel through an intersection
Key Actions and Flow of Events	Source	Key Action (Comments)
	Vehicle Operator	Approaches intersection
	RSU	Broadcasts SPaT and MAP messages
	Vehicle OBU	Does not receive SPaT and MAP messages, processes them, and determines that an alert, notification, or warning should be issued (Issuance of warning is based on data contained in the SPaT and MAP messages, as well as vehicle location and motion data obtained via GPS)
	Vehicle Operator	Does not receive alerts, notifications, or warning concerning the signal phase or timing of the intersection
	Vehicle Operator	• Continues through the intersection if a green indication is shown for that approach • Comes to a stop at the stop bar (At a hastened rate of deceleration) • Continues through the intersection with a red light indication being displayed for that approach
Post-Conditions	• The vehicle operator is not more aware of conditions at the intersection • The vehicle operator does not benefit from alerts, warnings, and notifications • The vehicle operator experiences delay, consumes more fuel, and increases their overall dissatisfaction with the commute • CV applications are not supported on vehicles that are capable of receiving SPaT data	
Inputs Summary	The vehicle OBU receives SPaT and MAP broadcasts from an RSU located at the intersection (Inputs may not be present during failure condition)	
Output Summary	The vehicle OBU provides an audible/visual notification, alert, or warning to the vehicle driver under certain conditions (Outputs may not be present during failure condition)	

6.2 USE CASE 2: TRANSIT SIGNAL PRIORITY (TSP)

UC2-S1: Normal Operations	**Transit Signal Priority (TSP)**	
Scenario Objective	Provide safe and efficient movement through intersections for transit vehicles	
Operational Event(s)	Signal priority is granted to the transit vehicle operator	
User(s)	User	Role
	Transit Vehicle Operator	Quickly and safely traverse an intersection to improve mobility
Key Actions and Flow of Events	Source	Key Action (Comments)
	Transit Vehicle Operator	Approaches an intersection
	Transit Vehicle OBU	Broadcasts the SRM containing data elements that indicate the requested approach
	RSU	Receives the SRM and processes it
	Message Handler/Processor	Determines if signal priority request can be accommodated
	RSU	Broadcasts the SSM containing data elements that indicated if the request was accepted and the priority order
	Transit Vehicle OBU	Receives the SSM and processes it
	Transit Vehicle OBU	Receives notification if the priority request has been granted, not granted, or revoked
	General	The green indication for the approach is called early or extended by the traffic signal controller
	Transit Vehicle Operator	Proceeds through the intersection safely
	General	The traffic signal controller resumes normal intersection operation
Post-Conditions	• Transit vehicle operator is more aware of signal priority while approaching the intersection • Transit vehicle proceeds through the intersection safely and efficiently with less delays	
Inputs Summary	The transit vehicle OBU receives SSM broadcasts from a RSU located at the intersection	
Output Summary	• The transit vehicle OBU sends SRM broadcasts to a RSU located at the intersection • The transit vehicle OBU provides an audible/visual notification to the vehicle driver under certain conditions if priority is granted, not granted, or revoked	

UC2-S2: Failure Conditions	Transit Signal Priority (TSP)	
Scenario Objective	Demonstrate the failure of the application to move transit vehicles safely and efficiently through intersections along the system corridor	
Operational Event(s)	Signal priority is not granted to the transit vehicle operator	
User(s)	User	Role
	Transit Vehicle Operator	Quickly and safely traverse an intersection to improve mobility
Key Actions and Flow of Events	Source	Key Action (Comments)
	Transit Vehicle Operator	Approaches an intersection
	Transit Vehicle OBU	Broadcasts the SRM containing data elements that indicate the requested approach
	RSU	Does not receive the SRM and processes it
	Message Handler/Processor	Does not determine if signal priority request can be accommodated
	RSU	Does not broadcast the SSM containing data elements that indicated if the request was accepted and the priority order
	Transit Vehicle OBU	Does not receive the SSM and processes it
	Transit Vehicle OBU	Does not receive notification if the priority request has been granted, not granted, or revoked
	General	The traffic signal controller continues to control the indications of the intersection
	Transit Vehicle Operator	Waits for their signal indication to turn green
	General	The traffic signal controller turns the green indication on for the approach
	Transit Vehicle Operator	Proceeds through the intersection safely
	General	The traffic signal controller continues normal operation
Post-Conditions	• The transit vehicle operator waits their turn for their approach to turn green and does not benefit from having priority at the intersection • Bus arrival and departure times fluctuate due to the unpredictability of the traffic signals • Vehicle operator does not benefit from notifications that would have been provided by the OBU	
Inputs Summary	The transit vehicle OBU receives SSM broadcasts from a RSU located at the intersection (Inputs may not be present during failure condition)	
Output Summary	• The transit vehicle OBU sends SRM broadcasts to a RSU located at the intersection (Outputs may not be present during failure condition) • The transit vehicle OBU provides an audible/visual notification to the vehicle driver under certain conditions if priority is granted, not granted, or revoked (Outputs may not be present during failure condition)	

6.3 USE CASE 3: PEDESTRIAN IN SIGNALIZED CROSSWALK WARNING (PSCW)

UC3-S1: Normal Operations	**Pedestrian in Signalized Crosswalk Warning**	
Scenario Objective	• Improve awareness of pedestrians to vehicle operators • Notify and warn vehicle operators when their path of travel is across a crosswalk with a pedestrian in it	
Operational Event(s)	• The system properly determines there is a pedestrian in the path of a vehicle • The system properly notifies the vehicle operator of a pedestrian in the path of the vehicle	
User(s)	User	Role
	Pedestrian	Safely traverse the crosswalk at the intersection
	Vehicle Operator	Safely navigate through the intersection
Key Actions and Flow of Events	Source	Key Action (Comments)
	General	Traffic signal controller turns the green signal indication for an approach on
	General	Traffic signal controller simultaneously turns the walk signal indication for the crosswalk on
	Pedestrian	Begins to cross the crosswalk
	Vehicle Operator	Enters the intersection with the intent of turning and waits for opposing traffic to clear
	General	The system detects the presence of a pedestrian in the crosswalk
	General	The system issues a notification to the vehicle operator that there is a pedestrian in the crosswalk
	Pedestrian	Continues to cross the crosswalk
	Vehicle Operator	Receives notification of a pedestrian in the crosswalk. Continues to wait after the opposing traffic has cleared
	Pedestrian	Clears the crosswalk
	General	The system ceases the notification to the vehicle operator
	Vehicle Operator	Completes the left turn maneuver
Post-Conditions	• The pedestrian crosses the crosswalk safely • The vehicle completes the turn movement at the intersection without compromising the safety of the pedestrian	
Inputs Summary	• Detection of pedestrians • The vehicle OBU receives SPaT, MAP, and TIM broadcasts from an RSU located at the intersection	
Output Summary	The vehicle OBU provides an audible/visual warning to the vehicle driver under certain conditions	

UC3-S2: Failure Conditions	Pedestrian in Signalized Crosswalk Warning	
Scenario Objective	Demonstrate the failure of the system of provide notifications to the vehicle driver concerning a pedestrian in the crosswalk along the vehicle path	
Operational Event(s)	Notifications are not issued to the vehicle operator	
User(s)	User	Role
	Pedestrian	Safely traverse the crosswalk at the intersection
	Vehicle Operator	Safely navigate through the intersection
Key Actions and Flow of Events	Source	Key Action (Comments)
	General	Traffic signal controller turns the green signal indication for an approach on
	General	Traffic signal controller simultaneously turns the walk signal indication for the crosswalk on
	Pedestrian	Begins to cross the crosswalk
	Vehicle Operator	Enters the intersection with the intent of turning and waits for opposing traffic to clear
	General	The system does not detect the presence of a pedestrian in the crosswalk
	General	The system does not issue a notification to the vehicle operator that there is a pedestrian in the crosswalk
	Pedestrian	Continues to cross the crosswalk
	Vehicle Operator	Does not receive notification of a pedestrian in the crosswalk. Continues to wait after the opposing traffic has cleared
	Vehicle Operator	• Continues to wait after the opposing traffic has cleared • Starts to proceed once the opposing traffic has cleared
	Pedestrian	Clears the crosswalk
	Vehicle Operator	Completes the left turn maneuver
Post-Conditions	• The pedestrian crosses the crosswalk safely • The vehicle completes the turn movement at the intersection without compromising the safety of the pedestrian	
Inputs Summary	• Detection of pedestrians (Inputs may not be present during failure condition) • The vehicle OBU receives SPaT, MAP, and TIM broadcasts from an RSU located at the intersection (Inputs may not be present during failure condition)	
Output Summary	The vehicle OBU provides an audible/visual warning to the vehicle driver under certain conditions (Outputs may not be present during failure condition)	

6.4 USE CASE 4: MOBILE ACCESSIBLE PEDESTRIAN SIGNAL SYSTEM (PED-SIG)

UC4-S1: Normal Operations	**Mobile Accessible Pedestrian Signal System (PED-SIG)**	
Scenario Objective	Improve the ability of the pedestrian to safely cross the intersection	
Operational Event(s)	• The pedestrian application must place a request for service • The pedestrian application must provide confirmation that a request for service has been acknowledged • The pedestrian application must provide notification and alerts to the pedestrians concerning encroaching vehicles, travelling outside of the crosswalk, and whether the pedestrian has the right to proceed in the crosswalk	
User(s)	User	Role
	Pedestrian	Safely traverse the crosswalk at the intersection
	Vehicle Operator	Safely navigate through the intersection
Key Actions and Flow of Events	Source	Key Action (Comments)
	Pedestrian	Approaches the intersection
	Pedestrian	A request for service is placed via the pedestrian application
	General	A confirmation is provided to the pedestrian that their request has been acknowledged
	General	Traffic signal controller turns the green signal indication for an approach on
	General	Traffic signal controller simultaneously turns the walk signal indication for the crosswalk on
	General	A notification through the pedestrian application is provided to the pedestrian that they now have the right of way and may begin to cross
	Pedestrian	Begins to cross the crosswalk
	Vehicle Operator	Enters the intersection with the intent of turning and waits for opposing traffic to clear
	Pedestrian	Continues to cross the crosswalk
	Vehicle Operator	• Notices the pedestrian in the crosswalk and continues to wait after the opposing traffic has cleared • Does not notice the pedestrian in the crosswalk and proceeds to complete the vehicle turning movement once the opposing traffic has cleared
	Pedestrian	Receives a notification if a vehicle is encroaching on them
	Pedestrian	Receives an alert if they travel outside of the marked crosswalk
	Pedestrian	Clears the crosswalk

	Vehicle Operator	Completes the left turn maneuver
Post-Conditions	• The pedestrian is notified if a vehicle is encroaching on them • The pedestrian is alerted if they begin to wander outside of the designated crosswalk area • The pedestrian receives confirmation that their service request has been received and acknowledged	
Inputs Summary	• Detection of pedestrians • Pedestrian application provides a request for service to the traffic signal controller	
Output Summary	Pedestrian application provides an audible/visual notification or alert to the pedestrian under certain conditions	

UC4-S2: Failure Conditions	Mobile Accessible Pedestrian Signal System (PED-SIG)	
Scenario Objective	Demonstrate the failure of the system of provide notifications and alerts to pedestrians attempting to cross at an intersection	
Operational Event(s)	Notifications and alerts are not issued to the pedestrian	
User(s)	User	Role
	Pedestrian	Safely traverse the crosswalk at the intersection
	Vehicle Operator	Safely navigate through the intersection
Key Actions and Flow of Events	Source	Key Action (Comments)
	Pedestrian	Approaches the intersection
	Pedestrian	A request for service is not placed via the pedestrian application. Pedestrian must push the push button at the intersection to request service
	General	A confirmation is not provided to the pedestrian that their request has been acknowledged
	General	Traffic signal controller turns the green signal indication for an approach on
	General	Traffic signal controller simultaneously turns the walk signal indication for the crosswalk on
	General	A notification through the pedestrian application is not provided to the pedestrian that they now have the right of way and may begin to cross
	Pedestrian	Begins to cross the crosswalk
	Vehicle Operator	Enters the intersection with the intent of turning and waits for opposing traffic to clear
	Pedestrian	Continues to cross the crosswalk
	Vehicle Operator	• Notices the pedestrian in the crosswalk and continues to wait after the opposing traffic has cleared • Does not notice the pedestrian in the crosswalk and proceeds to complete the vehicle turning movement once the opposing traffic has cleared
	Pedestrian	Does not receive a notification if a vehicle is encroaching on them
	Pedestrian	Does not receive an alert if they travel outside of the marked crosswalk

	Pedestrian	Clears the crosswalk
	Vehicle Operator	Completes the left turn maneuver
Post-Conditions	• The pedestrian does not benefit from notifications and alerts • The pedestrian does not receive confirmation that their request for service has been acknowledged	
Inputs Summary	• Detection of pedestrians (Inputs may not be present during failure condition) • Pedestrian application provides a request for service to the traffic signal controller (Inputs may not be present during failure condition)	
Output Summary	Pedestrian application provides an audible/visual notification or alert to the pedestrian under certain conditions (Outputs may not be present during failure condition)	

6.5 USE CASE 5: INTELLIGENT TRAFFIC SIGNAL SYSTEM (I-SIG)

UC5-S1: Normal Operations	**Intelligent Traffic Signal System (I-SIG)**	
Scenario Objective	Roadway users traverse through the intelligent traffic signal system	
Operational Event(s)	• Vehicle operators travel through intersections within the system • Transit vehicle operators maintain bus routes throughout the system and are given priority • Pedestrians and cyclists utilize crosswalks to cross the intersection and roadways utilizing pedestrian assistance applications • Central ATMS software intelligently monitors the system, priority requests, pedestrian requests, and other factors to optimize the efficiency and maximize the flow of the system	
User(s)	User	Role
	Vehicle Operator	Safely navigate through the signal system
	Transit Vehicle Operator	Safely navigate through the signal system
	Pedestrian	Safely traverse the crosswalk at the intersection
Key Actions and Flow of Events	Source	Key Action (Comments)
	Vehicle Operator	Approaches the intersection
	General	The traffic signal controller detects the vehicle and places a demand on that approach
	Transit Vehicle Operator	Approaches the intersection
	General	The traffic signal controller receives a request for priority from the transit vehicle
	Pedestrian	Approaches the intersection
	General	The traffic signal controller receives a request for service from the pedestrian application
	Pedestrian	The pedestrian presses the push button to request service
	General	The ATMS system determines the best course of action to take to optimize efficiency and flow of the system
	General	The traffic signal controller • Continues timing the current approach • Terminates the current approach early • Gives signal priority to the transit vehicle • Gives priority to the pedestrian
	Vehicle Operator	The vehicle safely travels through the intersection

	Transit Vehicle Operator	The vehicle safely travels through the intersection
	Pedestrian	Safely crosses the intersection
	General	The ATMS system reevaluates to determines the best course of action to take to optimize efficiency and flow of the system
Post-Conditions	• Vehicle operators travel safely and efficiently through the system • Transit vehicles receive priority and experience reduced delays and stops • Pedestrians are more aware of their priority and are served more efficiently • System performance increases as well as the safety of the users	
Inputs Summary	• Transit priority requests are sent from transit vehicles • Pedestrian requests are received from pedestrian applications • High resolution data is generated by the traffic signal controller • Data received by RSUs is collected and processed	
Output Summary	• Issue transit priority requests or revoke priority requests • Change timing plans as required due to changing demands • Terminate phases early as necessary to optimize the system	

UC5-S2: Failure Conditions	Intelligent Traffic Signal System (I-SIG)	
Scenario Objective	Demonstrate the failure to intelligently monitor and optimize system performance	
Operational Event(s)	• Vehicle operators travel through intersections within the system • Transit vehicle operators do not receive priority • Pedestrians and cyclists utilize crosswalks to cross the intersection without the assistance of pedestrian applications	
User(s)	User	Role
	Vehicle Operator	Safely navigate through the signal system
	Transit Vehicle Operator	Safely navigate through the signal system
	Pedestrian	Safely traverse the crosswalk at the intersection
Key Actions and Flow of Events	Source	Key Action (Comments)
	Vehicle Operator	Approaches the intersection
	General	The traffic signal controller detects the vehicle and places a demand on that approach
	Transit Vehicle Operator	Approaches the intersection
	General	The traffic signal controller receives a request for priority from the transit vehicle
	Pedestrian	Approaches the intersection
	General	The traffic signal controller receives a request for service from the pedestrian application
	Pedestrian	The pedestrian presses the push button to request service
	General	The ATMS system does not determine the best course of action to take to optimize efficiency and flow of the system
	General	The traffic signal controller continues timing the current approach while demand is present and based on time of day plans
	General	The traffic signal controller cycles to the next approach in the sequence
	Vehicle Operator	The vehicle safely travels through the intersection
	Transit Vehicle Operator	The vehicle safely travels through the intersection
	Pedestrian	Safely crosses the intersection
	General	The ATMS system reevaluates to determines the best course of action to take to optimize efficiency and flow of the system
Post-Conditions	• Vehicles are serviced depending on other demands at the location as well as their place in line	

	• Transit vehicles are serviced depending on other demands at the location as well as their place in line • Pedestrians are serviced depending on other demands at the location as well as their place in line • Users do not benefit from increased optimization, efficiency, and safety
Inputs Summary	• Transit priority requests are sent from transit vehicles (Inputs may not be present during failure condition) • Pedestrian requests are received from pedestrian applications (Inputs may not be present during failure condition) • High resolution data is generated by the traffic signal controller (Inputs may not be present during failure condition) • Data received by RSUs is collected and processed (Inputs may not be present during failure condition)
Output Summary	• Issue transit priority requests or revoke priority requests (Outputs may not be present during failure condition) • Change timing plans as required due to changing demands • Terminate phases early as necessary to optimize the system

6.6 USE CASE 6: RED LIGHT VIOLATION WARNING (RLVW)

UC6-S1: Normal Operations	**Red Light Violation Warning (RLVW)**	
Scenario Objective	Provide the vehicle operator with a warning when they must prepare to stop prior to a traffic signal turning red	
Operational Event(s)	• Intersection broadcasts SPaT and MAP messages that are received by the vehicle • The vehicle receives SPaT and MAP messages and determines if a red-light running event is imminent	
User(s)	User	Role
	Vehicle Operator	Safely come to a stop at a red signal indication. Proceed through intersection without running a red light
Key Actions and Flow of Events	Source	Key Action (Comments)
	General	The vehicle approaches an intersection with a green signal indication
	RSU	Broadcasts SPaT and MAP messages containing data elements that indicate intersection geometry and signal state information
	Vehicle OBU	Receives SPaT and MAP messages, processes them, and determines that a warning should be issued (Issuance of warning is based on data contained in the SPaT and MAP messages, as well as vehicle location and motion data obtained via GPS)
	Vehicle Operator	Receives a warning indicating the signal indication will turn yellow (Prior to entering the dilemma zone)
	Vehicle Operator	Reacts to warning by decelerating
	General	The signal indication turns yellow
	General	The signal indication turns red
	Vehicle Operator	The vehicle comes to a stop at the stop bar
Post-Conditions	• Vehicle operator is more aware of the signal state while approaching the intersection • Vehicle operator properly reacts to the in-vehicle warning	
Inputs Summary	The vehicle OBU receives SPaT and MAP broadcasts from an RSU located at the intersection	
Output Summary	The vehicle OBU provides an audible/visual warning to the vehicle driver under certain conditions	

UC6-S2: Failure Conditions	Red Light Violation Warning (RLVW)	
Scenario Objective	Demonstrate the failure of the application to provide a warning to the vehicle operator	
Operational Event(s)	Warnings are not issued to the vehicle operator	
User(s)	User	Role
	Vehicle Operator	Safely come to a stop at a red signal indication. Proceed through intersection without running a red light
Key Actions and Flow of Events	Source	Key Action (Comments)
	General	The vehicle approaches an intersection with a green signal indication
	RSU	Broadcasts SPaT and MAP messages containing data elements that indicate intersection geometry and signal state information
	Vehicle OBU	• The vehicle OBU does not receive the messages • The vehicle OBU does not process the messages correctly
	Vehicle Operator	Does not receive a warning indicating the signal indication will turn yellow (Prior to entering the dilemma zone)
	General	The signal indication turns yellow
	Vehicle Operator	Reacts to the signal indication turning yellow by either decelerating or continuing at speed through the intersection
	General	The signal indication turns red
	Vehicle Operator	The vehicle operator comes to a stop at the stop bar (At a hastened rate of deceleration)
	Vehicle Operator	The vehicle operator decides to continue through the intersection with a red light indication being displayed for that approach
Post-Conditions	• Vehicle operator must identify the safety-critical situation and react accordingly • Vehicle operator may not make the correct decision in the dilemma zone • Vehicle operator does not benefit from warnings that would have been provided by the OBU	
Inputs Summary	The vehicle OBU receives SPaT and MAP broadcasts from an RSU located at the intersection (Inputs may not be present during failure condition)	
Output Summary	The vehicle OBU provides an audible/visual warning to the vehicle driver under certain conditions (Outputs may not be present during failure condition)	

6.7 USE CASE 7: SPEED WARNING (SW)

UC7-S1: Normal Operations	**Speed Warning**	
Scenario Objective	Provide the vehicle operator with a warning when the vehicle speed exceeds a threshold	
Operational Event(s)	• Intersection broadcasts SPaT, MAP, and TIM messages that are received by the vehicle • The vehicle receives SPaT, MAP, and TIM messages to determine if the vehicle operator needs to decrease speed	
User(s)	User	Role
	Vehicle Operator	Monitor and control vehicle speed to ensure the vehicle is moving at a safe speed
Key Actions and Flow of Events	Source	Key Action (Comments)
	Vehicle Operator	Approaches a corridor with a speed limit
	RSU	Broadcasts SPaT, MAP, and TIM messages containing data elements that indicate intersection geometry and signal state information
	Vehicle OBU	Receives SPaT, MAP, and TIM messages, processes them, and determines that a warning should be issued (Issuance of warning is based on data contained in the SPaT, MAP, and TIM messages, as well as vehicle location and motion data obtained via GPS)
	Vehicle Operator	Receives a warning indicating the vehicle speed currently exceeds the speed limit for the roadway
	Vehicle Operator	Reacts to warning by decelerating while the warning is active
	Vehicle Operator	The vehicle speed drops to below the maximum limit. The warning ceases and the vehicle operator stops decelerating
	Vehicle Operator	The vehicle continues at the appropriate speed
Post-Conditions	• Vehicle operator is more aware of speed while traveling through the system • Vehicle operator properly reacts to the in-vehicle warning • Vehicle operator safely travels through the system	
Inputs Summary	The vehicle OBU receives SPaT, MAP, and TIM broadcasts from an RSU located at the intersection	
Output Summary	The vehicle OBU provides an audible/visual warning to the vehicle driver under certain conditions	

UC7-S2: Failure Conditions	Speed Warning	
Scenario Objective	Demonstrate the failure of the application to provide a warning to the vehicle operator	
Operational Event(s)	Warnings are not issued to the vehicle operator	
User(s)	User	Role
	Vehicle operator	Monitor and control vehicle speed to ensure the vehicle is moving at a safe speed
Key Actions and Flow of Events	Source	Key Action (Comments)
	Vehicle Operator	Approaches a corridor with a speed limit
	RSU	Broadcasts SPaT, MAP, and TIM messages containing data elements that indicate intersection geometry and signal state information
	Vehicle OBU	• The vehicle OBU does not receive the messages • The vehicle OBU does not process the messages correctly
	Vehicle Operator	Does not receive a warning indicating the vehicle speed currently exceeds the speed limit for the roadway
	Vehicle Operator	Recognizes the maximum speed limit for the roadway and decelerates the vehicle if necessary.
	Vehicle Operator	Does not recognize the maximum speed limit for the roadway. Maintains a speed above the maximum limit or continues to accelerate
Post-Conditions	• Vehicle operator must identify the safety-critical situation and adjust the speed of the vehicle accordingly • Vehicle operator may not recognize the speed limit of the roadway and travel at unsafe speeds • Vehicle operator does not benefit from warnings that would have been provided by the OBU	
Inputs Summary	The vehicle OBU receives SPaT, MAP, and TIM broadcasts from an RSU located at the intersection (Inputs may not be present during failure condition)	
Output Summary	The vehicle OBU provides an audible/visual warning to the vehicle driver under certain conditions (Outputs may not be present during failure condition)	

6.8 USE CASE 8: TRAVELER INFORMATION MESSAGE (TIM)

UC8-S1: Normal Operations	**Traveler Information Message (TIM)**	
Scenario Objective	Provide the vehicle operator with notifications and alerts with pertinent information	
Operational Event(s)	• Intersection broadcasts SPaT, MAP, and TIM messages that are received by the vehicle • The vehicle receives SPaT, MAP, and TIM messages and alerts the vehicle driver	
User(s)	User	Role
	Vehicle Operator	Monitor and control vehicle to ensure the vehicle is travelling safely through the system
Key Actions and Flow of Events	Source	Key Action (Comments)
	Vehicle Operator	Approaches an intersection
	General	Appropriate signage is in place for the location
	RSU	Broadcasts SPaT, MAP, and TIM messages containing data elements that indicate intersection geometry, signal state information, and other pertinent information
	Vehicle OBU	Receives SPaT, MAP, and TIM messages, processes them, and determines that a notification or alert should be issued (Issuance of warning is based on data contained in the SPaT, MAP, and TIM messages, as well as vehicle location and motion data obtained via GPS)
	Vehicle Operator	Receives a notification concerning important information for drivers
	Vehicle Operator	Receives an alert about urgent information such as impending weather events and amber alerts
	Vehicle Operator	Reacts to notification or alert by slowing the vehicle and becoming more attentive while the warning is active
	Vehicle Operator	The vehicle exits the intersection. The vehicle continues at the appropriate speed
Post-Conditions	• Vehicle operator is more aware of important information • Vehicle operator properly reacts to the in-vehicle notification or alerts • Vehicle operator safely travels through the intersection	
Inputs Summary	The vehicle OBU receives SPaT, MAP, and TIM broadcasts from an RSU located at the intersection	
Output Summary	The vehicle OBU provides an audible/visual notification or alert to the vehicle driver under certain conditions	

UC8-S2: Failure Conditions	Traveler Information Message (TIM)	
Scenario Objective	Demonstrate the failure of the application to provide a notification or alert to the vehicle operator	
Operational Event(s)	Notifications and alerts are not issued to the vehicle operator	
User(s)	User	Role
	Vehicle Operator	Monitor and control vehicle to ensure the vehicle is travelling safely through the system
Key Actions and Flow of Events	Source	Key Action (Comments)
	Vehicle Operator	Approaches an intersection
	General	Appropriate signage is in place for the location
	RSU	Does not broadcast SPaT, MAP, and TIM messages containing data elements that indicate intersection geometry, signal state information, and other pertinent information
	Vehicle OBU	Does not receive SPaT, MAP, and TIM messages, processes them, and determines that a notification or alert should be issued (Issuance of warning is based on data contained in the SPaT, MAP, and TIM messages, as well as vehicle location and motion data obtained via GPS)
	Vehicle Operator	Does not receive a notification concerning important information for drivers
	Vehicle Operator	Does not receive an alert about urgent information such as impending weather events and amber alerts
	Vehicle Operator	Must recognize any special circumstances or conditions at the location
	Vehicle Operator	Travels through the intersection safely
Post-Conditions	• Vehicle operator must identify safety-critical situations and take steps necessary to traverse the intersection in a safe manner • Vehicle operator may not recognize special conditions at the intersection and travel at unsafe speeds • Vehicle operator may not recognize safety-critical situations and fail to traverse through the intersection in a safe manner • Vehicle operator does not benefit from notifications and alerts that would have been provided by the OBU	
Inputs Summary	The vehicle OBU receives SPaT, MAP, and TIM broadcasts from an RSU located at the intersection (Inputs may not be present during failure condition)	
Output Summary	The vehicle OBU provides an audible/visual warning to the vehicle driver under certain conditions (Outputs may not be present during failure condition)	

6.9 USE CASE 9: HIGH RESOLUTION DATA (HRD)

UC9-S1: Normal Operations	**High Resolution Data**	
Scenario Objective	Provide high resolution data to transportation engineers	
Operational Event(s)	Data concerning signal states, detector states, and other items are stored by the controller unit every one tenth of a second and automatically uploaded to the TMC	
User(s)	User	Role
	TMC Operators	Monitor the daily operation of the signal system
	Transportation Engineers	Monitor the signal system and generate timing plans as needed including for special events, work zones, and seasonal traffic
	Vehicle Operators	Safely navigate through the intersection
Key Actions and Flow of Events	Source	Key Action (Comments)
	General	Traffic signal controller controls the intersection signal displays
	General	Traffic signal controller logs data on signal states, detector inputs, and other items every one tenth of a second
	General	High resolution data logs are transmitted automatically to the TMC
	General	TMC systems automatically retrieve the high resolution data, format it, and store it in a database style server for future use
	TMC Operators	Operators are able to monitor the performance of the intersection in nearly real-time and make adjustments to timing as necessary and identify issues faster
	Transportation Engineers	Real-time and historical data is used to generate better timing plans and quantify the performance of different countermeasures that are implemented
	Vehicle Operators	Experience less delays from a more optimized system with less equipment failure downtime
Post-Conditions	• High resolution data is archived for future use • Data about detectors, signal states, pedestrian accommodations, as well as priority and preemption requests is logged • Vehicle operators benefit from a more optimized system with less equipment failure downtime • Transportation engineers have access to more data to make better decisions	
Inputs Summary	High resolution data about signal states, detector states, and other items is stored by the traffic signal controller every one tenth of a second	
Output Summary	High resolution data logs are uploaded to the TMC and stored for future use	

UC9-S2: Failure Conditions	High Resolution Data	
Scenario Objective	Demonstrate the failure of the system to log high resolution data	
Operational Event(s)	High resolution data is either not stored by the controller, not transmitted to the TMC reliably, or not archived properly at the TMC	
User(s)	User	Role
	TMC Operators	Monitor the daily operation of the signal system
	Transportation Engineers	Monitor the signal system and generate timing plans as needed including for special events, work zones, and seasonal traffic
	Vehicle Operators	Safely navigate through the intersection
Key Actions and Flow of Events	Source	Key Action (Comments)
	General	Traffic signal controller controls the intersection signal displays
	General	Traffic signal controller fails to log data on signal states, detector inputs, and other items every one tenth of a second
	General	High resolution data logs are not transmitted to the TMC
	General	TMC systems do not retrieve the high resolution data, format it, and store it in a database style server for future use
	TMC Operators	Operators are not able to monitor the performance of the intersection in nearly real-time and make adjustments to timing as necessary and identify issues faster. Download logs from the intersection either manually or by scheduled events
	Transportation Engineers	Real-time and historical data is not available for use in generating better timing plans and quantify the performance of different countermeasures that are implemented.
	Vehicle Operators	Does not benefit from a more optimized system with less equipment failure downtime
Post-Conditions	• High resolution data is not archived for future use • Data about detectors, signal states, pedestrian accommodations, as well as priority and preemption requests is not logged • Vehicle operators do not benefit from a more optimized system with less equipment failure downtime • Transportation engineers do not have access to more data to make better decisions	
Inputs Summary	High resolution data about signal states, detector states, and other items is stored by the traffic signal controller every one tenth of a second (Inputs may not be present during failure condition)	
Output Summary	High resolution data logs are uploaded to the TMC and stored for future use (Outputs may not be present during failure condition)	

6.10 USE CASE 10: AUTOMATED TRAFFIC SIGNAL PERFORMANCE MEASURES (ATSPM)

UC10-S1: Normal Operations	**Automated Traffic Signal Performance Measures**	
Scenario Objective	Monitor system performance with signal performance measures available	
Operational Event(s)	System performance is monitored and optimized	
User(s)	User	Role
	Transportation Engineers	Monitor the signal system and generate timing plans as needed including for special events, work zones, and seasonal traffic
Key Actions and Flow of Events	Source	Key Action (Comments)
	General	High resolution data from the intersection is generated, stored, transmitted, and archived for use
	Transportation Engineer	Use reporting tools and software to access the stored historical data to evaluate the performance of the intersection by itself and within the system
	Transportation Engineer	Makes adjustments to timing and phasing based on the generated performance measures to optimize and enhance operation of the intersection
	Transportation Engineer	Monitors the real-time high resolution data to evaluate the effectiveness of changes
	Transportation Engineer	Monitors historical and seasonal trends with archived data to optimize system performance and increase safety
Post-Conditions	• Timing plans are generated when necessary • Timing plan efficiency is continuously verified • Timing plans are proactively adjusted • Engineer is aware of a problem before a complaint is issued	
Inputs Summary	High resolution data about signal states, detector states, and other items is archived	
Output Summary	Reporting tools and software generate reports and graphs concerning performance measures	

UC10-S2: Failure Conditions	Automated Traffic Signal Performance Measures	
Scenario Objective	Demonstrate the failure of the system to provide signal performance measures	
Operational Event(s)	System performance is monitored and optimized	
User(s)	User	Role
	Transportation Engineers	Monitor the signal system and generate timing plans as needed including for special events, work zones, and seasonal traffic
Key Actions and Flow of Events	Source	Key Action (Comments)
	General	High resolution data from the intersection is not generated, stored, transmitted, or archived for use
	Transportation Engineer	Can't use reporting tools and software to access the stored historical data to evaluate the performance of the intersection by itself and within the system
	Transportation Engineer	Schedules system or location to have counts performed
	Transportation Engineer	Uses the count information to generate new timing plans for the intersection
	Transportation Engineer	Can't monitor the real-time high resolution data to evaluate the effectiveness of changes
	Transportation Engineer	Monitors the intersection and system for performance quality
	Transportation Engineer	Can't monitor historical and seasonal trends with archived data to optimize system performance and increase safety
	Transportation Engineer	Responds to complaints from citizens concerning efficiency of timing plans
	Transportation Engineer	Retime the intersection on a scheduled time frame
Post-Conditions	• Timing plans are generated on a predetermined schedule • Timing plan efficiency is not verified outside of the limited time spent on-site by the engineer • Timing plans are not proactively adjusted • Engineer is not aware of a problem until a complaint is issued	
Inputs Summary	High resolution data about signal states, detector states, and other items is archived (Inputs may not be present during failure condition)	
Output Summary	Reporting tools and software generate reports and graphs concerning performance measures (Outputs may not be present during failure condition)	

6.11 USE CASE 11: WORK ZONE WARNING (WZW)

UC11-S1: Normal Operations	**Work Zone Warning**	
Scenario Objective	Provide the vehicle operator with notifications and alerts when they are approaching a work zone	
Operational Event(s)	• Intersection broadcasts SPaT, MAP, and TIM messages that are received by the vehicle • The vehicle receives SPaT, MAP, and TIM messages and alerts the vehicle driver of a work zone	
User(s)	User	Role
	Vehicle Operator	Monitor and control vehicle speed to ensure the vehicle is moving at a safe speed
Key Actions and Flow of Events	Source	Key Action (Comments)
	Vehicle Operator	Approaches a work zone
	RSU	Broadcasts SPaT, MAP, and TIM messages containing data elements that indicate intersection geometry, signal state information, and information about work zone
	Vehicle OBU	Receives SPaT, MAP, and TIM messages, processes them, and determines that a notification or alert should be issued (Issuance of warning is based on data contained in the SPaT, MAP, and TIM messages, as well as vehicle location and motion data obtained via GPS)
	Vehicle Operator	Receives a notification indicating the vehicle is approaching a work zone
	Vehicle Operator	Receives an alert if the vehicle speed if in excess of the posted work zone speed limit
	Vehicle Operator	Reacts to notification or alert by slowing the vehicle and becoming more attentive while the warning is active
	Vehicle Operator	The vehicle exits the work zone. The vehicle continues at the appropriate speed
Post-Conditions	• Vehicle operator is more aware of the work zone • Vehicle operator properly reacts to the in-vehicle notification or alerts • Vehicle operator safely travels through the work zone • Workers in the work zone can go home safe and spend quality time with their family	
Inputs Summary	The vehicle OBU receives SPaT, MAP, and TIM broadcasts from an RSU located at the intersection	
Output Summary	The vehicle OBU provides an audible/visual notification or alert to the vehicle driver under certain conditions	

UC11-S2: Failure Conditions	Work Zone Warning	
Scenario Objective	Demonstrate the failure of the application to provide a notification or alert to the vehicle operator	
Operational Event(s)	Notifications and alerts are not issued to the vehicle operator	
User(s)	User	Role
	Vehicle Operator	Monitor and control vehicle speed to ensure the vehicle is moving at a safe speed
Key Actions and Flow of Events	Source	Key Action (Comments)
	Vehicle Operator	Approaches a work zone
	RSU	Broadcasts SPaT, MAP, and TIM messages containing data elements that indicate intersection geometry, signal state information, and information about work zone
	Vehicle OBU	• The vehicle OBU does not receive the messages • The vehicle OBU does not process the messages correctly
	Vehicle Operator	Does not receive a notification indicating the vehicle is approaching a work zone
	Vehicle Operator	Does not receive an alert if the vehicle speed if in excess of the posted work zone speed limit
	Vehicle Operator	Recognizes the work zone and takes the necessary steps to traverse through the work zone safely
	Vehicle Operator	• Does not recognize the work zone • Fails to take the necessary steps to traverse through the work zone safely • May continue through the work zone at speeds above the work zone speed limits
Post-Conditions	• Vehicle operator must identify the safety-critical situation and take steps necessary to traverse the work zone in a safe manner • Vehicle operator may not recognize the speed limit of the work zone and travel at unsafe speeds • Vehicle operator may not recognize the safety-critical situation and fail to traverse through the work zone in a safe manner • Vehicle operator does not benefit from notifications and alerts that would have been provided by the OBU	
Inputs Summary	The vehicle OBU receives SPaT, MAP, and TIM broadcasts from an RSU located at the intersection (Inputs may not be present during failure condition)	
Output Summary	The vehicle OBU provides an audible/visual warning to the vehicle driver under certain conditions (Outputs may not be present during failure condition)	

7 GLOSSARY OF TERMS

Term	Definition
Application	One or more pieces of software designed to perform some specific function.
Basic Safety Message (BSM)	Data broadcasted from vehicles through V2V and V2I at a frequency of 10 Hz. The core contents of a BSM are data elements that describe a vehicle's position and motion.
Concept of Operations (ConOps)	A user-oriented document that describes a system's operational characteristics from the end user's viewpoint.
Connected Vehicle (CV)	A vehicle (car, truck, bus, etc.) that is equipped with a wireless communication device. A CV uses any of the available wireless communication technologies to communicate with other cars on the road (vehicle-to-vehicle [V2V]), roadside infrastructure (vehicle-to-infrastructure [V2I]), and other travelers and the cloud.
Dedicated Short Range Communication (DSRC)	A communications protocol developed to address the safety critical issues associated with sending and receiving data among vehicles and between moving vehicles and fixed roadside access points.
Dilemma Zone	An area where drivers approaching a signalized intersection must decide, when facing a yellow indication, to either proceed through the intersection or decelerate and come to a stop
Intelligent Traffic Signal System (I-SIG)	A traffic signal system that uses data collected from vehicles through V2V and V2I communications as well as pedestrian and non-motorized travelers to control signals and maximize flows in real time. The I-SIG application also plays the role of an overarching system optimization application, accommodating transit or freight signal priority, preemption, and pedestrian movements to maximize overall network performance.
Interoperability	The ability of a system to communicate with other systems to provide the same service in different physical locations. It is also the ability of one system (or component) to replace another without degrading the service being provided.
Mobile Accessible Pedestrian Signal System (PED-SIG)	An application that allows for an automated call from a smart phone to the traffic signal, as well as cues to safely navigate the crosswalk.
On-board Equipment (OBE)	A piece of ITS related hardware that is located in a vehicle to collect data from the vehicle and/or provide an interface through which ITS services can be provided, e.g. tolls, navigation, trip planning, travel information.

Term	Definition
On-board Unit (OBU)	A piece of equipment located in a vehicle to receive and transmit data to and from other CV devices (such as a RSU or another OBU).
Pedestrian in Signalized Crosswalk Warning (Transit)	An application that warns drivers when pedestrians, within the crosswalk, are in the intended path of the vehicle.
Portable Personal Information Device	A portable device that allows the user to receive data wirelessly. For example, a smartphone.
Signal Phase and Timing (SPaT)	The signal state of the intersection and how long this state will persist for each approach and lane that is active, according to the SPaT Benefits Report. The SPaT message sends the current state of each phase, with all-red intervals not transmitted. Movements are given to specific lanes and approaches by use of the lane numbers present in the message.
Signal Request Message (SRM)	Broadcast by vehicles to request priority.
Signal Status Message (SSM)	Broadcast by roadside units (RSU) to announce pending priority requests.
Transit Signal Priority (TSP)	An application that provides signal priority to transit at intersections.
Vehicle to Infrastructure (V2I)	A communication that promotes the exchange of information between the vehicles and the infrastructure.
Vehicle to Vehicle (V2V)	A communication that promotes the exchange of information between vehicles.
Vehicle to Many (V2X)	Pronounced “vehicle to many,” a communication that promotes the exchange of information between the vehicles and various counterparts including other means of transport, the infrastructure, traffic management centers and various Internet applications.

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