NCDOT Multimodal Connected Vehicle Pilot

System Requirements Specification

01/26/2022

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Version History

Version	Date	Summary of Changes
1.0	6/9/21	Final version
1.1	1/26/22	Minor updates to requirements

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
GPS	Global Positioning System
HRD	High Resolution Data
IEEE	Institute of Electrical and Electronics Engineers
ITRE	Institution for Transportation Research and Education
I-SIG	Intelligent Signal System
MMCVP	Multimodal Connected Vehicle Pilot
MUTCD	Manual on Uniform Traffic Control Devices
NCDOT	North Carolina Department of Transportation
NCSU	North Carolina State University
OBU	On-Board Unit
PID	Personal Information Device
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
SAE	Society of Automotive Engineers
SCMS	Security Credential Management System
SOP	Standard Operating Procedure
SPaT	Signal Phase and Timing
SRM	Signal Request Message
SSM	Signal Status Message
SW	Speed Warning
THEA	Tampa Hillsborough Expressway Authority
TIM	Traveler Information Message
TMC	Traffic Management Center
TOC	Traffic Operations Center
TSMO	Transportation Systems Management and Operations
TSP	Transit Signal Priority
USDOT	United States Department of Transportation
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 THE DOCUMENT

This document describes the system requirements for the MMCVP. The Systems Requirements is one of the steps of the systems engineering process, explaining what needs to happen to meet the user needs for the pilot.

The user needs are documented in the Concept of Operations and are cross referenced throughout the document for each system requirement.

1.2 SCOPE OF THE PROJECT

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.

1.3 REFERENCES

The following table lists the references used to develop the concepts in this document.

Table 1 – References

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1	USDOT Guidance Summary for Connected Vehicle Deployments Concept of Operations and the CVRIA/SET-IT Tool, USDOT, Final Report: July 2016 https://rosap.ntl.bts.gov/view/dot/31555
2	Connected Vehicle Pilot Deployment Program Phase 1, Concept of Operations (ConOps) – Tampa (THEA), USDOT, Final Report: February 2016 https://rosap.ntl.bts.gov/view/dot/3588
3	Connected Vehicle Pilot Deployment Program Phase 1, Concept of Operations (ConOps) – New York City, USDOT, Final ConOps: April 8, 2016 https://rosap.ntl.bts.gov/view/dot/30881
4	Connected Vehicle Pilot Deployment Program Phase 1, Concept of Operations (ConOps), ICF/Wyoming, USDOT, Draft Report – December 14, 2015 https://rosap.ntl.bts.gov/view/dot/3582
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8	Raleigh Pedestrian Safety Demonstration Project: Pedestrian Crash Analysis and Needs Assessment, UNC Highway Safety Research Center, November 2011 https://www.raleighnc.gov/business/content/PlanDev/Articles/TransPlan/PedestrianProgram.html
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12	Complete Streets: Best Policy and Implementation Practices, American Planning Association, Report Number 559, April 2010 https://www.planning.org/publications/report/9026883/
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14	Manual on Pedestrian and Bicycle Connections to Transit, Federal Transit Administration, FTA Report No. 0111, August 2017 https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/64496/ftareportno0111.pdf
15	Discussion Guide for Automated and Connected Vehicles, Pedestrians, and Bicyclists, Pedestrian and Bicycle Information Center, August 2017 http://www.pedbikeinfo.org/cms/downloads/PBIC_AV_Discussion_Guide.pdf
16	Evaluation of Transit Bus Turn Warning Systems for Pedestrians and Cyclists, Federal Transit Administration, Draft Final Report, FTA Report No. 0084, May 2015 https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA_Report_No._0084.pdf
17	Transit Signal Priority with Connected Vehicle Technology, The University of Virginia, Final Report, January 2014 https://nacto.org/wp-content/uploads/2016/04/1-4_Park-Hu-Transit-Signal-Priority-with-Connected-Vehicle-Technology_2014.pdf
18	2017 Pedestrian Traffic Safety Fact Sheet, NHTSA, March 2019 https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812681
19	Automated and Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, and Pedestrian Safety, Texas A&M Transportation Institute, Concept of Operations, February 2017 https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6875-P1.pdf

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21	Accelerated Vehicle-to-Infrastructure (V2I) Safety Applications, Systems Requirement Document, FHWA, Joint Program Office, Final Report, July 2012 https://rosap.ntl.bts.gov/view/dot/26495
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23	Connected Vehicle Pilot Deployment Program Phase 1, System Requirements Specification (SyRS) – New York City, Joint Program Office, Final Report, July 2016 https://rosap.ntl.bts.gov/view/dot/31403
24	Connected Vehicle Pilot Deployment Program Phase 1 : System Requirements Specification (SyRS) : Tampa (THEA), Joint Program Office, Final Report, August 2016 https://rosap.ntl.bts.gov/view/dot/31733
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2 SYSTEM DESCRIPTION

2.1 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. Figure 1 shows the project area and Figure 2 depicts the system concept.

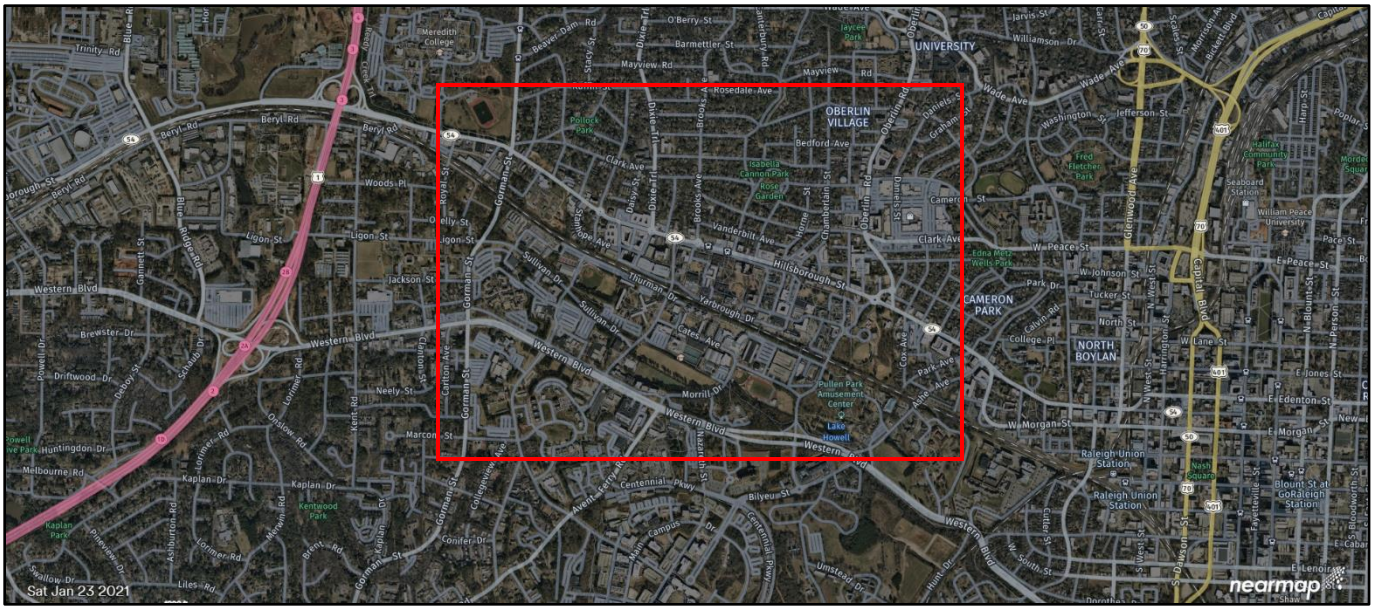

Figure 1 Project Area

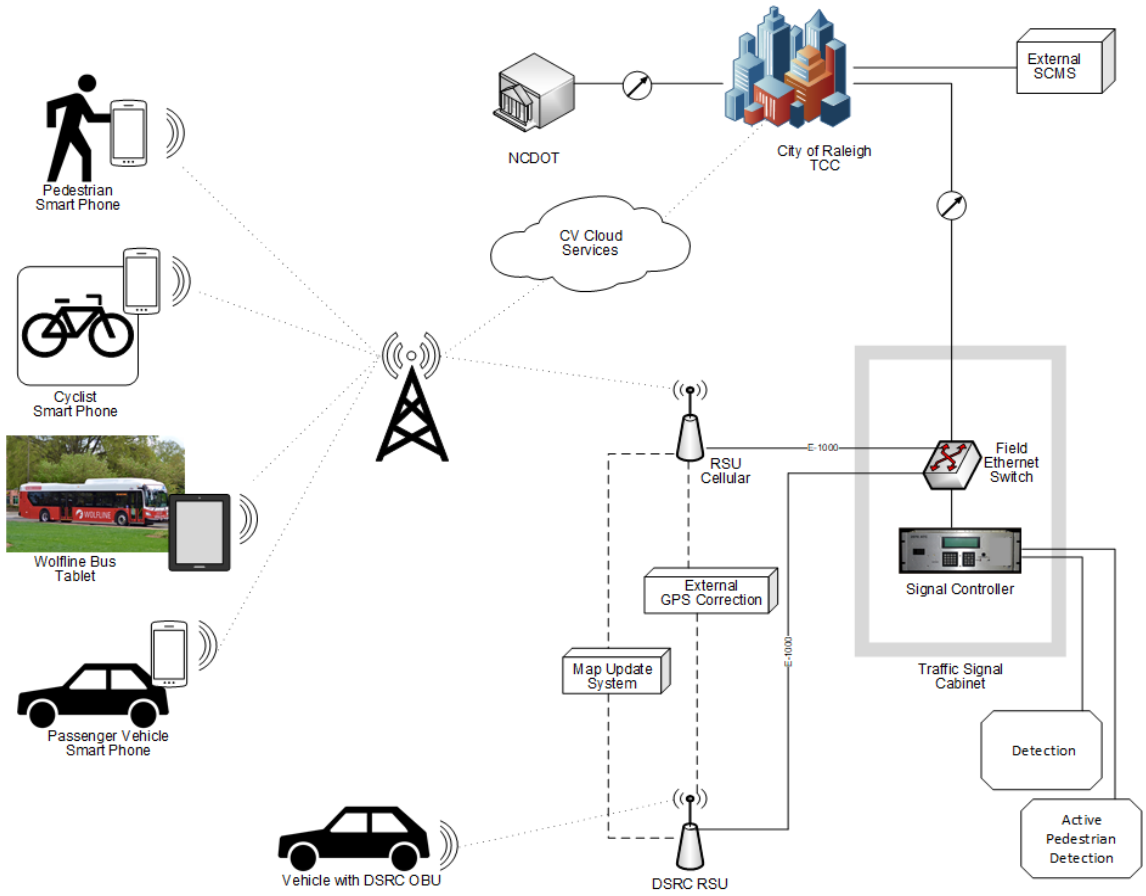

Figure 2 – System Overview

2.2 USER CHARACTERISTICS

The primary users of the system are identified below.

2.2.1 INFRASTRUCTURE OWNERS/OPERATORS

Users who own and are responsible for operating and maintaining different parts of the system:

- NCDOT – the primary manager of the project
- City of Raleigh – the owner/operator of the signal system
- NCSU – the owners of the transit system

2.2.2 ROADWAY USERS

A broad group of users who will utilize the system on a regular basis:

- Wolfline Bus Drivers – transit bus operators employed by Transdev
- Wolfline Passengers – any riders of Wolfline buses
- NCSU Students, Faculty, Visitors – as drivers, pedestrians, cyclists, or transit riders
- Governor Morehead Students, Faculty, Visitors – as drivers, pedestrians, cyclists, or transit riders
- Meredith College Students, Faculty, Visitors – as drivers, pedestrians, cyclists, or transit riders
- Motorists – any driver/operator of a motor vehicle in the project area
- Non-Motorized Vehicle Users – those riding scooters, skateboards, or other non-motorized modes of transportation
- Pedestrians – any pedestrian or individual using a wheelchair in the project area
- Cyclists – any person riding a cycle regardless of the number of wheels

2.2.3 DATA USERS

Users who will provide guidance, oversight, and monitor the data for performance measurements.

- NCDOT – use to evaluate the system for real time and project level success
- ITRE – assist with the data collection, surveying, and analysis
- City of Raleigh – use to guide decision making for signal system

2.3 ASSUMPTIONS AND DEPENDENCIES

The table below lists the known assumptions for the pilot.

Table 2 – Pilot Assumptions

Number	Assumption
1	A working Security Credential Management System (SCMS) will be available when needed by the pilot
2	Roadside units (RSUs) will by hybrid, meaning each can communicate using Direct Short Range Communication (DSRC) based on Society of Automotive Engineers (SAE) SAE J2945/1 as well as through cellular communications
3	Signal controllers and signal controller software will provide an interface to RSUs from which Signal Phase and Timing (SPaT) is retrieved
4	Signal controllers and signal controller software will output SPaT in a format that the RSU can directly translate to the SAE J2735 SPaT format
5	There is a reliable communication network from all RSUs to the Master Server in the Traffic Operations Center (TOC)
6	NCSU Wolfline buses will be fully equipped with cellular connectivity

2.4 PROJECT RISKS

The following project risks can be mitigated through clear systems requirements and selecting a partner who can meet those systems requirements most effectively. This is a subset of the project risks that were identified in the project management document.

Table 3 – Project Risks

ID	Possible Risk	Risk Description
1	Traffic signal equipment delivery delays	Delays in receiving traffic signal equipment could lead to deployment delays.
2	Delays integrating CV equipment in the buses	Delays in receiving equipment or scheduling conflicts could lead to the integration of CV equipment with the bus fleet being delayed.
3	Data Security	Risk of data breach
4	Driver Distraction for transit operators	Integration of new technology could be a distraction at first for transit drivers
5	Driver distraction from smart phone application	Integration of new technology could be a distraction at first for drivers
6	Keeping pace with connected vehicle technology	CV technology is constantly evolving and there is a risk of falling behind or deploying the wrong technology

2.5 OPERATIONAL SCENARIOS

Operational scenarios can be found in Chapter 6 of the Concept of Operations.

3 USE CASE-SPECIFIC SYSTEM REQUIREMENTS

This chapter describes the system requirements derived from the user needs and the system concept. Each use case's system requirements are mapped back to the user needs to which it applies. The user needs can be found in the Concept of Operations.

The nomenclature for the system requirement ID (xxx-SR-ZZZ) is defined in Table 4.

Table 4 – Requirement Nomenclature

ID Position	Definition
xxx	A distinct abbreviation for the subsystem to which the system requirement refers
SR	Identifies that the ID is a System Requirement
zzz	Sequential number starting at 001 and is incremented by one for the next requirement. The numbering resets to 001 for each new requirement type.

3.1 USE CASE 1 – SIGNAL PHASE AND TIMING (SPAT) REQUIREMENTS

Table 5 – Use Case 1 Signal Phase and Timing (SPaT) System Requirements

ID	Requirement	User Need
SPAT-SR-001	The signal system shall provide data to the Connected Vehicle Roadside Equipment.	SPAT-UN-01
SPAT-SR-002	The roadside equipment shall communicate with users to provide current signal phase and timing information for all lanes and approaches at a signalized intersection.	SPAT-UN-01

ID	Requirement	User Need
SPAT-SR-003	The roadside equipment shall communicate with users to provide information concerning the geographical layout of the intersection through MAP broadcasts as well as receive GPS correction data.	SPAT-UN-02
SPAT-SR-004	The roadside equipment shall send status information to the traffic operations center.	SPAT-UN-03
SPAT-SR-005	The roadside equipment shall collect current signal phase and timing data from the traffic signal controller.	SPAT-UN-03
SPAT-SR-006	The roadside equipment shall provide real time signal phase and timing information for all lanes at a signalized intersection to a user.	SPAT-UN-03
SPAT-SR-007	The system shall interface with the traffic signal controller.	SPAT-UN-01
SPAT-SR-008	The Wolfline OBU shall have the ability to receive SPaT data.	SPAT-UN-01

3.2 USE CASE 2 – TRANSIT SIGNAL PRIORITY (TSP) REQUIREMENTS

Table 6 – Use Case 2 Transit Signal Priority (TSP) System Requirements

ID	Requirement	User Need
TSP-SR-001	The system shall receive requests for transit signal priority.	TSP-UN-01
TSP-SR-002	The system shall notify transit drivers of the priority request status.	TSP-UN-02 TSP-UN-03
TSP-SR-003	The roadside unit shall receive transit signal priority requests from transit vehicles and send that request to the signal system.	TSP-UN-01
TSP-SR-004	The roadside unit shall determine whether requests for priority are from authorized vehicles based on digital credentials.	TSP-UN-05
TSP-SR-005	The TMC shall adjust signal timing in response to signal prioritization requests and defined rules.	TSP-UN-01
TSP-SR-006	The transit vehicle shall determine schedule deviation and estimated time of arrival at the transit stops.	TSP-UN-01
TSP-SR-007	The transit vehicle shall send priority requests to the roadside unit along the route.	TSP-UN-01
TSP-SR-008	The transit vehicle shall send schedule deviation data and status of priority requests to the transit vehicle operator.	TSP-UN-01
TSP-SR-009	The transit vehicle shall only request priority when it is behind schedule.	TSP-UN-01
TSP-SR-010	The system shall respond to requests from transit management centers for signal priority at one or more intersections along a transit route.	TSP-UN-01
TSP-SR-011	The roadside unit shall collect current SPaT data from the traffic signal controller.	TSP-UN-01
TSP-SR-012	The transit vehicle shall be equipped with Automatic Vehicle Location for GPS tracking.	TSP-UN-01
TSP-SR-013	The system shall provide extended green time or shorten the red time to expedite the movement of transit vehicles on the identified approach when priority request is granted.	TSP-UN-01
TSP-SR-014	The system shall include rules to negotiate competing calls for priority.	TSP-UN-01
TSP-SR-015	The system shall revert to normal traffic signal operation through pre-determined signal phase sequencing and timing.	TSP-UN-01

ID	Requirement	User Need
TSP-SR-016	The system shall collect ridership data through an automatic passenger counter.	TSP-UN-04

3.3 USE CASE 3 – PEDESTRIAN IN SIGNALIZED CROSSWALK WARNING (PSCW) REQUIREMENTS

Table 7 – Use Case 3 Pedestrian in Signalized Crosswalk Warning System Requirements

ID	Requirement	User Need
PSCW-SR-001	The personal device application shall provide current location of non-motorized travelers.	PSCW-UN-03
PSCW-SR-002	The system shall collect images or sensor data for pedestrians.	PSCW-UN-04
PSCW-SR-003	The system shall provide warnings to pedestrians or cyclists when vehicles are infringing on a crosswalk.	PSCW-UN-04
PSCW-SR-004	The vehicle shall provide data describing the vehicle's location, heading, speed, acceleration, braking status, and size.	PSCW-UN-04
PSCW-SR-005	The roadway equipment shall alert drivers of stop signs, red lights, and crossing conflicts or violations of a non-motorized user.	PSCW-UN-01
PSCW-SR-006	The vehicle or application shall be capable of providing warnings to the driver based on information received.	PSCW-UN-02

3.4 USE CASE 4 – MOBILE ACCESSIBLE PEDESTRIAN SIGNAL SYSTEM (PED-SIG) REQUIREMENTS

Table 8 – Use Case 4 Mobile Accessible Pedestrian Signal System (PED-SIG) System Requirements

ID	Requirement	User Need
PEDSIG-SR-001	The system shall alert pedestrians who are visually impaired of priority status through their personal device.	PEDSIG-UN-01
PEDSIG-SR-002	The system shall alert pedestrians who are visually impaired if they travel outside of the crosswalk.	PEDSIG-UN-02
PEDSIG-SR-003	The system shall detect vehicles encroaching on the crosswalk.	PEDSIG-UN-08
PEDSIG-SR-004	The system shall alert pedestrians who are visually impaired of vehicles encroaching on the crosswalk.	PEDSIG-UN-03, PEDSIG-UN-04
PEDSIG-SR-005	The system shall alert pedestrians not in marked crossing areas of vehicles in the vicinity of where the pedestrian is crossing.	PEDSIG-UN-05
PEDSIG-SR-006	The system shall detect pedestrians in marked crossing areas.	PEDSIG-UN-06
PEDSIG-SR-007	The system shall detect pedestrians not in marked crossing areas.	PEDSIG-UN-07

3.5 USE CASE 5 – INTELLIGENT TRAFFIC SIGNAL SYSTEM (I-SIG) REQUIREMENTS

Table 9 – Use Case 5 Intelligent Traffic Signal System (I-SIG) System Requirements

ID	Requirement	User Need
ISIG-SR-001	The system shall log and analyze transit priority requests and their effect on the overall system.	ISIG-UN-01
ISIG-SR-002	The system shall log and analyze pedestrian crossing requests and their effect on the overall system.	ISIG-UN-02

ID	Requirement	User Need
ISIG-SR-003	The system shall optimize performance under changing circumstances.	ISIG-UN-03, ISIG-UN-04, ISIG-UN-05
ISIG-SR-004	The signal system shall collect, process, digitize, and send traffic sensor data to the Raleigh traffic operations center for further analysis and storage.	ISIG-UN-03
ISIG-SR-005	The signal system shall collect, process, and send traffic images to the Raleigh traffic operations center for analysis and distribution.	ISIG-UN-03
ISIG-SR-006	The system shall collect traffic data including speed, heading, starts and stops, and speed changes.	ISIG-UN-03
ISIG-SR-007	The RSU shall communicate with OBU or personal device on passing vehicles to collect current vehicle position, speed, and heading and a record of previous events (e.g., starts and stops, link travel times) that can be used to determine current traffic conditions.	ISIG-UN-03
ISIG-SR-008	The traffic operations center shall monitor, analyze, and store traffic sensor data (speed, volume, occupancy) collected from field elements under remote control of the center.	ISIG-UN-03
ISIG-SR-009	The traffic operations center shall monitor, analyze, and distribute traffic images from CCTV systems under remote access by the TOC.	ISIG-UN-03
ISIG-SR-010	The traffic operations center shall remotely control detection devices to detect traffic.	ISIG-UN-03
ISIG-SR-011	The traffic operations center shall remotely control traffic signal controllers.	ISIG-UN-03
ISIG-SR-012	The traffic operations center shall implement control plans to coordinate signalized intersections based on data from sensors and connected vehicles.	ISIG-UN-03, ISIG-UN-04, ISIG-UN-05
ISIG-SR-013	The vehicle OBU or personal device shall provide its location with lane-level accuracy to on-board applications.	ISIG-UN-03
ISIG-SR-014	The vehicle OBU or personal device shall exchange location and motion information with roadside equipment and nearby vehicles.	ISIG-UN-03
ISIG-SR-015	The vehicle OBU or personal device shall provide data describing the vehicle's location in three dimensions, heading, speed, acceleration, braking status, and size.	ISIG-UN-03
ISIG-SR-016	The field element shall notify the TOC of pedestrian calls and pedestrian accommodations.	ISIG-UN-03
ISIG-SR-017	The field element shall respond to pedestrian crossing requests.	ISIG-UN-03
ISIG-SR-018	The field element shall return the status of the sensor and CCTV system to the controlling traffic operations center.	ISIG-UN-03
ISIG-SR-019	The field element shall accept configuration information from the traffic operations center.	ISIG-UN-03
ISIG-SR-020	The field element shall pass data provided by the traffic operations center to local field devices and report data from the field devices back to the center.	ISIG-UN-03
ISIG-SR-021	The field element shall report the current signal control information to the traffic operations center.	HRD-UN-06 HRD-UN-07

ID	Requirement	User Need
ISIG-SR-022	The field element shall return system fault data of the sensor and CCTV to the controlling traffic operations center.	ISIG-UN-03
ISIG-SR-023	The field element shall return operational status of the traffic signal controller to the traffic operations center.	ISIG-UN-03
ISIG-SR-024	The field element shall return traffic signal controller fault data to the traffic operations center.	ISIG-UN-03
ISIG-SR-025	The traffic operations center shall collect environmental sensor operational status.	ISIG-UN-03
ISIG-SR-026	The traffic operations center shall collect traffic signal controller fault data from the field element.	ISIG-UN-03
ISIG-SR-027	The signal controller shall send high resolution data every tenth of a second.	HRD-UN-01
ISIG-SR-028	The system shall collect and store high resolution data to control and monitor signals.	HRD-UN-02
ISIG-SR-029	The local controller software shall be compatible with high resolution data system.	HRD-UN-03
ISIG-SR-030	The system shall store and manage high resolution data in a secure way that ensures integrity and authenticity of the data.	HRD-UN-04
ISIG-SR-031	The system shall notify motorists regarding driving efficiency, recommended driving speeds, optimal acceleration and deceleration.	CED-UN-02
ISIG-SR-032	The vehicle shall receive notifications through the on board unit or application.	CED-UN-01

3.6 USE CASE 6 – RED LIGHT VIOLATION WARNING (RLVW) REQUIREMENTS

Table 10 – Use Case 6 Red Light Violation Warning (RLVW) System Requirements

ID	Requirement	User Need
RLVW-SR-001	The system shall alert drivers that they are likely to violate a red light based on speed and SPaT data.	RLVW-UN-01
RLVW-SR-002	The system shall alert drivers when they violate a red light.	RLVW-UN-02
RLVW-SR-003	The system shall alert pedestrians if a vehicle is on a trajectory to violate a red light at their location.	RLVW-UN-03
RLVW-SR-004	The application shall receive the following information: enforceable speed limit, SPaT, and latitude/longitude.	RLVW-UN-01
RLVW-SR-005	The application shall receive vehicle information including GPS location, heading, speed, and acceleration.	RLVW-UN-01
RLVW-SR-006	The application shall generate an audial and/or haptic notification within 1 second of being triggered by the application.	RLVW-UN-01

3.7 USE CASE 7 – SPEED WARNING (SW) REQUIREMENTS

Table 11 – Use Case 7 Speed Warning (SW) System Requirements

ID	Requirement	User Need
SW-SR-001	The system shall alert drivers if their speed exceeds the speed threshold.	SW-UN-02

SW-SR-002	The system shall identify changes to the vehicle speeds that trigger the violation alert.	SW-UN-03
SW-SR-003	The application shall receive the following information: enforceable speed limit and latitude/longitude.	SW-UN-02
SW-SR-004	Warnings received shall not contradict or conflict with roadside signage on the corridor.	SW-UN-01
SW-SR-005	The application shall receive vehicle information including GPS position, heading, speed, and acceleration.	SW-UN-03
SW-SR-006	The application shall generate an audial and/or haptic notification within 1 second of being triggered by the application.	SW-UN-01

3.8 USE CASE 8 – HIGH RESOLUTION DATA REQUIREMENTS

Table 12 – Use Case 8 High Resolution Data System Requirements

ID	Requirement	User Need
HRD-SR-001	The system shall provide high resolution data every tenth of a second.	HRD-UN-01
HRD-SR-002	The system shall collect and store data for control and monitoring signals.	HRD-UN-02
HRD-SR-003	The system shall support high resolution data, NTCIP communications, and CV applications.	HRD-UN-03
HRD-SR-004	The system shall provide a way for users to access and analyze authentic data.	HRD-UN-04, HRD-UN-05, HRD-UN-06

3.9 USE CASE 9 – ATSPM REQUIREMENTS

Table 13 – Use Case 9 ATSPM System Requirements

ID	Requirement	User Need
ATSPM-SR-001	The detection devices shall report detected vehicles to the traffic signal controller.	ATSPM-UN-03
ATSPM-SR-002	The detection devices shall report vehicle speeds to the terminal server.	ATSPM-UN-03
ATSPM-SR-003	The controller shall collect and record high resolution data and communicate it to the server.	ATSPM-UN-03
ATSPM-SR-004	The system shall produce charts and graphics that highlight performance measures to be defined by NCDOT.	ATSPM-UN-01
ATSPM-SR-005	The system shall provide data for analysis by users.	ATSPM-UN-02

3.10 USE CASE 10 – WORK ZONE WARNING REQUIREMENTS

Table 14 – Use Case 10 Work Zone Warning System Requirements

ID	Requirement	User Need
WZW-SR-001	The system shall alert drivers of their speed when it exceeds a threshold in a work zone.	WZW-UN-01
WZW-SR-002	The system shall alert drivers of lane shifts and lane reductions within the work zone.	WZW-UN-02

WZW-SR-003	The system shall issue alerts and notifications in a work zone.	WZW-UN-02
WZW-SR-004	The system shall change and customize alerts and notifications in a work zone.	WZW-UN-03

3.11 USE CASE 11 – CONNECTED ECO DRIVING REQUIREMENTS

Table 15 – Use Case 11 Connected Eco Driving Requirements

ID	Requirement	User Need
CED-SR-001	Motorists need to receive notifications and feedback regarding driving efficiency including recommended driving speeds, optimal acceleration, and optimal deceleration.	CED-UN-01
CED-SR-002	The system needs to issue notifications and feedback regarding driving efficiency including recommended driving speeds, optimal acceleration, and optimal deceleration.	CED-UN-02

4 SYSTEM CONDITIONS AND REQUIREMENTS

The following sections include overarching systems conditions for safety and performance that must be met for the system to improve safety and evaluate the efficacy of the system. Table 16 contains the Safety Requirements and Table 17 includes the performance measure requirements.

4.1 SAFETY REQUIREMENTS

Table 16 – Safety Requirements

ID	Requirement
SAF-SR-001	Equipment, software, processes, and interfaces shall comply with IEEE and SAE standards as prescribed by one of the USDOT approved certification entities.
SAF-SR-002	Equipment, software, processes, and interfaces shall be tested for interoperability before deployment to ensure they meet those standards for interoperability.
SAF-SR-003	The contractor shall perform checks on the equipment, software, interfaces, and processes on a six month basis at a minimum.
SAF-SR-004	The contractor shall maintain the RSUs installed along the roadside for the duration of the project.
SAF-SR-005	OBU/Application failure shall not affect the normal operation of the vehicle.
SAF-SR-006	RSU/Application failure shall not affect the safe operation of the signal controller.
SAF-SR-007	RSUs shall be installed such that they receive GPS and DSRC signals.
SAF-SR-008	RSUs shall be installed near signal cabinets such that the RSU and signal controller can be connected.
SAF-SR-009	The in-vehicle applications shall present information to drivers using a device that drivers are familiar with and that minimizes interaction.
SAF-SR-010	CV device suppliers shall provide and follow an approved quality management process in designing, constructing, and producing their devices.
SAF-SR-011	The proposed user interface(s) shall be reviewed and approved by NCDOT and core team members.
SAF-SR-012	Safety checks for OBU's and RSU's shall include the equipment reset functions upon power loss and restoration.
SAF-SR-013	Safety checks for OBU's and RSU's shall include the redundancy actions upon power loss and restoration.
SAF-SR-014	Safety checks for OBU's and RSU's shall include the security actions upon power loss and restoration.
SAF-SR-015	Device installers shall be approved by NCDOT and NCSU - Transit to install devices in buses.
SAF-SR-016	Device installers shall be approved by NCDOT and the City of Raleigh to install devices in signal cabinets and along the roadside.
SAF-SR-017	Devices installed for the pilot shall have a failsafe mode.
SAF-SR-018	All basic safety messages shall include longitude, latitude, vertical position, and yaw.
SAF-SR-019	All basic safety messages shall conform to the SAE J2735 and SAE J2495/1 standards.
SAF-SR-020	All basic safety messages generated by the global navigation satellite system shall include orientation, speed, and heading.

4.2 PERFORMANCE MEASURES SYSTEM REQUIREMENTS

Table 17 – Performance Measures System Requirements

ID	Requirement
PFM-SR-001	The Primary Server shall collect historical or "before CV treatment" performance metrics for each CV App used in each Use Case if available.
PFM-SR-002	The Primary Server shall store historical or "before CV treatment" performance metrics for each CV App used in each Use Case if available.
PFM-SR-003	The Primary Server shall collect performance metrics for each CV App used during each Use Case.
PFM-SR-004	The Primary Server shall store performance metrics for each CV App used during each Use Case.
PFM-SR-005	The Primary Server shall enable the analysis or compare historical or "before CV treatment" performance metrics for each CV App used in each Use Case to "after CV treatment" performance metrics for each CV App used in each Use Case.
PFM-SR-006	The Primary Server shall automate routine performance reports.
PFM-SR-007	The Primary Server shall automate on demand performance reports.
PFM-SR-008	The Primary Server shall automate daily performance reports.
PFM-SR-009	The Primary Server shall automate weekly performance reports.
PFM-SR-010	The Primary Server shall automate monthly performance reports.
PFM-SR-011	The system shall collect and store: • delay time • queue length • travel time reliability indices • travel times • percent arrival on green • percent red light running/violation • number of time red light running/violation warning issued • bus travel time through the deployment region • bus percent arrival on schedule • bus percent arrival on green • bus percent red light violation/running • number of times priority is requested and granted • number of time priority is requested and denied • number of times priority is requested, granted, and then denied due to a higher priority

5 MAJOR SYSTEM CONSTRAINTS

System constraints are those items that limit or restrict the system. For the pilot, system constraints include system wide constraints and individual use case constraints. The table below identifies these constraints. Constraints that apply to more than one use case are grouped together.

Table 18 – System Wide and Use Case Constraints

ID	Constraint
System	The system is limited by the geographical boundaries set forth by the locations identified in this pilot.

ID	Constraint
System	The range of the communications for RSUs, OBUs, and Personal Information Devices (PID)
System	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.
System	Ensuring security is in place to ensure the integrity and authenticity of the data.
System	Ensuring privacy concerns are addressed.
System	Training NCDOT, City of Raleigh, and Wolfline staff to support, operate, and maintain this system.
System	Timely troubleshooting and repair of roadside equipment, on-board equipment, and personal portable information devices.
UC2	The actual number of buses outfitted with an OBU or portable personal information device.
UC4	Educating students at the Governor Morehead School in the use of the mobile accessible pedestrian signal application.
UC5	The actual number of vehicles, buses, and pedestrians with an OBU or portable personal information device.
UC3, 4	Integrating a pedestrian detection system to ensure pedestrians are accurately detected and located within or near the crosswalk.
UC3, 4	The actual number of pedestrians with a portable personal information device using the crosswalk.
UC1, 2, 3, 6, 7, 8, 11	The alerts, warnings, and notifications to the driver shall not be distracting.
UC1, 2, 3, 6, 7, 8, 11	The actual number of vehicles with an OBU or portable personal information device.
UC9, 10	The actual number of signal controllers that are upgraded.
UC10	The actual number of detection zones that are implemented at each location.

6 SYSTEM CAPABILITIES AND CONDITIONS REQUIREMENTS

The system capabilities and conditions in this chapter are system requirements that are not directly tied to a specific user need but must be maintained to keep the system operational.

6.1 PHYSICAL REQUIREMENTS

The physical systems requirements for construction, mechanical, electrical, durability, scalability, and environmental are listed in the following subsections.

ID	Requirement
PHY-SR-001	DSRC Antenna shall be mounted in a location with a clear path to the directions from which it is anticipated CV communications will take place.
PHY-SR-002	GPS Antenna shall be installed with a clear view of the sky.
PHY-SR-003	RSUs shall be installed with the proper environmental protection from rain, flooding, freezing, or high winds.
PHY-SR-004	Equipment wiring diagrams and any other documentation shall be provided to the Department prior to installation of the equipment.
PHY-SR-005	All CV devices shall meet USDOT requirements as determined by USDOT certification entities for durability including withstanding wear and tear, operating time, and damage.
PHY-SR-006	The system shall be adaptable to scale up or down in terms of geography and the quantities of RSUs, OBUs, and PIDs.

6.2 PERFORMANCE CHARACTERISTICS

The system performance requirements are needed to ensure the system is meeting expectations and is functioning as needed.

Table 19 – System Performance Characteristics Requirements

ID	Requirement
SPC-SR-001	The system shall have redundancy.
SPC-SR-002	The system shall be in real-time.
SPC-SR-003	The RSUs shall return to operational state within five minutes of losing power.

6.3 SECURITY REQUIREMENTS

System security is of the utmost importance from both a personally identifiable information perspective as well as a system intrusion perspective. Security requirements for the pilot are listed in the table below.

Table 20 – Security Requirements

ID	Requirement
SEC-SR-001	All systems shall be compatible with Security Credential Management System (SCMS) to ensure authenticity and privacy.
SEC-SR-002	All roadside equipment shall support remote authenticated access.
SEC-SR-003	An RSU shall verify received messages per IEEE 1609.2 and per the relevant security profiles before using them for operations in any application.
SEC-SR-004	An RSU shall require that 1609.2 signed messages are signed by a certificate that is protected from modification by, or chains back to a certificate that is protected from modification by, the secure boot process.

ID	Requirement
SEC-SR-005	An RSU shall provide tamper evidence to detect tampering of the device (e.g. opening of the case).
SEC-SR-006	An RSU shall implement a firewall blocking all IP access from devices to any IP address other than those approved for specific applications.
SEC-SR-007	An RSU shall comply with IEEE 1609.2: Standard for WAVE Security Services for Applications and Management Messages.
SEC-SR-008	An RSU shall delete old certificates if it has been moved to another intersection.
SEC-SR-009	An OBU shall verify received messages per IEEE 1609.2 and per the relevant security profiles before using them for operations in any application.
SEC-SR-010	An OBU shall verify a DSRC message when other potential threat situations such as red-light violations, and other safety applications are active.

6.4 INFORMATION MANAGEMENT REQUIREMENTS

The pilot will include some personal data and system generated data which must be managed and protected according to the systems requirements in Table 21 and Table 22.

Table 21 – Personal Data Information Management Requirements

ID	Requirement
PDI-SR-001	Data shall not include personally identifiable information (PII) or it shall be removed prior to public release.
PDI-SR-002	The system shall protect personal information including name, address, and vehicle make/model meeting standards for security of PII.
PDI-SR-003	There shall be an established list of personnel that have access to participant data but shall not have access to CV data generated by the participants.
PDI-SR-004	The participant's location information shall not be provided unless it is part of an application and no correlation to the participant's personal information.
PDI-SR-005	For broadcast and transactional unicast transmissions by OBUs, temporary and one-time identifiers shall be used to protect against inadvertently providing PII.
PDI-SR-006	Personal data access shall require a login with password protection.

Table 22 – System Generated Data Requirements

ID	Requirement
SGD-SR-001	Data collected shall be property of NCDOT.
SGD-SR-002	Data delivered by vendor systems, software, or applications will be considered property of NCDOT and free of IP limitations.
SGD-SR-003	The system shall, in all ways, comply with the policies of the data management plan.
SGD-SR-004	The data shall be collected and stored in standard, non-proprietary formats.
SGD-SR-005	The data shall be described in type, scale, collection method, and format.
SGD-SR-006	Any proprietary data collected shall require rationale, format, standards, and a data dictionary.
SGD-SR-007	Metadata standards shall be required in accordance with the Project Open Metadata Schema.
SGD-SR-008	Data and metadata shall be transmitted to master servers through a secure communications connection.

ID	Requirement
SGD-SR-009	Data shall be securely backed up on a regular schedule to protect against a single point of failure.
SGD-SR-010	Data shall be in accordance with the data retention schedule determined by NCDOT.
SGD-SR-011	Messages transmitted and received by RSUs shall be stored on a storage device connected locally to the RSU.
SGD-SR-012	The frequency at which data locally stored on RSUs is transmitted to the Master Server shall be determined based on the RSUs' storage capacity.

6.5 OPERATIONAL REQUIREMENTS

The following subsections include requirements as they pertains to systems operations for maintainability and reliability.

6.5.1 MAINTAINABILITY REQUIREMENTS

Table 23 – Maintainability Requirements

ID	Requirement
MAI-SR-001	RSU communication failures shall be responded to within one business day in accordance with the City of Raleigh response time for signal controllers.
MAI-SR-002	RSU communication failures shall be restored in accordance with the City of Raleigh response time for signal controllers.
MAI-SR-003	RSU hardware failures shall be addressed in accordance with the City of Raleigh response time for signal controllers.
MAI-SR-004	RSU application issues shall be responded to in accordance with the City of Raleigh response time for signal controllers.
MAI-SR-005	Planned maintenance shall be performed during off peak hours of the pilot's operation and be coordinated in advance with the City of Raleigh.
MAI-SR-006	Support staff shall be trained to troubleshoot and diagnose the system including RSUs, OBUs, and portable personal information device issues.
MAI-SR-007	A set of support, diagnostic, and troubleshooting procedures shall be developed to guide the support staff.
MAI-SR-008	The contractor shall maintain the RSUs installed in the signal cabinets as part of this pilot.

6.5.2 RELIABILITY REQUIREMENTS

Table 24 – System Reliability Requirements

ID	Requirement
REL-SR-001	RSUs shall meet the latest published specification as of April 2021 as a minimum.
REL-SR-002	RSUs shall store their data and not delete or rollover the data until it has confirmed the data has been successfully transmitted to the Master server and properly stored.

6.6 POLICY AND REGULATION

All systems must follow federal, state, and local law as it pertains to the project including obtaining proper licensing for DSRC through the FCC.

Table 25 – Policy and Regulation Requirements

ID	Requirement
PAR-SR-001	Proper licensing to broadcast using DSRC shall be obtained.
PAR-SR-002	The system shall comply with all local, state, and federal laws.
PAR-SR-003	All OBUs shall meet license requirements of FCC rules.

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 (V2X).
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.
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).

Term	Definition
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.