NCDOT Multimodal Connected Vehicle Pilot

Advanced Transportation and Congestion Management Technologies Deployment Initiative

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Project Name	NCDOT Multimodal Connected Vehicle Pilot
Eligible Entity Applying to Receive Federal Funding	North Carolina Department of Transportation
Total Project Cost (from all sources)	$4,744,59.18
ATCMTD Request	$2,117,50.00
Are matching funds restricted to a specific project component? If so, which one?	No
State in which the project is located	North Carolina
Is the project currently programmed in? • **Transportation Improvement Plan?** • **Statewide Transportation Improvement Program?** • **MPO Long Range Transportation Plan?** • **State Long Range Transportation Plan?**	No
Technologies Proposed to be Deployed	Connected Vehicle Applications (V2I, V2X), Transit Signal Priority (TSP), Multimodal Application (Pedestrian, Driver, Bike Rider, etc.), Intelligent Traffic Signal Timing, Red Light Violation Warning, Speed Warning, Traveler Information, High Resolution Data, Automated Traffic Signal Performance Measures (ATSPM) Pedestrian Presence Detection Accessible Pedestrian Signal System (PED-SIG)

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I. PROJECT NARRATIVE

INTRODUCTION

In 2017, there was one pedestrian fatality every 88 minutes in the United States on average and pedestrian fatalities accounted for 16% of traffic fatalities nationally. This national average represents a traffic fatality rate of 1.84 deaths per 100,000 population. North Carolina's traffic fatality rate per 100,000 was 1.93, almost 5% higher than the national average. 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.

To address these safety concerns, the North Carolina Department of Transportation (NCDOT) Multimodal Connected Vehicle Pilot (MMCVP) aims to create a connected environment that can evaluate the impact of Connected Vehicle (CV) technology on driver and pedestrian safety. This connected environment will include an application delivering safety notifications to all users of the multimodal application: pedestrians, cyclists, transit, and motorists. The CV applications will use a hybrid DSRC/cellular communication system with in-vehicle and roadside CV infrastructure.

The pilot will also focus heavily on improvements to the NCSU Wolfline bus system. To improve transit vehicle efficiency, a new Intelligent Traffic Signal System (I-SIG) will be deployed to implement Transit Signal Priority (TSP) and collect and analyze High-Resolution Data. The list of technologies to be deployed is found in Table 1.

TABLE 1 CONNECTED VEHICLE PILOT TECHNOLOGIES

Signal & Intersection Improvements	Multimodal Applications
✓ Signal Phase and Timing (SPaT)	✓ Pedestrian in Crosswalk Warning
✓ Transit Signal Priority (TSP)	✓ Mobile Accessible Pedestrian Signal System
✓ Intelligent Traffic Signal System (I-SIG)	✓ Red Light Violation Warning
✓ High-Resolution Data	✓ Speed Threshold Warning
✓ DSRC/Cellular Hybrid Communications	✓ Work Zone Warning
✓ Automated Traffic Signal Performance Measures (ATSPM)	✓ Connected Eco-Driving

PROJECT DESCRIPTION

This section addresses the project description, geographic area, and description of transportation systems and services included in the project – numbers 1, 2, and 4 listed in the NOFO Project Narrative minimum content list.

The NCDOT MMCVP explores technologies to improve the day-to-day transportation experience for pedestrians, cyclists, motorists, and transit drivers and passengers. To properly evaluate the integration of these technologies, a small geographic area inclusive of the NCSU campus was identified as an ideal location for testing. Using the data gathered in the pilot,

NCDOT hopes to expand the successful technologies to additional geographic areas in the region and across the state.

A key component of the experience for students, faculty, and visitors on the NCSU campus is the free bus system, Wolfline. The integration of the NCSU Wolfline bus system includes the use of the existing Wi-Fi connection on the buses to support a transit signal priority (TSP) system and supplementary safety notifications displayed on on-vehicle tablets. This technology will be deployed on 45 buses operating on 11 routes and covering a network encompassing 29 signalized intersections. Because Wolfline buses are available for public use, the pilot benefits extend beyond the student population to the entire geographic area served by the system. A map of the geographic area is found in Figure 1. A map of the intersections served by the project is found in Figure 2.

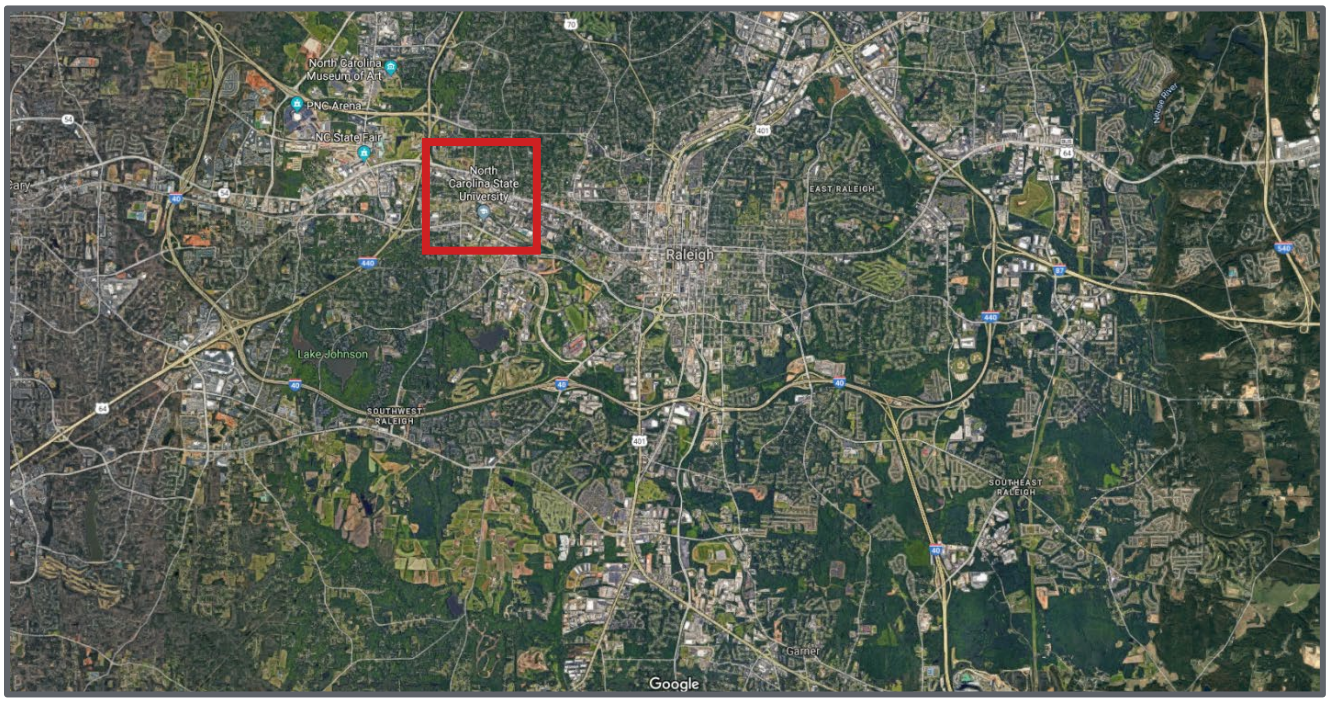

FIGURE 1 MAP OF GEOGRAPHIC AREA - RALEIGH, NC

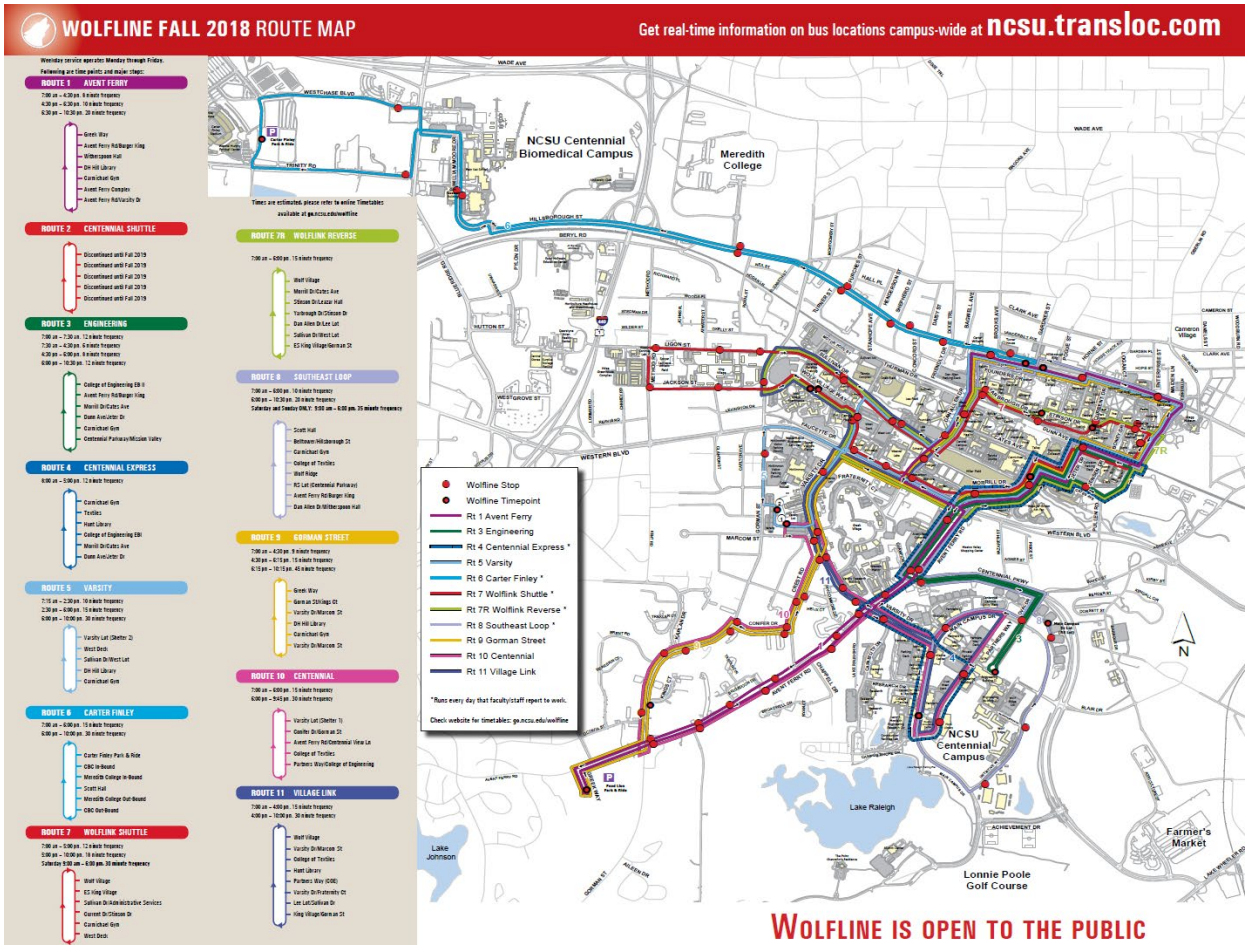

FIGURE 2 WOLFLINE BUS ROUTES

The TSP component of the project will include upgrading traffic signal software and hardware as necessary to provide a system that can give the bus priority. This improved data driven communication will streamline the dispatch system and improve the efficiency of the area's bus system. The pilot will also deploy necessary technology to cohesively optimize arterial performance.

Along with the TSP technology, signal system upgrades will use Intelligent Traffic Signal System (I-SIG) solutions that can integrate information from the range of data sources available (TSP, pedestrian activity, ATSPM) and provide system optimization along the corridors in real time. Upgraded traffic signal controllers will provide the ability to collect and store high-resolution data to support ATSPM. In addition, new radio equipment will support broadcasting Signal Phase and Timing (SPaT) and MAP messages to devices enabled to receive such communication. This not only achieves an important Traveler Information Messaging (TIM) objective, but also lays the groundwork for future CV technology and applications.

While optimizing the corridor for vehicle operators is important to the mobility of the geographic area, the project also focuses on the travel experience for cyclists and pedestrians. The project area surrounds a college campus with heavy pedestrian foot traffic, thus it will be helpful to enhance detection of pedestrians. As part of this objective, roadside detectors for pedestrian activity will be installed at two key intersections with the highest pedestrian volume. This will help mitigate the risk for pedestrian collisions by alerting other users when a pedestrian is in or approaching a crosswalk.

The student body at the Governor Morehead School (GMS), which serves the needs of visually impaired students, is another important group of users that will benefit from this project. To best aid the GMS population, an accessible mobile application will be developed to increase crosswalk safety at critical intersections and will include notifications when users have priority to cross the street. These applications will build upon the same pedestrian presence detection and notification infrastructure implemented in other portions of the project area.

Delivery of all alerts in the pilot will be achieved through a multimodal application developed for this pilot. The application will aid motorists by issuing pedestrian safety warnings, speed warnings when a speed threshold has been exceeded, red light violation warnings when their anticipated trajectory and speed is calculated to result in a red-light violation, and the ability to issue warnings related to work zone activity. The CV applications will follow the CV Pilot Deployment Program as outlined by the Intelligent Transportation Systems Joint Program Office. Figure 3 depicts the System Concept and communication network between various components of the pilot.

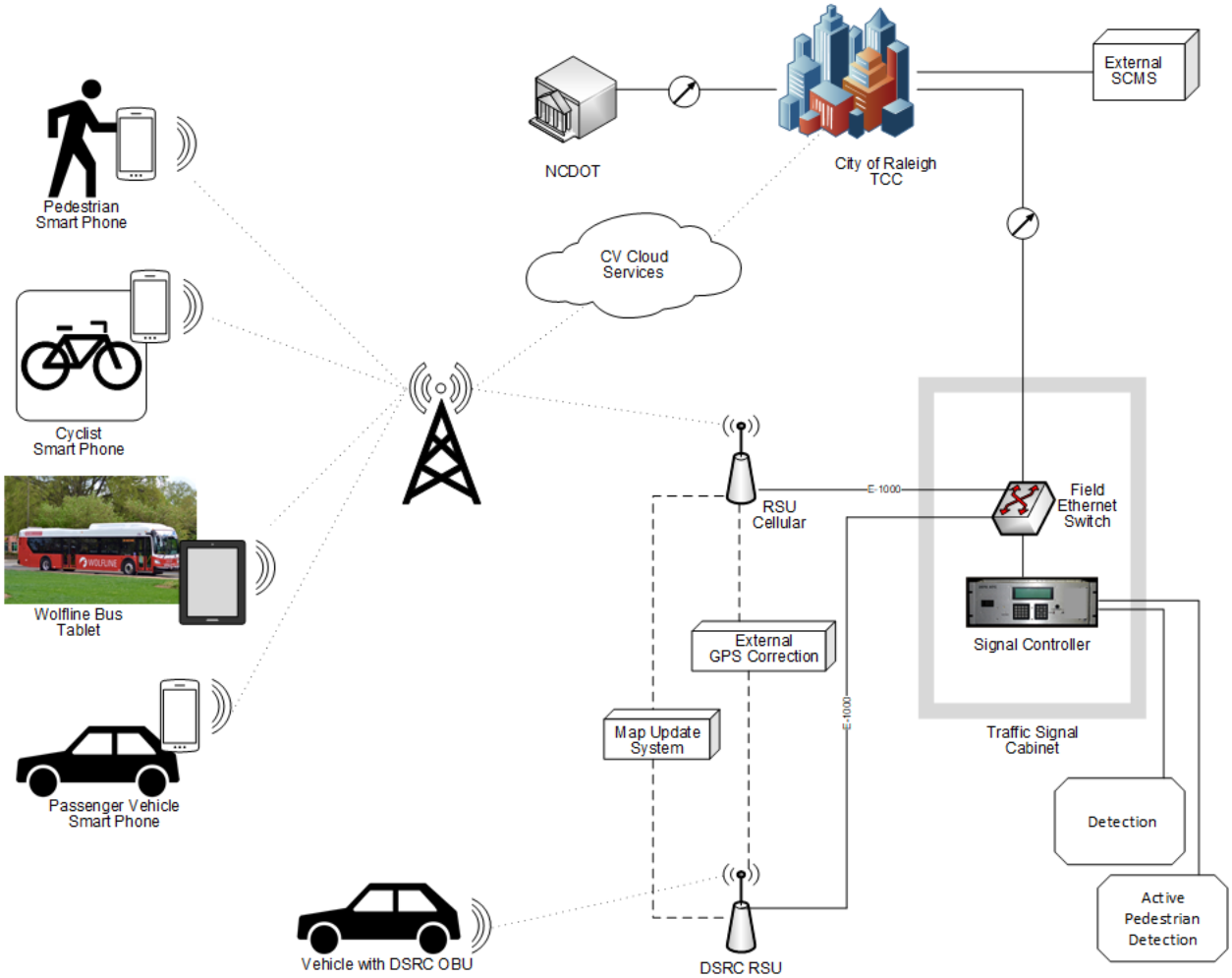

FIGURE 3 SYSTEM CONCEPT

The broad scope of the NCDOT MMCVP project will generate a large amount of data. This data will be secured to ensure the integrity and authenticity of messages while also maintaining privacy. The captured high-resolution data will support NCDOT's ability to assess the functionality and impact of CV technology in the project area. High-resolution data will facilitate a range of Measures of Effectiveness (MOE), including platoon size, flow, and transit system Travel Time Reliability (TTR). Based on this assessment, NCDOT can evaluate the success of the pilot and identify which components are providing the greatest impact on the defined MOE. The validated data analysis will allow NCDOT to expand on the successes of this pilot and provide the technology to other campuses and cities statewide. This expansion will provide mobility, safety, and economic benefits to the state and can be replicated in other cities and states as warranted.

To minimize costs and expedite deployment, existing infrastructure will be used where possible, including existing traffic signal cabinets and fiber optic communication. Most of the upgrades for the traffic signal systems can be accomplished without impacting most of the cabinets.

There are six intersections, including two currently owned by NCSU, that will need to be upgraded to allow for integration with the City of Raleigh and with new central ATMS software.

PROJECT NEEDS

This section addresses the real-world issues and challenges to be addressed by the proposed technology deployments – number 3 on the NOFO Project Narrative minimum content list.

The following real-world issues were identified by the Project Management Team.

Bus system use and reliability. Improve the bus system reliability in terms of adherence to a posted schedule and travel time reliability to increase ridership of the bus system. The reduction of idling buses to reduce emissions is a related need.

Improve pedestrian safety. In a pedestrian heavy area with students hurrying to class and visitors who are unfamiliar with the nuances of the geographic area, there is a heightened risk of collisions with pedestrians.

Overall mobility for road users. The geographic area can become congested and all road users can benefit from improved mobility through signal system optimization and real time information for road users.

VISION, GOALS, AND OBJECTIVES

This section addresses the vision of the organization and goals, objectives, and activities to be pursued in addressing the identified issues and challenges – number 9 on the NOFO Project Narrative minimum content list.

The project management team's vision for the project is to create a connected environment through various CV applications and infrastructure while measuring the impacts of the deployed technologies on increasing safety and mobility in the project area. The team has identified program-specific goals and objectives presented in Table 2. These closely align with 10 of the 11 Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) goals as outlined in the NOFO:

1. Delivery of environmental benefits that alleviate congestion and streamline traffic flow;
2. Measurement and improvement of operational performance of the applicable transportation networks;
3. Reduction in the number and severity of traffic crashes and an increase in driver, passenger, and pedestrian safety;
4. Collection, dissemination, and use of real-time transportation related information to improve mobility, reduce congestion, and provide for more efficient and accessible transportation, including access to safe, reliable, and affordable connections to employment and education;
5. Monitoring transportation assets to improve infrastructure management, reduce maintenance costs, prioritize investment decisions, and ensure a state of good repair;

6. Delivery of economic benefits by reducing delays, improving system performance and throughput, and providing for the efficient and reliable movement of people, goods, and services;
7. Accelerated deployment of vehicle-to-vehicle, vehicle-to-infrastructure, and automated vehicle applications;
8. Integration of advanced technologies into transportation system management and operations;
9. Demonstration, quantification, and evaluation of the impact of these advanced technologies, strategies, and applications towards improved safety, efficiency, and sustainable movement of people and goods; and
10. Reproducibility of successful systems and services for technology and knowledge transfer to other locations facing similar challenges.

Table 2 NCDOT MMCVP Goals and Objectives

Goal 1: Deploy CV infrastructure to support the applications for the project
Objective 1.1: Deploy DSRC and cellular technology to support V2X applications
Objective 1.2: Upgrade traffic signal hardware, software, and TCC software to ensure compatibility with CV applications
Objective 1.3: Recruit a fleet of transit and private vehicle owners as well as individuals carrying V2X enabled mobile devices to participate in the pilot and use the CV technology offered by the pilot
Goal 2: Improve mobility within the pilot area
Objective 2.1: Replace traffic signal controllers and software at intersections within the system for compatibility to help improve traffic progression
Objective 2.2: Provide transit signal priority applications to help Wolfline buses stay on a predictable and reliable schedule
Objective 2.3: Provide drivers with signal phase and timing information and applications that will improve overall mobility within the system
Goal 3: Reduce the number of safety incidents within the pilot area
Objective 3.1: Provide potential conflict warnings to drivers and pedestrians
Objective 3.2: Provide speed warnings to drivers
Objective 3.3: Provide red light violation warnings to drivers
Goal 4: Reduce environmental impacts within the pilot area
Objective 4.1: Provide drivers with signal phase and timing information and applications that will help reduce stops and idle times of vehicles, thus reducing emissions
Objective 4.2: Provide transit signal priority applications to reduce idle time of Wolfline buses
Goal 5: Improve agency efficiency
Objective 5.1: Improve traffic data collection capability, reducing the costs of collecting data
Objective 5.2: Reduce the time it takes agencies to gather crash data along system corridors
Objective 5.3: Reduce the resources needed from police and rescue
Objective 5.4: Improve technology for crash statistics analysis
Objective 5.5: Improve scheduling and dispatching of Wolfline buses through improve trip times and added vehicle information

BENEFITS AND OUTCOMES

This section addresses the quantifiable system performance improvements – numbers 7 and 8 on the NOFO Project Narrative minimum content list.

The NCDOT MMCVP fully aligns with all the expected ATCMTD program deployment benefits as outlined in the NOFO:

- Reduced traffic-related fatalities and injuries
- Reduced congestion and improved travel time reliability
- Reduced transportation-related emissions
- Optimized multimodal system performance
- Improved access to transportation alternatives, including underserved populations
- Public access to real time integrated information to make informed decisions, and
- Cost savings to transportation agencies, businesses, and the traveling public

Each of the technologies defined within this pilot is intended to improve safety or optimize mobility on the project corridor.

NCDOT will use the data collected during the pilot to gauge the effectiveness of various CV technologies. Lessons learned from this project will help refine the Department's policies and standards for future CV implementations. This pilot project will allow NCDOT to more effectively deploy CV technology and applications within the State of North Carolina with the goal of improving safety, increasing mobility, and protecting the environment for all citizens. Data collected will be available to USDOT to support evaluations and implementations of similar improvements at a national level.

Table 3 expands on the expected environmental, mobility, safety, and accessibility impacts from the pilot and defines quantifiable MOEs relative to each technology. Deploying these cutting-edge technologies allows the pilot to demonstrate quantifiable effects on safety and mobility. A before and after study will be conducted by the Institute for Transportation Research and Education (ITRE) to measure each of the following MOEs.

TABLE 3 EXPECTED IMPACTS OF CV TECHNOLOGY

Technology/ Application	Expected Impacts	Measure of Effectiveness
Signal Phase and Timing (SPaT)	• Reduce congestion along the corridor by informing motorists when a traffic signal will change and allowing them to adjust their speed to smooth their routes • Reduce emissions and fuel consumption by reducing the number of stops a motorist must make	Delay, Number of Stops
Transit Signal Priority (TSP)	• Reduce delays experienced by transit drivers and riders • Increase travel time reliability (TTR) of transit schedules • Reduce emissions by encouraging transit ridership and reduced vehicle trips	Delay, Number of Stops, TTR
Pedestrian in Signalized Crosswalk	• Reduce pedestrian related crashes • Reduce potential pedestrian conflicts with vehicles	Crash Reduction
Mobile Accessible Pedestrian Signal System	• Increase safety for pedestrians needing assistance, such as those who are visually impaired • Increase safety for pedestrians as more people use the crosswalk infrastructure • Improve safety for GMS students and faculty	Crash Reduction, Pedestrian Level of Service
Intelligent Traffic Signal System (I-SIG)	• Increase system performance through real-time optimization • Decrease fuel consumption and emissions as delays are minimized for all users • Increase quality of life for all users as stress and anxiety from delays, conflict points, and crashes are reduced	Delay, Number of Stops, Crash Reduction
Red Light Violation Warning (RLVW)	• Reduce the number of vehicles entering an intersection during the red phase of a signal • Assess violation data to determine locations and mitigation strategies for improved safety • Reduce number of crashes resulting from vehicles entering the intersection during the red phase of a signal	Crash Reduction, Reduced Traffic Violations
Speed Warning	• Improve compliance to posted speed limits • Increase safety for all users of the system due to reduction in vehicle speeds • Assess violation data to determine if additional enforcement resources are needed	Reduced Traffic Violations, Crash Reduction

Technology/ Application	Expected Impacts	Measure of Effectiveness
Traveler Information Message	• Communicate real time data to users promoting better trip decision making • Increase safety for all users due to information being accessible sooner • Provide information to the public during emergencies	Travel Time Reliability, Level of Service, Delay
High Resolution Data	• Optimize the signal systems for pedestrians, motorists, and transit users • Improve traffic flow through the project area • More accurately evaluate performance data relative to the application and its effect on the system	System Performance, Delay, Queuing
Automated Traffic Signal Performance Measures (ATSPM)	• Optimize travel times on system corridors • Improve system performance during special events, weather events, and seasonal events	System Performance, Delay, Density
Work Zone Warning	• Increase safety for workers within a work zone • Increase driver awareness of a work zone, reducing crashes	Crash Reduction

An Expansion Feasibility Study is planned during the second year of the NCDOT MMCVP project. The Expansion Feasibility Study will assess initial findings and investigate potential applications of the technologies vetted during the initial CV pilot implementation. The management team will reference preliminary findings to determine the practicality and potential benefit of similar deployments on additional routes or in additional geographic locations. Alternatively, the Expansion Feasibility Study will aim to identify additional CV applications for deployment such as Dynamic Transit Operations to enhance the connection between travelers and transit vehicles through real-time arrival prediction or dynamic schedule management. In addition, the Expansion Feasibility Study could identify refinements to the NCDOT MMCVP pilot implementation based on initial findings.

LEVERAGING AND OPTIMIZING EXISTING TECHNOLOGY INVESTMENTS

This section addresses the plan to optimize existing local and regional advanced transportation technology investments – number 10 on the NOFO Project Narrative minimum content list.

The pilot project will build upon existing and planned infrastructure to balance the investment with the anticipated return on investment from the proposed technology applications. This process includes integrating with existing technology deployments while also planning for and incorporating pending or planned technology implementation and upgrades—such as Bus Rapid Transit (BRT) and ATSPM.

The City of Raleigh and NCDOT have planned several signal system upgrades. This project will build on those plans to provide accelerated deployments and preliminary equipment installations. Currently, all but two traffic signals are interconnected with fiber optic communications cable and connected to the City of Raleigh Traffic Control Center (TCC). This communication infrastructure will support ATSPM strategies, including data collection and signal timing upgrades. Fiber optic communication infrastructure is proposed for the two outstanding traffic signals currently maintained by NCSU. NCDOT recently completed an ATSPM Implementation Plan that defines the statewide approach for infrastructure and data management for high-resolution data. This project will follow the approach defined within the implementation plan and will include collecting all data in the central database established for ATSPM.

The City of Raleigh is designing a BRT implementation for Western Boulevard, which is a primary route within the project study area. The NCDOT MMCVP pilot project will coordinate with the design progress of the BRT implementation and integrate proposed technology applications that can support the future BRT implementation. This integration includes field equipment in the signal cabinets and on the transit vehicles. All technology deployed will be considered in concert with the vision for connected and sustainable transportation systems in the framework of the Smart City future of Raleigh.

DEPLOYMENT TIMELINE

This section addresses the deployment plan, including long-term operation and maintenance of advanced transportation and congestion management technologies to improve safety and efficiency – numbers 5 and 11 on the NOFO Project Narrative minimum content list.

With a commitment to sound practices for system deployment, operations, and maintenance, the team will institute a proactive maintenance strategy to sustain the benefits of the NCDOT MMCVP project. NCDOT, NCSU, and City of Raleigh currently share ownership and maintenance responsibilities of existing infrastructure. With the deployment of the NCDOT MMCVP, the City of Raleigh will play a key role in providing access to the signal system in the pilot area and aiding in maintenance and enhancement of the system as needed. NCDOT and NCSU will support the City to ensure the pilot project is meeting the identified system goals. The team will follow the systems engineering approach in planning and deploying the proposed project as shown in Figure 4.

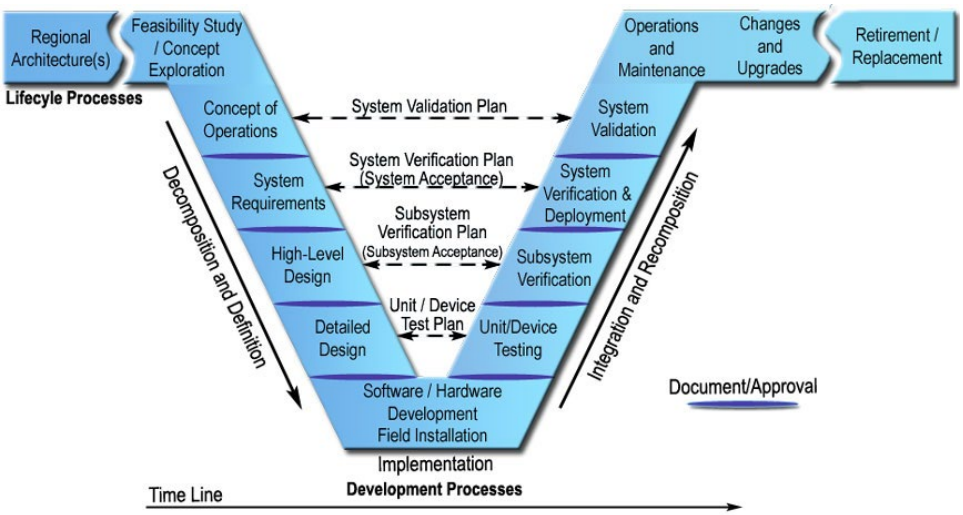

FIGURE 4 SYSTEMS ENGINEERING "V" DIAGRAM

Project Management Plan (PMP) - The PMP will be led by NCDOT and will include an overall plan and approach to managing the project components and deliverables. It will also include a Communication Plan, Risk Management Plan, Schedule, and Schedule Management Plan.

Systems Engineering Management Plan (SEMP) – The SEMP will identify roles, responsibilities, and relationships of projects activities, major decision points, and key milestones. It will detail stakeholder coordination and involvement in technical decisions.

Concept of Operations (ConOps) – The ConOps will build on the project concept, identify system characteristics and describe the overall vision of the NCDOT MMCVP project.

High-Level System Requirements – The project team will document the requirements for the NCDOT MMCVP deployment. Insight and lessons learned from USDOT's Connected Vehicle Pilot Deployment Program will be leveraged to create the specific requirements to support this MMCVP deployment objectives.

Operations and Maintenance (O&M) Plan – The O&M Plan will describe the agreements, processes, maintenance needs, and future system integration needs to operate, maintain, and improve the system. Roles and responsibilities for O&M will be identified for each agency.

System Design and Equipment Procurement – The system design and equipment procurement phase will be the most comprehensive and will take the project all the way from O&M Plan to System Validation. This phase will include design, development, installation, testing, and adjustments to equipment or applications to ensure all components are functioning as desired and described in the previous systems engineering phases.

System Operations and Maintenance – Following system testing and acceptance will be three years of system operations and maintenance. During this time, the NCDOT MMCVP system will

be evaluated, and updates and fixes will be made as necessary. Specific performance reviews will also be conducted.

Systems Evaluation – The goals and objectives of the NCDOT MMCVP are described in the project narrative. An annual evaluation report will be developed at the end of each full year of deployment and evaluated in comparison to data collected in the before collection period. At the end of the four-year commitment for this grant, an overall evaluation report will document the performance against project goals.

The Gantt Chart in Figure 5 shows the project deployment schedule from Project Selection through System Evaluation. After the testing is complete in the end of September 2023, the system will be fully deployed.

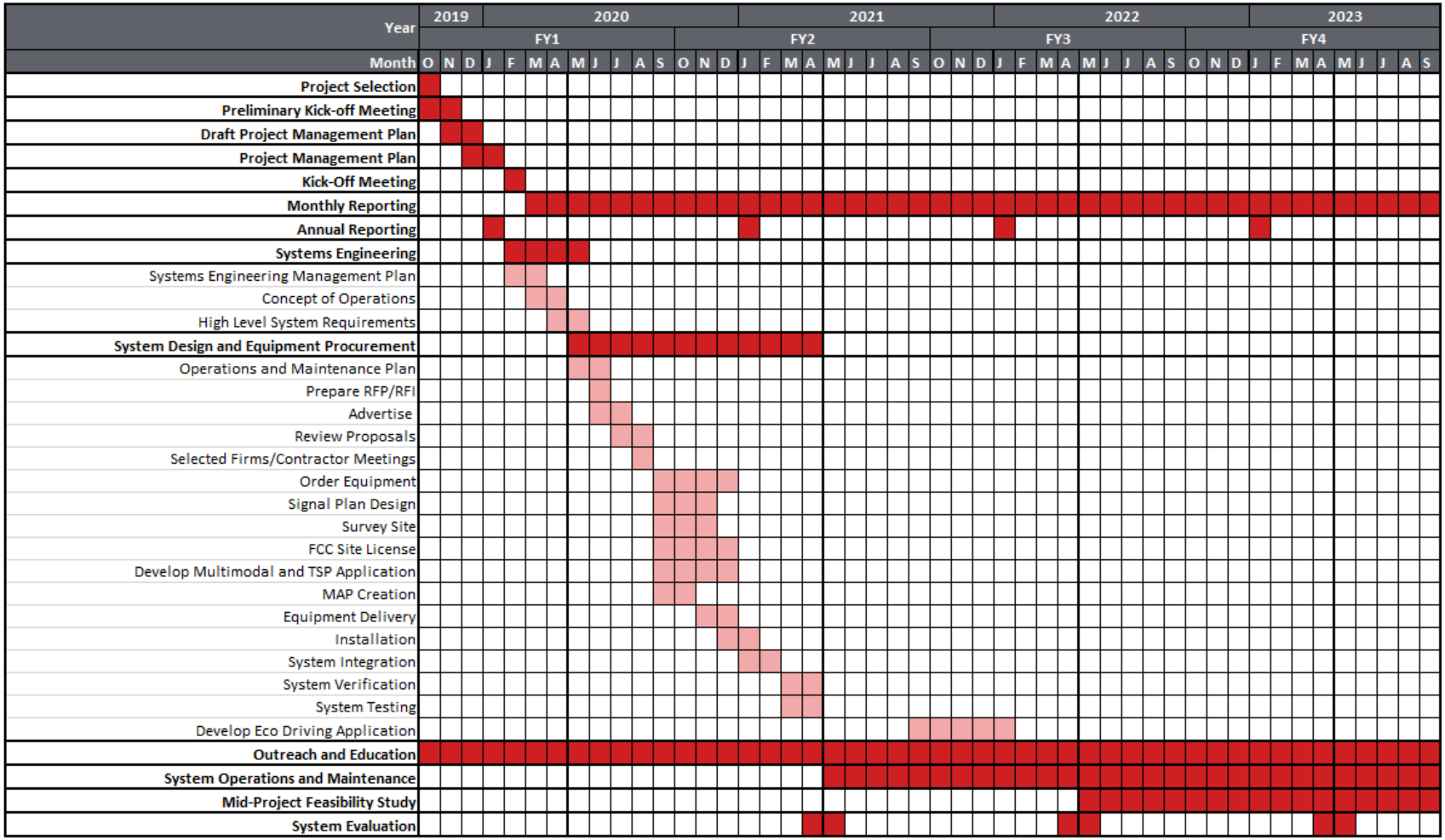

FIGURE 5 PROJECT DEPLOYMENT GANTT CHART

RELATED POLICY AND DEPLOYMENT CHALLENGES

This section addresses the challenges in regulatory, legislative, or institutional obstacles to deployment – number 6 on the NOFO Project Narrative minimum content list.

NCDOT and the Department of Motor Vehicles (DMV) recently collaborated to develop a Connected and Automate Vehicle (CAV) Roadmap that defines the current environment in North Carolina relative to emerging CAV technologies and focus areas for how the state can prepare as these technologies continue to evolve. The roadmap speaks to institutional, infrastructure, research, and business development characteristics. The foundation of this roadmap will support the implementation of this pilot project.

The City of Raleigh also has current initiatives to implement TSP and BRT on a few key corridors. One such corridor, Western Boulevard, is a key route in the pilot project study area. This pilot project will closely coordinate with and build upon the infrastructure and institutional framework established through those projects.

NCDOT recently completed an ATSPM Implementation Plan that will guide deployments for high resolution data collection on several corridors. The Department's direction related to ATSPM will be followed when implementing equipment for the pilot project.

NCDOT is aware of the following policy documents and will design the project in compliance with each.

- Manual on 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 SOP
- City of Raleigh Transportation Operations Division SOP
- Signal System Timing Philosophy Manual

NCDOT is not aware of any other policies that would deter the successful deployment of the pilot. However, the following challenges and corresponding mitigation strategies have been identified.

TABLE 4 DEPLOYMENT CHALLENGES AND MITIGATION STRATEGIES

Challenges	Mitigation Strategies
Adoption of the smart phone application	Public outreach to promote the pedestrian application and training for how to use it to increase user adoption
Accuracy of pedestrian presence detection	Integrate high performing pedestrian presence detection systems at critical intersections
Driver distraction from smart phone application	Ensure alerts, warnings, notifications do not create a layer of distraction to vehicle operators
Driver distraction for transit operators	Ensure the on-board units use effective notifications and do not require driver interaction; align notifications with current on-board units (Paseo unit) to streamline information provided to the driver
Data security	Involve IT departments in project development to ensure security for the integrity and authenticity of the data
User data privacy	Ensure privacy concerns are addressed through public outreach
Full understanding of project components by staff at NCDOT, City of Raleigh, and Wolfline	Train all staff to support, operate, and maintain the system
Morehead student and faculty application adoption	Educate students at Morehead on the use of mobile accessible pedestrian signal system (PED-SIG) application
Responsiveness to system failures	Establish maintenance roles and responsibilities that include back-up support for system uptime of critical components—roadside equipment, on-board equipment, and personal portable connectivity devices
Keeping pace with connected vehicle technology	Continuous maintenance plan for equipment assessment and upgrades to align with agency decisions and technology requirements
Regional transit plan includes future Bus Rapid Transit (BRT)	Confirm that the NCDOT MMCVP is compatible with the plans for BRT along Western Blvd; use Work Zone Warning application developed for the pilot to increase safety during construction

DOT ALIGNMENT SUMMARY TABLE

This section includes a summary table to address the USDOT focus areas, goals, objectives, and technology initiatives – numbers 3, 12, and 13 on the NOFO Project Narrative minimum content list.

USDOT is focused on connected vehicles as an important innovative technology initiative. The NCDOT MMCVP centers around CV technology for motorists and V2X communications for pedestrians, cyclists, and bus passengers. The 2015-2019 Strategic Plan for USDOT outlines CV technology's potential to improve safety, mobility, system efficiency, environmental impacts, and access to resources for disadvantaged groups. CV real-time data provides an unprecedented opportunity for optimization. Data collection is important for USDOT's investment into enterprise data collection from sensors, mobile devices, and CVs to be used for system performance and improved safety and mobility across all modes of travel.

As mentioned in the Project Narrative, the NCDOT MMCVP closely aligns with USDOT's focus areas, goals, objectives, and technology initiatives identified for the ATCMTD project.

Table 5 expands upon how each technology or the overall MMCVP connects with these project initiatives.

TABLE 5 USDOT ALIGNMENT SUMMARY TABLE

DOT ALIGNMENT SUMMARY TABLE	
Focus Area Alignment	
Installation of connected vehicle technologies at intersections, pedestrian crossing locations, and other conflict areas	
Comprehensive CV Pilot	The overarching goal of the NCDOT MMCVP is to improve intersection interactions between drivers, cyclists, and pedestrians by integrating a multimodal application that provides safety improvements, roadside units to detect pedestrians, and signal timing improvements—including transit signal priority—for overall enhanced mobility through intersections.
Initiative Goal Alignment	
A.4.i – Enhanced use of existing transportation capacity	
Transit Signal Priority (TSP)	Rather than investing in a new fleet with connected technology on board, NCDOT will work with NCSU and the existing bus fleet. Using on-board WiFi, an application will be developed for a tablet, enabling quick and easy deployment on existing transportation infrastructure.

DOT ALIGNMENT SUMMARY TABLE	
A.4.ii – Delivery of environmental benefits	
Transit Signal Priority (TSP)	Allowing signal priority for buses keeps their schedules running on time, which in turn enables the bus to serve more riders and create a more efficient transit system. This decreases idle time and maximizes ridership, thereby providing reduced emissions.
A.4.iii – Measurement and improvement of operational performance	
High-Resolution Data	The pilot project will collect high-resolution data from traffic signal controllers to evaluate performance metrics of the system and effectiveness of techniques during deployment as well as expedite the maintenance of the system.
Automated Traffic Signal Performance Measures (ATSPM)	Implementing signal performance measures will aid NCDOT in improving signal timing and improving operational performance for buses and all road users.
A.4.iv – Reduction in number and severity of traffic crashes and increase in driver, passenger, and pedestrian safety	
Comprehensive CV Pilot	One focus of the pilot is safety for motorists, pedestrians, and transit riders. Sharing data in real time will allow for optimization of corridor timing. Pedestrian presence detection and alerts for drivers of both buses and passenger vehicles will foster a safety environment and reduce the number and severity of crashes.
A.4.v – Collection, dissemination, use of real time transportation related information to improve mobility, reduce congestion, and providing a more efficient and accessible transportation	
Transit Signal Priority (TSP)	TSP uses real time bus location and schedule information to provide priority to buses while simultaneously optimizing changes to signal timing for other vehicles. This will improve Travel Time Reliability, mobility, and customer satisfaction with the improved efficiency of the transit system.
Multimodal Application	Aiding citizens who are visually impaired by increasing pedestrian safety improves mobility and accessibility. The application also encourages pedestrian patience by sharing wait times and managing expectations for crossing intersections.
A.4.vi – Monitoring transportation assets to improve infrastructure management, reduce maintenance costs, prioritize investment decisions, and ensure a state of good repair	
High-Resolution Data	HRD enables operators to monitor the signal infrastructure, enables maintenance staff to prioritize issues and reduces unnecessary maintenance calls to sites, leading to reduced maintenance costs; HSR also enables a proactive response to maintenance issues as they occur instead of waiting on public complaints.

DOT ALIGNMENT SUMMARY TABLE	
A.4.vii – Economic benefits by reducing delays, improving system performance and throughput and providing for the efficient and reliable movement of people, goods and services	
Transit Signal Priority (TSP)	Keeping the bus system running on-time reduces wait time for riders, which in turn provides economic benefits. Increased system efficiency also aids the performance and throughput for the Wolfline.
A.4.viii – Accelerated deployment of V2V, V2I applications	
Multimodal Application	Using personal devices and DSRC already deployed in vehicles allows for an accelerated deployment of the applications.
Comprehensive CV Pilot	This pilot is scheduled for an accelerated deployment beginning Fall 2019 with a full launch of the technologies by the end of 2020. The infrastructure laid as part of this pilot will allow for continued quick deployments of future CV technology.
A.4.ix – Integration of advanced technologies into transportation system management and operations	
Comprehensive CV Pilot	This initiative is an integration of advanced technologies geared towards system management and operations. The program integrates signal improvements with real time data from user applications and roadside equipment.
A.4.x – Demonstration, quantification, and evaluation of the impact of these advanced technologies, strategies, and applications towards safety, mobility, and sustainable movement of people and goods	
High-Resolution Data	The collection of high-resolution data will provide a quantifiable way to assess the technologies' impact.
A.4.xi – Reproducibility of successful systems and services for technology and knowledge transfer to other locations facing similar challenges	
Comprehensive CV Pilot	After deploying various CV applications and infrastructure, a before and after study will be completed to assess the value of each application. This data will be used to reproduce the pilot at other locations. Similar locations will include other college and university campuses and small- to mid-sized municipal bus systems.

DOT ALIGNMENT SUMMARY TABLE	
Initiative Objective Alignment	
Leveraging federal funding to attract other non-Federal sources of infrastructure investment	
Comprehensive CV Pilot	This initiative, with the support of federal funding, will attract more non-Federal partnerships—such as future adoption of the evaluated technology by other campuses and municipalities for both pedestrian safety and transit efficiency.
Accountability for specific measurable outcomes	
High-Resolution Data	This high-resolution data will be used to evaluate the effectiveness of applications, methods, and technology and help to make a case for expanding the pilot to other locations.
Automated Traffic Signal Performance Measures (ATSPM)	Various signal performance measures will be captured to validate the system and corridor performance. The use of this data will allow NCDOT to stay accountable to the expected measurable outcomes.
Initiative Technology Alignment	
A.3.i – Advanced Traveler Information Systems	
Pedestrian in Signalized Crosswalk Warning	Real-time detection when a pedestrian is in a signalized crosswalk or approaching an intersection based on sensors and alerts delivered to drivers with connectivity.
Traveler Information Messaging (TIM)	Drivers, pedestrians, and other users will be able to receive information messages on smart phones and tablets from roadside units.
A.3.ii – Advanced Transportation Management Technologies	
Intelligent Traffic Signal System (I-SIG)	System optimization application uses data collected from CV technology, including information from pedestrians and TSP to maximize flow in real time.
Signal Phase and Timing (SPaT)	SPaT and MAP messages will be transmitted to vehicles that are properly equipped to provide information regarding the signal state and the amount of time until the current phase ends.
A.3.iv – Advanced Public Transportation Systems	
Transit Signal Priority (TSP)	Assists public transportation system operators by optimizing the bus system, primarily through an extension of the green time when a bus is behind schedule.

DOT ALIGNMENT SUMMARY TABLE	
A.3.vi – Advanced Safety Systems (V2V, V2I, Collision Avoidance)	
Red Light Violation Warning	Drivers will receive an alert and recommendation when it is anticipated that their trajectory will result in running a red light.
Speed Warning	Drivers will receive an alert when their current speed exceeds a given threshold by location.
A.3.ix – Advanced mobility and access technologies to support human services for elderly and disabled individuals	
Mobile Accessible Pedestrian Signal System (PED-SIG)	This application supports those who are visually impaired while they cross the street. It will be implemented using a personal portable device that assists the pedestrian in confirming location, allowing them to request service from a traffic signal controller and provide audible information regarding the signal state.

MANAGEMENT STRUCTURE

ORGANIZATION DESCRIPTION

The following subsections describe the partner agencies in the NCDOT MMCVP.

North Carolina Department of Transportation

One of the state's largest government agencies, the North Carolina Department of Transportation (NCDOT) is responsible for maintaining approximately 80,000 miles of roadways, 9,400 traffic signals, and 18,000 bridges and culverts across North Carolina, as well as regulating and implementing programs to support rail, aviation, ferry, public transit, and bicycle and pedestrian transportation.

NCDOT is a performance-based organization with a strategic, data-driven decision-making process that is transparent and accountable. The Department's mission is connecting people, products, and places safely and efficiently with customer focus, accountability, and environmental sensitivity to enhance the economy and vitality of North Carolina.

As the lead agency for the NCDOT MMCVP, NCDOT will oversee the project deployment and coordination with members of the partnership.

North Carolina State University

North Carolina State University (NCSU) is a public research university in Raleigh, North Carolina. The University is in one of the three areas of the Research Triangle that also includes Duke University and University of North Carolina at Chapel Hill. The school was founded by the NC General Assembly in 1887 as a land-grant university. NCSU is the largest of the 16 higher-education institutions in the University of North Carolina system, employing more than 2,000 faculty members and 5,500 administrative and support staff and enrolling nearly 25,000 undergraduates and 9,000 graduate students from across the state and around the world.

As a partner agency for the NCDOT MMCVP, NCSU will provide support for deployment of CV technology, specifically the TSP application to improve the reliability and mobility of the Wolfline bus system.

City of Raleigh

The City of Raleigh, the capitol of North Carolina, is governed by an eight-member City Council elected to two-year terms. The team includes the Mayor, two at-large members, and five district members. The City Council sets City policy, enacts City laws, and adopts a yearly City budget.

The City’s mission is to build a stable platform of evolving services for the community through which they champion positive and sustainable growth and realize visionary ideas for all. The vision is to pursue world-class quality of life by actively collaborating with the community towards a fulfilling and inspired future for all.

As a partner agency for the NCDOT MMCVP, the City of Raleigh will participate in the project management team and guide the project development in line with upcoming initiatives such as the BRT implementation on Western Boulevard. In addition, the City will maintain equipment at the signalized intersections, provide necessary central equipment to support the signal system operations and data collection, and provide NCDOT access to the collected data.

PLAN FOR PARTNERING

In preparation for the pilot, each of the key players was contacted and have formed and signed a Partnership Charter, found in Appendix A. The partners may determine additional agencies who should be involved in the project development either through local collaboration and project coordination or through contracted services that can support project implementation.

The partnership is envisioned as a collaborative effort in which each agency's time and resources are committed to the good of the whole.

PROJECT ADMINISTRATORS

NCDOT will act as the project administrator and shall be responsible for managing the project tasks, schedule, reporting, and budget. Specific responsibilities include approving the project work plan and managing project tasks accordingly, tracking and managing partner contributions to the project, managing vendors and consultants for the project, and completing any required reporting to FHWA or other entities.

TECHNICAL ADVISORY GROUP (TAG)

Upon initiation of the NCDOT MMCVP Project, one or more representatives from each partner agency—NCDOT, NCSU, and City of Raleigh—will be identified for the project's Technical Advisory Group (TAG). The TAG members will be responsible for providing technical oversight to the Project and, upon project implementation, be responsible for operations and management of the deployment as it pertains to their agency. The TAG shall meet in person or by teleconference on a regular basis. Partners commit to providing a representative to attend scheduled TAG meetings as these meetings are of the utmost importance to the success of the pilot and future deployments. Additional key players identified during the process of deployment will also be involved at relevant stages in meetings with the TAG.

STAFFING

The members of the TAG will implement a plan for engaging the private sector and other agencies in the region, including the Go Raleigh bus system, as they prepare to deploy Bus Rapid Transit in the future. They will also work to promote public education and adoption of the multimodal application. Figure 7 displays the key roles of each of the partners. Key résumés for members of the TAG can be found in Appendix C.

FIGURE 6 KEY PLAYER ROLES AND RESPONSIBILITIES

Technical Advisory Group Members

Mohd Aslami is the NCDOT State ITS & Signals Management Engineer. He has more than 25 years of experience focusing on intelligent transportation, signals, and highway sign lighting systems design, management, and operations. Throughout his career, Mohd has taken a forward-thinking approach to his projects. He initially modernized highway sign lighting design by introducing visual lighting analysis applications and improved operational and maintenance costs by migrating to more efficient and longer life HID technology. As the chairperson of a technical committee on the use and application of LED technology in transportation, Mohd led the Department's effort in migrating to all LED-based signal indications and dynamic message signs (DMS), always working to implement new technologies to create a better transportation system.

Mohd also led the Department's efforts to transition from proprietary communications protocol and multiple DMS central control software applications to National Transportation Communications for Intelligent Transportation Systems Protocol (NTCIP) compliant DMS and single NTCIP compliant central software. Recognizing the advantages of Ethernet communications technology, Mohd transitioned from serial to Ethernet communications in new ITS designs. While acting as the State ITS Operations Engineer in cooperation with the Department of Information Technology, he initiated efforts to interconnect regional traffic management centers through a statewide ITS network based on Ethernet technology—ultimately improving the state's traffic and incident management programs.

Mohd's recent initiatives include pilot projects on high-resolution data and connected vehicle technologies. In support of these initiatives, Mohd and his team of electrical engineers are leading the efforts to qualify the latest traffic signal hardware and software technologies for statewide deployment to facilitate readiness for Connected Autonomous Vehicles (CAV) and Automated Traffic Signal Performance Measures (ATSPM).

Keith Mims is a Signal Equipment Design Engineer for NCDOT. Keith has more than 20 years of experience in the transportation industry, serving in various roles within the Signals Management section of the Department. He leads a team of electrical engineers who use their individual perspective to ensure innovative designs and emerging technologies are deployed safely and efficiently on the State Highway System. Keith's technical skill set includes writing technical specifications and reports, a strong understanding of the hardware and software used to control traffic signals, as well as a broad knowledge of communication protocols, standards, and hardware. He embraced the use of new technology and innovative methods of addressing complex issues.

Keith has recently spent much of his time leading efforts to modernize the state's infrastructure and bring advanced technology and state-of-the-art practices to the state. Preparing the infrastructure for current and future initiatives is a major part of his mission. As part of this, the Department has recently transitioned to the latest traffic signal controller hardware and

software. Keith is also involved in leading efforts to deploy automated traffic signal performance measures (ATSPM) and connected vehicle technology in the state. He continues to explore detection technology and other solutions that will help the Department deploy innovative solutions to problems. Keith is committed to making NCDOT a leader when it comes to embracing, deploying, and using state-of-the-art technology.

Ryan Hough is a Signal Equipment Design Engineer with NCDOT. He is responsible for managing the preparation of electrical details associated with traffic signal designs throughout the state of North Carolina. He has 14 years of traffic engineering experience, the majority of which is related to managing and designing traffic signal projects. He has extensive experience in project management, scoping, plan preparation, cost estimates, and specification development for traffic signal projects. Ryan works extensively with NCDOT and municipal staff as well as other stakeholders to address needs related to operations, safety, and efficiency of intersections on the NC State Highway System.

Andrew Skuce is the ITS Design and Development Engineer for the NCDOT ITS & Signals Unit where he is responsible for managing the ITS Design team through the design and review of ITS projects. He has 5 years of experience working on plans and special provisions for signal communications projects, ITS projects, and computerized signal system projects. Andrew is involved with writing specifications and evaluating new ITS devices and technologies, including new wireless radios for signal and ITS device communications as well as the new full color DMS specification. He has also worked on testing, evaluating, and troubleshooting CV technologies currently deployed on pilot projects in the state.

Neil Avery is the ITS Engineer for the State of North Carolina and is responsible for managing the preparation of plans for the deployment of ITS devices and infrastructure through individual ITS projects, computerized signal systems, and signals communications plans for the NC Highway System. He has 29 years of experience working with ITS initiatives focusing on plans, specifications, operations, and maintenance. Neil also works closely with the State Traffic Operations Center to identify and assess needs and gaps that are critical to providing vital information to the center's operational needs. He is currently working on two computerized signal systems that will be deploying CV Technology. One system is deploying DSRC technology at approximately 18 intersections and the second project is installing DSRC and cellular technologies at approximately 29 intersections. Future deployments with other upcoming computerized signal systems are looking at deploying both technologies on a city-wide basis.

Mike Kennon is the Assistant Director of the North Carolina State University (NCSU) Transportation Department after a career in public service at the City of Raleigh and City of Durham. He is responsible for managing the University's transportation planning and operations program—including the Wolfline bus system, transit, parking, bike and pedestrian planning, operations, transportation demand management, and other special projects. Mike has 33 years of experience, the majority of which took place in the transportation department

at City of Raleigh. He has extensive experience in traffic control, traffic signal system management, public works, and traffic engineering.

NCDOT MMCVP Primary Point of Contact
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North Carolina Department of Transportation
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APPENDIX A – PROJECT PARTNERSHIP CHARTER

In 2017, there was one pedestrian fatality every 88 minutes in the United States on average. Pedestrian fatalities accounted for 16% of traffic fatalities nationally in 2017. This national average represents a traffic fatality rate of 1.84 deaths per 100,000 population. North Carolina's traffic fatality rate per 100,000 was 1.93, almost 5% higher than the national average. 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.

To address these safety concerns, the North Carolina Department of Transportation (NCDOT) Multimodal Connected Vehicle Pilot (MMCVP) aims to create a connected environment that can evaluate the impact of Connected Vehicle (CV) technology on driver and pedestrian safety. This connected environment will include an application delivering safety notifications to all users of the multimodal application: pedestrians, cyclists, transit operators and riders, and motorists. The CV applications will use a hybrid DSRC/Cellular communication system that integrates in-vehicle and roadside CV infrastructure.

The pilot will also focus heavily on improvements to the NCSU Wolfline bus system. To improve transit vehicle efficiency a new Intelligent Traffic Signal System (I-SIG) will be deployed to implement Transit Signal Priority (TSP) and collect and analyze High Resolution Data (HRD). The list of technologies to be deployed is found in Table 1.

To best support the deployment of the pilot, a Partnership of the following agencies will be formed:

- **NCDOT – Transportation Systems Management and Operations Unit (TSMO)**
- **North Carolina State University Transportation**
- **City of Raleigh**

Table 6 Multimodal Connected Vehicle Pilot (MMCVP) Technology

Signal & Intersection Improvements	Multimodal Applications
✓ Signal Phase and Timing (SPaT)	✓ Pedestrian in Crosswalk Warning
✓ Transit Signal Priority (TSP)	✓ Mobile Accessible Pedestrian Signal System
✓ Intelligent Traffic Signal System (I-SIG)	✓ Red Light Violation Warning
✓ High Resolution Data (HRD)	✓ Speed Threshold Warning
✓ DSRC/Cellular Hybrid Communications	✓ Work Zone Warning
✓ Automated Traffic Signal Performance Measures (ATSPM)	✓ Connected Eco-Driving

VISION AND GOALS

The Partnership's vision for the NCDOT MMCVP is to ***improve the quality of life for the residents of Raleigh and students at NCSU, Meredith College, and Governor Morehead School***. It is envisioned that this pilot will improve safety, increase mobility, and help reduce environmental impacts. The information gathered through the pilot deployment is expected to support further deployments of CV technology within the state, expanding the safety and mobility benefits to North Carolina residents in similar areas across the state. The partnership is organized around the following goals:

- Deploy CV infrastructure that supports V2X applications inclusive of upgrades to traffic signal hardware, software, and TMC systems to support compatibility with CV applications,
- Upgrade traffic signal controllers to improve mobility around the NCSU campus through improved traffic progression, application of transit signal priority applications to support schedule adherence of Wolfline buses, and provide SPaT data to enhance mobility of equipped vehicles,
- Use of multimodal application safety warnings to reduce the number of incidents within the pilot area through pedestrian alerts, speed warnings, and red-light violation notifications
- Reduce environmental impacts within the pilot area by providing SPaT data to reduce stops and idle times to support emissions reductions, and
- Improve agency efficiency by integrating new technologies related to data collection and analysis - streamline bus system scheduling and dispatch, reduce demand on first responders based on crash reductions (number and severity).

PURPOSE OF THE PARTNERSHIP

The purpose for forming the Partnership in support of the NCDOT MMCVP project is to:

- Create an environment for innovative solutions
- Promote collaboration between partners with a stake in the improved mobility and safety of the geographic area
- Provide a forum for the exchange of data and information for constant improvements to the pilot system and performance evaluation for expanding to other pilot test sites.

GUIDING PRINCIPLES

The following principles guide the partner participation in the project:

- Partners will be guided by the vision and goals reflected in this Charter
- Partners will foster a spirit of collaboration to facilitate key decision making, identification of opportunities, risk management, and problem resolution
- Partners will commit to active participation in project-related meetings, workshops and activities
- Partners will pool time, talent, and resources to achieve agreed-upon goals associated with the project
- Partners agree to measure and report progress and success

PARTNERSHIP ORGANIZATION AND GOVERNANCE

The Partnership is envisioned as a collaborative effort in which each agency's time and resources are committed to the good of the whole. Partner agencies commit to 1) adopt this Charter by signature; 2) participate regularly in project meetings; 3) provide a level of financial or in-kind support as designated in a formal letter of support; and 4) provide the level of operational support and data agreed upon by the Technical Advisory Group (TAG).

PROJECT ADMINISTRATORS

NCDOT will act as the project administrator and shall be responsible for managing the project tasks, schedule, reporting, and budget. Specific responsibilities include approving the project work plan and managing project tasks accordingly, tracking and managing partner contributions to the project, managing vendors and consultants for the project, and completing any required reporting to FHWA or other entities.

TECHNICAL ADVISORY GROUP (TAG)

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SIGNATORIES

DocuSigned by:
Mohd Aslami
5D9B0BA6DBB64D5...

8/1/2019

Mohd Aslami, NCDOT – TSMO

DocuSigned by:
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FB8CF07A630C4F6...

8/2/2019

Michael Kennon - North Carolina State University Transportation

DocuSigned by:
Tansy Hayward
CF0BFEE6AFF24DC...

8/1/2019

Tansy Hayward - City of Raleigh

APPENDIX C – ARCHITECTURE DIAGRAMS

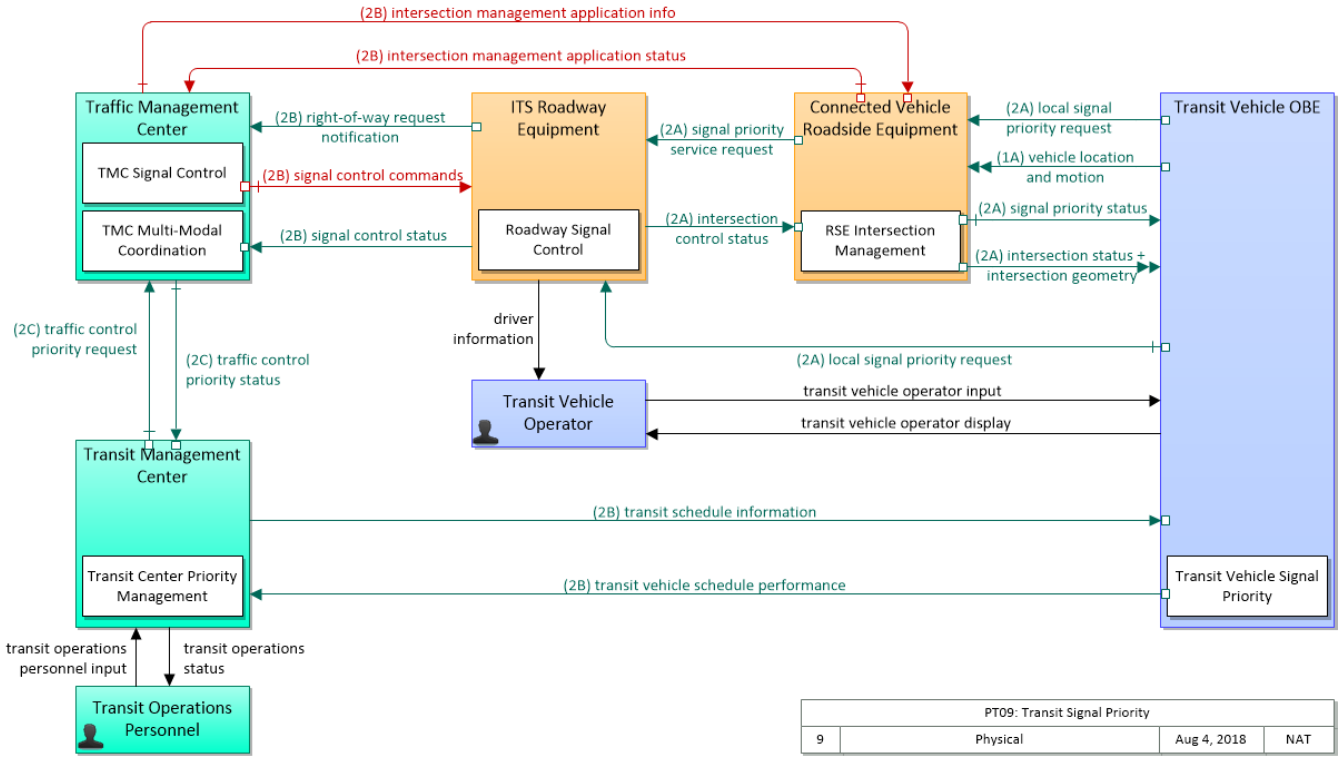

FIGURE 7 TRANSIT SIGNAL PRIORITY ARCHITECTURE

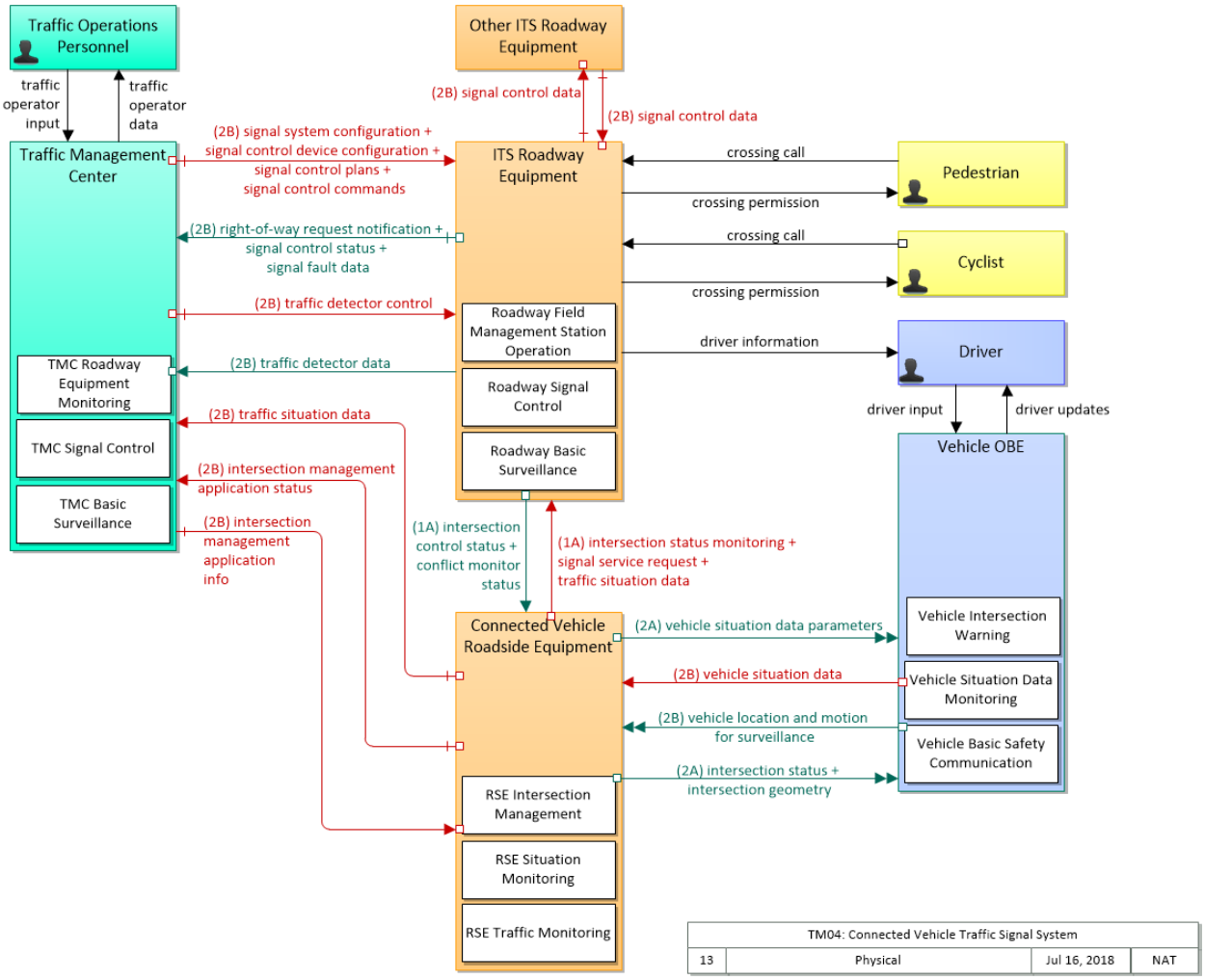

FIGURE 8 CONNECTED VEHICLE TRAFFIC SIGNAL SYSTEM ARCHITECTURE

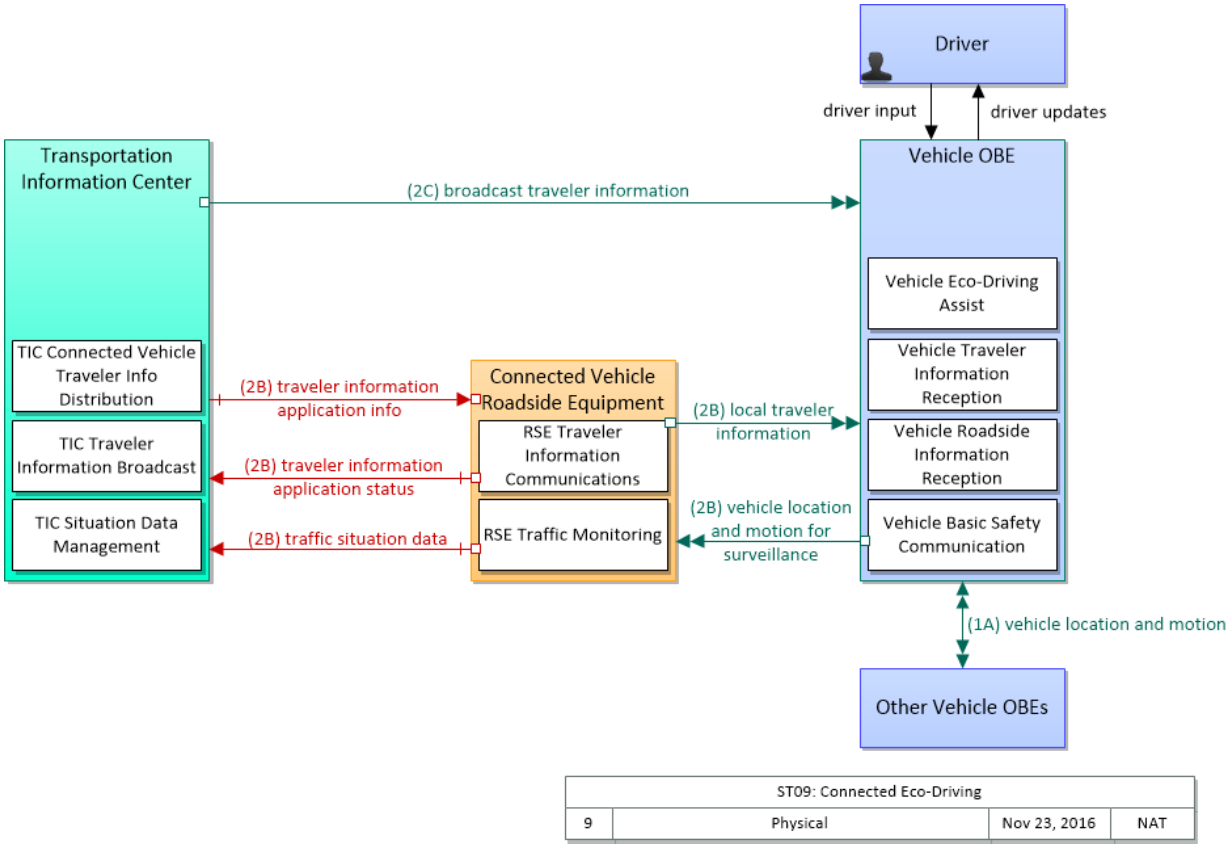

FIGURE 9 CONNECTED ECO-DRIVING ARCHITECTURE