Leading in Sustainable Safety with V2X Technology in Oakland County Michigan

Prototype Deployment Plan

Recipient Name: Road Commission Oakland County (RCOC)

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Prototype Deployment Plan

ROAD COMMISSION for OAKLAND COUNTY

1 Table of Contents

2 Scope

The *Leading in Sustainable Safety with C-V2X Technology in Oakland County Project* (referred to as the "Project") in Oakland County, Michigan aims to build an economically sustainable model for the deployment of Cellular-Vehicle-to-Everything (C-V2X) technology. The Road Commission for Oakland County (RCOC) was awarded a $2 million USDOT Stage 1 Planning and Prototyping SMART Grant to develop this model. This document will focus on the prototyping aspects of the project.

This "Prototype Demonstration Plan" (referred to as the "Plan") serves as a comprehensive guide and blueprint for the successful prototype demonstration of C-V2X technology in Oakland County, Michigan. This document outlines the objectives of the prototype, technology architecture, deployment area, and integration considerations necessary for an effective V2X system. Importantly, this document not only guides the current prototype process but also serves as input for the future County-Wide Deployment plan, which will be developed as a separate document for Stage 1 of the project and executed in Stage 2 of the project.

The prototype will be deployed at five intersections and ten vehicles to demonstrate the foundational components of a V2X system. Given the short duration of the Stage 1 project and the limited size of the prototype, use cases are planned to establish a foundational C-V2X system that can demonstrate a variety of capabilities of V2X technology. Additional use cases may be introduced as part of the Stage 1 lessons learned. The anticipated scale of a Stage 2 deployment is a multi-year plan for RCOC to install and maintain this lifesaving V2X technology in a sustainable manner across more than 2,700miles of roads and over 1500 traffic signals in the Oakland County in line with the USDOT's national V2X deployment plan: "Saving Lives with Connectivity: A Plan to Accelerate V2X Deployment".

The C-V2X use cases that will be demonstrated are C-V2X Signal Priority, Vulnerable Road User (VRU) alerts via Cooperative Perception, C-V2X Fleet Intelligence and utilizing the unlicensed Wi-Fi spectrum for V2X communications that are not expected to fit in the newly reduced 5.9 GHz spectrum.

Partners on the Project

The key partners for the prototype demonstration are:

- **The Road Commission for Oakland County** – The project lead with ultimate decision-making on the intersections selected, proving fleet vehicles, traffic engineering guidelines, and traffic management connectivity in alignment with their policies and procedures.
- **P3Mobility** – A digital infrastructure project development firm that provides consulting services and a software platform that enables fee-collection and a sustainable commercial business model in the V2X ecosystem. System design lead, V2X software lead, and project management lead for the prototype.
- **The Mannik & Smith Group** – A transportation engineering firm that has led the infrastructure programming and design for three of the Midwest's most significant smart mobility test centers. Traffic analysis and inputs into the prototype intersection criteria and selection.
- **Integral Blue** – ITS technology expert responsible for V2X RSU installation, integration, and FCC registration, including the guidelines and checklists for deployment.
- **UM CEE** – A research and development group within the University of Michigan Transportation Research Institute. Responsible for object detection machine learning and algorithm development for Vulnerable Road User use cases.
- **Brandmotion** –A developer and distributor of automotive retrofit safety technology. Responsible for the OBU and antenna installation in the test vehicles.

3 Reference Documents

This Prototype Deployment Plan has been developed by drawing upon a diverse set of reference documents that provide valuable insights and best practices in the field of C-V2X technology. These documents include:

- Industry standards and guidelines from the Institute of Electrical and Electronics Engineers (IEEE), the Society of Automotive Engineers (SAE), and Institute of Transportation Engineers (ITE)
    - CTI 4501 v01.01
    - SAE J2735, Sep 2023 revision
    - SAE J3224, Aug 2022
    - CAMP Red Light Violation Warning Application Vehicle System, Concept of Operations. Version 2.4
    - Creation of a Guidance Document for MAP Preparation, prepared by Athey Creek Consultants, LLC and Synesis Partners, LLC.
- Documents published by the USDOT from past V2X projects, specifically the CV pilot projects led by the New York City Department of Transportation (NYCDOT), the Tampa Hillsborough Expressway Authority (THEA), and the Wyoming Department of Transportation (WYDOT).
- Various data that was provided from the Southeast Michigan Council of Governments (SEMCOG) to assist with site selection, such as Traffic Counts, Crash Data, Bike Lane Locations, and Truck Routes.

List of Acronyms

Acronym	Description
AAA	Authentication, authorization, accounting services
AARM	Authorization Request Response Message
ARM	Authorization Request Message
AS	Authorization Server
ATC	Advanced Traffic Controller

Acronym	Description
AV	Autonomous Vehicle
AWS	Amazon Web Service
BSM	Basic Safety Message
CP	Cooperative Perception (detecting vulnerable road users VRU)
CPM	Cooperative perception messages
C-V2X	Cellular Vehicle to Everything (referring to the specific use of the 5.9 Ghz ITS spectrum)
ETA	Estimated Time of Arrival
EVTA	Equipped Vehicle Trajectory Awareness
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning Service
HMI	Human Machine Interface
IOO	Infrastructure Owners and Operators
ITS	Intelligent Transportation System
NTCIP	National Transportation Communications for Intelligent Transportation System Protocol
OBU	On Board Unit
PDU	Power Distribution Unit
PII	Personal identifiable information
RCOC	Road Commission of Oakland County
RSU	Roadside Unit
SAE	Society of Automotive Engineers
SAE J2735	Personal safety messages (PSM)
SAE J3224	Cooperative perception messages ((CPM), a.k.a. SDSM)
SCMS	Security Credential Management System
SCP	Signal Control Prioritization
SDSM	Sensor Data Sharing Message
SPaT	Signal Phase and Timing
SRM	Signal Request Message
SSP	Service Specific Permissions
SSS	Sensor Sharing Service (defined in SAE J3224)
TSP	Transit Signal Priority

Acronym	Description
U-NII	Unified or Unlicensed National Information Infrastructure
V2I	Vehicle to Infrastructure
V2X	Vehicle to Everything (general connectivity, may or may not be within the 5.9 Ghz range)
VPN	Virtual Private Network
VRU	Vulnerable Road User (e.g. pedestrian)
WSA	WAVE Service Announcement
XTS	Extended Transportation Spectrum

4 Current Situation

V2X Deployment Background

Transportation safety is an unmet crisis in the United States. In 2021, there were nearly 7 million traffic crashes and 43,000 traffic deaths. This is the highest number of fatalities since 2005 and the largest annual percentage increase in the USDOT's reporting history. These deaths and crashes could largely be avoided if V2X infrastructure and V2X-equipped vehicles were deployed across the country.

The adoption of V2X in the United States has been stalled by numerous challenges over the past several years, but the USDOT has made it clear that it is looking for collaboration between public and private sector leaders to advance the V2X ecosystem.

RCOC has answered this call. As a proven leader in intelligent transportation and advanced transportation technologies, RCOC is partnering with a coalition of private sector organizations to develop a financially sustainable plan for deploying V2X technology to help accelerate the deployment of this technology across the nation.

To date, RCOC has deployed many advanced transportation and traffic technologies, but the deployment of V2X technology has been limited. In 2007, in a joint project with the Federal Highway Administration and the Michigan Department of Transportation, RCOC deployed the first large-scale demonstration of connected vehicle applications in the nation. 55 roadside units (RSUs) were installed at 43 traffic signals covering about 45 square miles. The project successfully proved that data could be shared between the infrastructure and vehicles in a timely, accurate and useful manner to support connected vehicle applications. RCOC will continue its leadership in advanced transportation and traffic technologies with this SMART grant project.

5 Goals and Objectives

The goals and objectives for the RCOC Stage 1 Prototype Deployment are:

Goal 1: Deploy V2X Infrastructure to Support the Applications Identified During Stage 1

Objective	Description
1	Deploy V2X technologies to support V2X applications.
2	Upgrade traffic cabinet hardware and software at the prototype locations to ensure compatibility with V2X Applications.
3	Demonstrate V2X technologies and applications in RCOC fleet vehicles.
4	Demonstrate how the unlicensed Wi-Fi spectrum can be utilized to provide SAE-conforming, SCMS encrypted V2X messages to vehicles by creating a de-facto dedicated spectrum.
5	Identify the solutions required for existing network and security architecture to allow intersection connectivity to outside Internet services.

Goal 2: Demonstrate improvements in Safety enabled by C-V2X Technology

Objective	Description
1	Install Gridsmart Cameras and Gridsmart Processors at the prototype locations and integrate the Gridsmart system into the V2X system.
2	Utilize artificial intelligence and a machine learning algorithm to generate cooperative perception messages.

3	Provide detection of pedestrians and warnings to drivers of potential pedestrian conflicts giving feedback on false warnings, distractions, and value-added alerts.

Goal 3: Demonstrate improvements in Mobility enabled by V2X Technology

Objective	Description
1	Replace existing traffic controllers with controllers that better support V2X technologies.
2	Provide Signal Priority applications to RCOC fleet vehicles to improve overall mobility and reduce stops and idle time, thus reducing emissions.

Goal 4: Demonstrate the Potential Revenue Generating V2X Applications that Enable an Economically Sustainable C-V2X Deployment

Objective	Description
1	Deploy a V2X Authorization Server that manages the Authorization, Authentication, and Accounting for subscription C-V2X services for fleet vehicles.

Goal 5: Demonstrate how C-V2X Technology Improves Agency Efficiency

Objective	Description
1	Improve traffic data collection capability, reducing the costs of collecting data.
2	Reduce the number of incidents and RCOC responses to incidents.
3	Reduce the time agencies take to gather data.

Goal 6: Education and Business Case Inputs

Objective	Description
1	By installing technology in vehicles and intersections, more accurate costs for the business case will be gathered
2	By deploying a prototype, education of the emerging technology is made available to internal and external stakeholders for feedback

6 Applications and Concepts of the Proposed System

This prototype will demonstrate the following V2X applications:

Cooperative Perception

Summary

Cooperative Perception applications, such as Vulnerable Road User (VRU) Alerts, utilize infrastructure-based sensors such as cameras, radar, and lidar to enhance road safety by detecting VRUs and alerting vehicles to potential collisions. This technology extends a vehicle's sensory range beyond its immediate line of sight, offering both human drivers and Autonomous Vehicles (AVs) critical warnings about hazards that may be obscured by blind spots, other vehicles, or lack of attention. By integrating data from external sensors, Cooperative Perception can significantly improve safety. Specifically, at signalized intersections and marked crosswalks these applications can alert drivers about pedestrians potentially hidden from view or acting unpredictably. The effectiveness of these systems in preventing incidents is quantifiable through the measurement of alerts issued, conflicts observed, and crash data collected. Utilizing C-V2X for direct communication ensures reliable, low-latency transmission of safety-critical information, thereby contributing to safer, more efficient road use for all participants.

Cooperative Perception from infrastructure-based sensors does not require individual VRUs to carry a specific device or technology to be protected. This approach ensures safety for all VRUs, irrespective of their access to smart devices, avoiding privacy invasions and providing equitable protection.

This prototype will generate SAE J3224 Cooperative Perception Messages based on data from video detection cameras and processed by a machine learning detection algorithm. An alert will be displayed to a driver on a tablet mounted in the vehicle if a potential conflict is detected. There are three levels of alert that the driver may receive based on the location of the detected VRU, the location of the vehicle, and the traffic signal status. The prototype will not classify different types of VRUs (e.g. pedestrian, bicycle, scooter). An alert for the general category of "VRU" will be displayed on the tablet and be accompanied by an audio alert.

Level 1: Provides awareness that a VRU is in an area they are permitted to be in. E.g. a pedestrian crossing within the crosswalk when they have the walk signal.

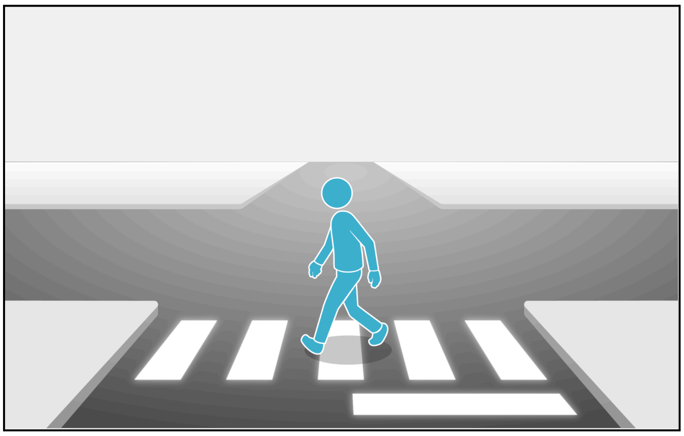

Figure 1

Level 2: Provides an alert that a VRU is in an area they are not permitted to be in. E.g. a pedestrian crossing when they do not have the walk signal or a pedestrian walking outside of a designated crosswalk.

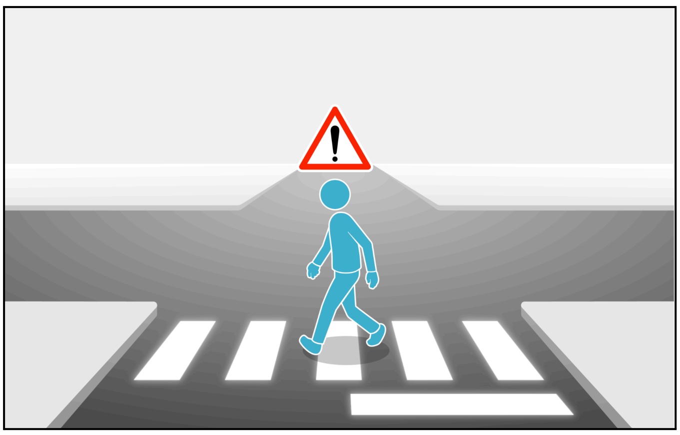

Figure 2

Level 3: Provides a warning that a VRU is in the immediate path of the vehicle regardless of crosswalk status. Level 3's visual warning will be supplemented with an audio warning alert to further warn the driver.

Figure 3

Operational Scenarios

Application	**Cooperative Perception**			
Scenario	CP1: VRU Alert over 5.9 GHz spectrum			
Objective	To alert a driver of the presence of a pedestrian			
Sequence of Events	**Source**	**Step**	**Key Actions**	**Comments**
	VRU	1a	VRU approaches equipped intersection	
	Vehicle	1b	Vehicle approaches equipped intersection	
	Intersection Sensor	2	Intersection sensor captures raw data of the presence of the VRU	
	Machine Learning Algorithm	3	Machine learning algorithm that has been trained processes raw data from sensor to generate an object list	Object list includes GPS position

Application	Cooperative Perception			
	P3M V2X Hub	4	P3M V2X Hub receives the object list and generates an SDSM	SDSM is a SAE J3224 message
	P3M V2X Hub	5a	P3M V2X Hub sends the SDSM as an Immediate Forward message to the RSU	
	P3M V2X Hub	5b	P3M V2X Hub sends the SDSM to the data repository for archiving	
	P3M V2X Hub	5c	P3M V2X Hub sends information from the SDSM to the V2X Fleet Intelligence where it is stored for future analysis	
	RSU	6	RSU securely broadcasts the SDSM along with MAP and SPAT messages over the 5.9 GHz Spectrum	Managed with a configure
	OBU	7	OBU receives SDSM, MAP and SPAT messages	
	OBU	8	OBU triggers a VRU alert based on a calculation using the SDSM, MAP, SPAT and its own BSM	
	Driver Display	9	Driver display displays the appropriate VRU alert to the driver	
	Vehicle	10	Vehicle takes corrective action	
	IOO Operator	11	Accesses V2X Fleet Intelligence to visually display the vehicle's trajectory, signal status and VRU information	

Table 1

Application	**Cooperative Perception**			
Scenario	CP2: VRU Alert over Extended Transportation Spectrum			
Objective	To alert a driver of the presence of a pedestrian			
Sequence of Events	**Source**	**Step**	**Key Actions**	**Comments**
	VRU	1a	VRU approaches equipped intersection	
	Vehicle	1b	Vehicle approaches equipped intersection	
	Intersection Sensor	2	Intersection sensor captures raw data of the presence of the VRU	
	Machine Learning Algorithm	3	Machine learning algorithm processes raw data from sensor to generate an object list	Object list includes GPS position
	P3M V2X Hub	4	P3M V2X Hub receives the object list and generates an SDSM	SDSM is a SAE J3224 message
	P3M V2X Hub	5a	P3M V2X Hub sends the SDSM as an Immediate Forward message to the RSU	
	P3M V2X Hub	5b	P3M V2X Hub sends the SDSM to the data repository for archiving	
	P3M V2X Hub	5c	P3M V2X Hub sends information from the SDSM to the V2X Fleet Intelligence where it is stored for future analysis	
	RSU	6a	RSU securely broadcasts the SDSM over the Extended Transportation Spectrum	Managed with a configuration
	RSU	6b	RSU securely broadcasts MAP and SPAT messages over the 5.9 GHz Spectrum	
	OBU	7	OBU receives SDSM, MAP and SPAT messages	
	OBU	8	OBU triggers a VRU alert based on a calculation using the SDSM, MAP, SPAT and its own BSM	

Application	**Cooperative Perception**			
Scenario	CP2: VRU Alert over Extended Transportation Spectrum			
	Driver Display	9	Driver display displays the appropriate VRU alert to the driver	
	Vehicle	10	Vehicle takes corrective action	
	IOO Operato r	11	Accesses V2X Fleet Intelligence to visually display the vehicle's trajectory, signal status and VRU information	

Table 2

Signal Priority and Preemption

C-V2X Signal Priority and Preemption both aim to improve road safety and traffic flow. Signal preemption grants emergency vehicles like ambulances, fire trucks, or snowplows immediate green lights, ensuring faster response times in critical situations. Signal priority benefits public transit and freight vehicles by adjusting traffic signals to reduce stops and delays, also improving safety and travel time.

This system operates by sending Signal Request Messages (SRMs) from C-V2X OBUs in vehicles to C-V2X Roadside Units (RSUs) based on vehicle location and traffic signal status. The OBU maintains a target intersection based on proximity and vehicle directionality. MAP messages are used to identify lanes and stop bar distance (and therefore ETA). One of the key innovations introduced in this prototype is the mapping of the SSP (Service Specific Permissions) in the SCMS certificates to the *vehicleClassType* and *vehicleClassLevel* fields defined in the NTCIP 1211 request.

Another innovation introduced in this prototype is that the cloud based V2X Authorization Server authenticates the OBU based on the security credentials presented in the request. This allows the OBU to securely identify itself to the V2X Authorization Server. The V2X Authorization Server manages subscription accounts to keep track of the services delivered to individual vehicles. This ensures that only authorized vehicles can access Signal Priority. Once a vehicle is considered authorized, the

C-V2X system operating at the infrastructure transposes SRMs into NTCIP 1211 requests, which are forwarded to an Econolite Advanced Traffic Controller (ATC) where it is processed based on predefined strategies.

This prototype will demonstrate Signal Priority for ten RCOC maintenance vehicles to test and validate the technology. In the future, this application may expand to other vehicles, such as RCOC's salt trucks.

Operational Scenarios

Application	Signal Priority			
Scenario	SP1: Signal Priority is Authorized and Processed			
Objective	To allow a vehicle to pass more safely and efficiently through an intersection by extending the length of the green light			
Sequence of Events	**Source**	**Step**	**Key Actions**	**Comments**
	Vehicle	1	Vehicle approaches equipped intersection	
	RSU	2	RSU broadcasts WAVE Service Announcement (WSA) that indicates which services are available. WSA indicates that Signal Priority is available.	
	OBU	3a	OBU receives WSA and generates an Authorization Request Message (ARM) and sends it to the V2X Authorization Server via IPv6 routing in the RSU	
	OBU	3b	OBU generates a Signal Request Message (SRM) and broadcasts it to the RSU	
	V2X Authorization Server	4	Receives the ARM and validates that the vehicle is authorized for Signal Priority for these conditions. An Authorization Request Response Message (ARRM) is generated and sent to the OBU via IPv6 routing in the RSU	Conditions may be location, time of day or other criteria

Application	Signal Priority			
Scenario	SP1: Signal Priority is Authorized and Processed			
	P3M V2X Hub	5	Receives the SRM and generates an NTCIP 1211 request to be sent to the traffic controller	
	P3M V2X Hub	5b	P3M V2X Hub sends the SRM to the data repository for archiving	
	P3M V2X Hub	5c	P3M V2X Hub sends information from the SRM to the OpMonitor where it is stored for future analysis	
	Traffic Controller	6	Traffic controller determines if the request is valid and can be processed based on current conditions. In this case, the request is valid, and the green light duration is extended accordingly.	The traffic controller takes into account the signal status and other criteria
	Vehicle	7	Vehicle passes through the intersection	
	IOO Operator	8	Accesses OpMonitor to visually display the history of signal priority requests	
	IOO Operator	9	Accesses V2X Fleet Intelligence to visually display the vehicle's trajectory, signal status and environment information	

Table 3

Application	**Signal Priority**			
Scenario	SP2: Signal Priority is NOT Authorized and NOT Processed			
Objective	To not respond to a non-enrolled vehicle requesting extending the length of the green light.			
SP Sequence of Events	**Source**	**Step**	**Key Actions**	**Comments**
	Vehicle	1	Vehicle approaches equipped intersection	
	RSU	2	RSU broadcasts WAVE Service Announcement (WSA) that indicates which services are	

Application	**Signal Priority**			
Scenario	SP2: Signal Priority is NOT Authorized and NOT Processed			
			available. WSA indicates that Signal Priority is available.	
	OBU	3a	OBU receives WSA and generates an Authorization Request Message (ARM) and sends it to the V2X Authorization Server via IPv6 routing in the RSU	
	OBU	3b	OBU generates a Signal Request Message (SRM) and broadcasts it to the RSU	
	V2X Authorization Server	4	Receives the ARM and determines the vehicle is not authorized for Signal Priority for these conditions. An Authorization Request Response Message (ARRM) is generated and sent to the OBU via IPv6 routing in the RSU indicating the request was denied.	
	Vehicle	5	Vehicle passes through the intersection without priority	

Table 4

V2X Fleet Intelligence

V2X Fleet Intelligence is designed to capture enhanced data related to a driving situation. Fleet Intelligence aggregates critical V2X data, including Basic Safety Messages (BSMs), MAP messages, Signal Phase and Timing (SPAT), and Sensor Data Sharing Messages (SDSMs). The data is stored and distributed for a variety of use cases. It can provide fleet operators with insights into driver behavior, traffic conditions, and potential hazards. It can also offer an enhanced, comprehensive view of driving scenarios to insurance companies to help with more accurate policy writing or crash investigation. Lastly, the data can be used by Infrastructure Owner Operators to enable more informed operational decision-making.

Operational Scenarios

Application	V2X Fleet Intelligence			
Scenario	FI1: Fleet Intelligence is logged			
Objective	To aggregate granular data related to a driving scenario			
Sequence of Events	Source	Step	Key Actions	Comments
	Vehicle	1	Vehicle approaches equipped intersection	
	OBU	2	OBU broadcasts BSMs 10 times per second	
	RSU	3	RSU receives the BSM and routes the message to the P3M V2X Hub	
	P3M V2X Hub	4	P3M V2X Hub aggregates data elements from the BSM, SPAT, MAP and SDSMs and sends that information to the OpMonitor	
	Vehicle	5	Vehicle passes through the intersection	
	IOO Operator	6	Accesses V2X Fleet Intelligence to visually display the vehicle's trajectory, signal status and environment information	

Table 5

Other Concepts of the Proposed System

Authorization/Revenue Generation

RCOC recognizes that federal grants cannot be the only source of funding to support the deployment and operation of V2X infrastructure. This prototype will explore technical requirements to facilitate revenue generating services that can be used to finance ongoing operation and maintenance or support private investment to create digital infrastructure public-private partnerships (P3s).

The commercial V2X applications are facilitated by the technology architecture of the system. The core of the platform is the V2X Authorization Server, which manages the authorization of the services and each vehicle's subscription account. For each commercial V2X application offered at a specific infrastructure location, the V2X Roadside Unit (RSU) is configured to announce the application availability. Upon receiving the announcement, any V2X on-board unit (OBU) within range and possessing the appropriate security credentials for the application will send a request to the V2X Authorization Server. The V2X Authorization Server authenticates a vehicle's request for a commercial V2X application based on the Security Credential and Management System (SCMS) certificates presented in the request. The V2X Authorization Server is part of the SCMS chain-of-trust by obtaining a "component certificate". The public key for this certificate is included in the application announcement broadcast by the RSU, which in turn enables the OBU to encrypt PII before it is transmitted over the air. This ensures compliance with the SCMS requirements for protection of anonymity, while simultaneously enabling the V2X Authorization Server to manage identified subscription accounts and to keep track of the applications delivered to individual vehicles.

Extended Transportation Spectrum

This prototype applies C-V2X communication principles to the U-NII, or unlicensed, Wi-Fi spectrum - known as the Extended Transportation Spectrum. This addresses the low-latency bandwidth limitations imposed by the recent FCC ruling to reduce the amount of available dedicated 5.9 GHz ITS spectrum.

A periodic scanning of neighboring U-NII bands feeds information about traffic volume, channel numbers and signal strength of detected traffic (RSSI) to a control system with decision-making authority to change the operating conditions. In this way, if the volumes and RSSI of neighboring U-NII traffic reach pre-configured thresholds for interference, the RSU can dynamically change to a less congested or contested U-NII spectrum channel, or be switched back to using the C-V2X protocol (over the 30 MHz portion of the 5.9 GHz spectrum) or alternatively, the presence of Cooperative Perception, as indicated by its Provider Service Identifier (PSID) can be withdrawn from its WAVE Service Announcement so that approaching OBUs are notified that the Cooperative Perception service is no longer available.

This use case accommodates the data necessary for critical C-V2X applications. This prototype will demonstrate the feasibility of broadcasting cooperative perception messages in the U-NII spectrum. By leveraging the unlicensed spectrum, it ensures that safety-critical use cases that require low-latency are not compromised. This solution not only adheres to the evolving regulatory landscape but also ensures that the full potential of technology is realized, fostering safer and more connected transportation systems.

Operations Monitoring

The operations monitoring software (OpMonitor) is a real-time host application that monitors the operational status of the C-V2X equipment and technology deployed at the prototype intersections. There are three responsibilities of the OpMonitor:

1. **Monitoring of the V2X Hub plugins – Covered in Section 13 Maintenance and Operations**
2. **Recording of operational events:**

Operational events are defined as events associated with the activation or termination of any Smart Road services supported by one or more plugins. The occurrence of these events is observed and reported by the appropriate plugin. For example, with respect to the EVTA plugin, these events are defined as:

- Start and end of an EVTA trajectory for an individual OBU
- Received request from the AAA Server for a specific trajectory
- Transmitted specific trajectory to the AAA Server
- Received acknowledgment from the AAA Server
- Vulnerable Road User detected (SDSM sent to RSU for broadcast)

3. **Recording of SPaT (Signal Phase and Timing) data:**

SPaT data is recorded to facilitate the observation of ATC (advanced traffic controller) performance during specific operational conditions. While these conditions are in effect, the V2X Hub SPaT plugin reports to the OpMonitor. In this project, the detection of VRU will trigger the SPaT plugin to begin reporting to the OpMonitor. This process will terminate once the VRU is no longer in the intersection. The SPaT information can be observed through the OpMonitor's Web UI. This provides a simple tool for traffic management personnel to determine whether an ATC, configured to enhance VRU safety in an intersection, is operating as expected.

7 Technical Design

The prototype demonstration includes innovative new technologies that RCOC did not have defined requirements for the system to meet. There was an inherent expectation the system would utilize the existing standards, best practices and lessons learned from prior projects, and the expertise of the hardware vendors selected to deliver a functioning system on time with managed risk.

Hardware Integration Steps:

1. Customer Kickoff Meetings (critical to agree on the use cases and RASICs)
2. Requirements Capture
3. System Architecture
4. Vendor Selection and Procurement [(1)]
5. Intersection Assessments [(2)]
6. Testing for Deployment
    a. Bench
    b. Layout
    c. Intersection

Notes:

- [(1)] Reduced risk by using proven vendors the project team had experience with.
- [(2)] Planned for a 2nd loop of Procurement after the (5) intersections were surveyed (e.g. additional cameras, updated controller, mounting PoE injectors).

Software Integration Steps:

The major work packages for the prototype demonstration were predominantly software integration related and followed the basic process of:

1 Software Integration Design
2 Software Integration Development
3 Testing and Verification Loops

The main technical software architecture decision was that application software handing the communications to the traffic controller (NTCIP 1202/1211) would not reside in the RSU but instead in the edge computer. The thought process in putting this software on an edge computer was longer term; this gives the IOO the flexibility to own, license, and modify without dependence on a hardware RSU provider.

The following software elements were integrated with minor tailoring and verification for RCOC system at the project start:

- V2X Hub
- Priority request generator plug in
- Equipped Vehicle Trajectory Awareness plug in
- SRM authentication
- Authentication Server (on premise)
- Operational Monitor Server (on premise)
- MSight object detection algorithm (UM)
- Updated MAP, SPaT plug ins
- Cooperative Perception plug in
- OBU VRU alert application
- Extended Wi-Fi (XTS)
- Moving Authorization Server and OpMonitor to the AWS cloud

System Integration Steps:

One technical challenge was as seamless an integration as possible into the existing RCOC traffic operations and intersection hardware with the new technology. To reduce the risk the following approaches were agreed:

- Must use existing camera vendor Cubic including their support processor (edge #1) with no changes.
- RCOC IT to lead the VPN tunnel connection to their firewall protected systems – ultimate judge on safety and security.
- Combined the UM object detection software and the P3M V2X hub and plugins on edge device #2. Each software system will be separately containerized.
- Request system access via web services accounts to allow for remote V2X edge updates for VRU algorithm enhancements.

System Architecture

High Level System Architecture:

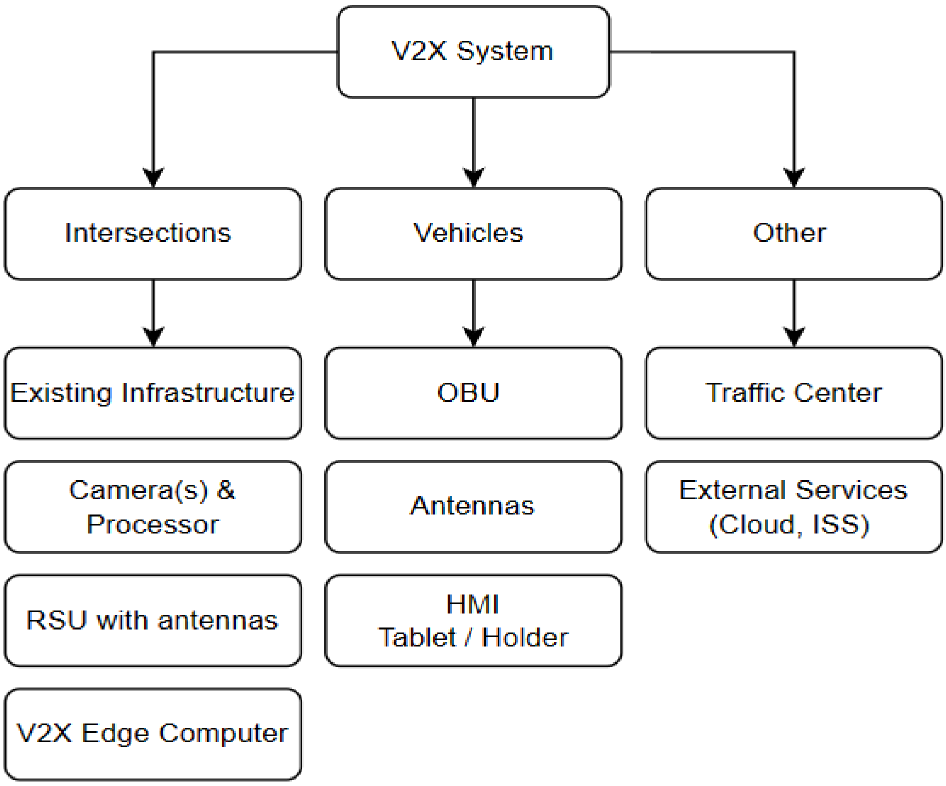

Figure 4

Hardware View Intersections (sample intersection):

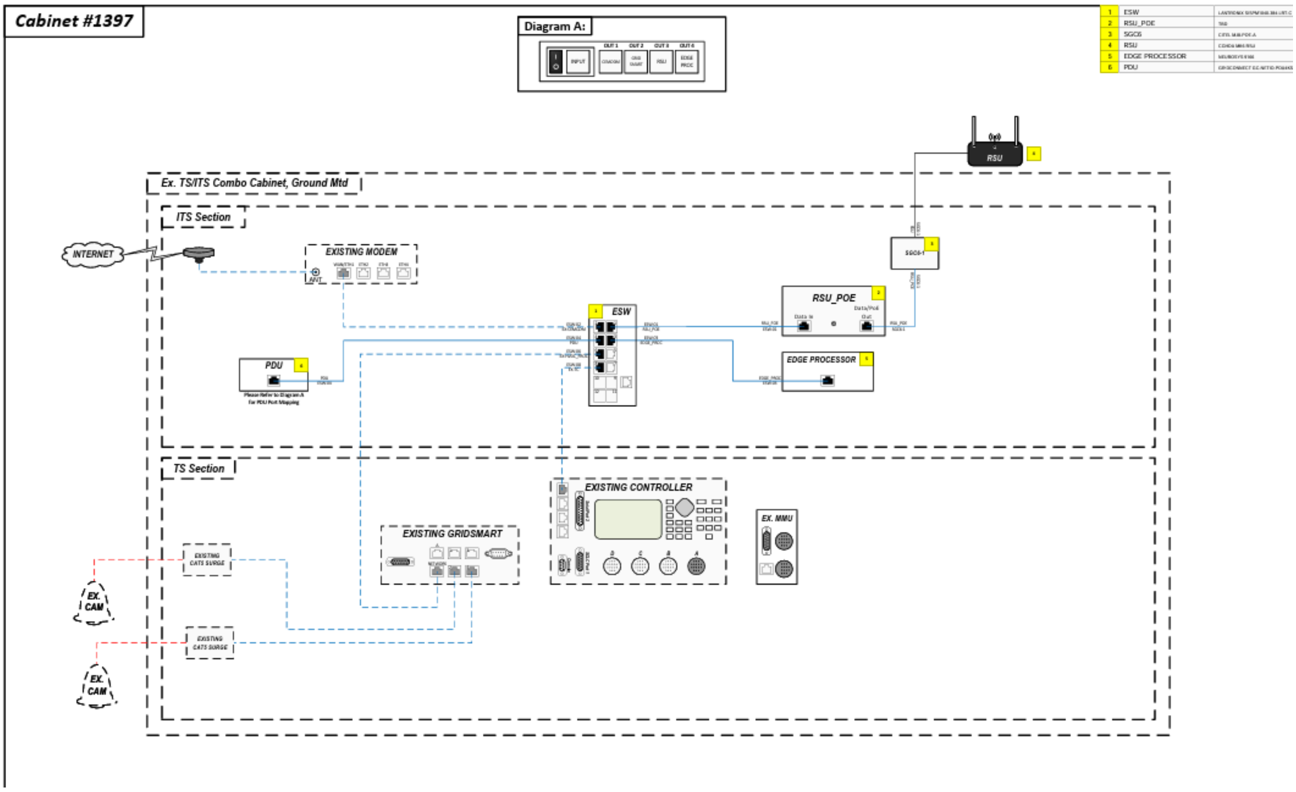

Figure 5

Hardware View Vehicle:

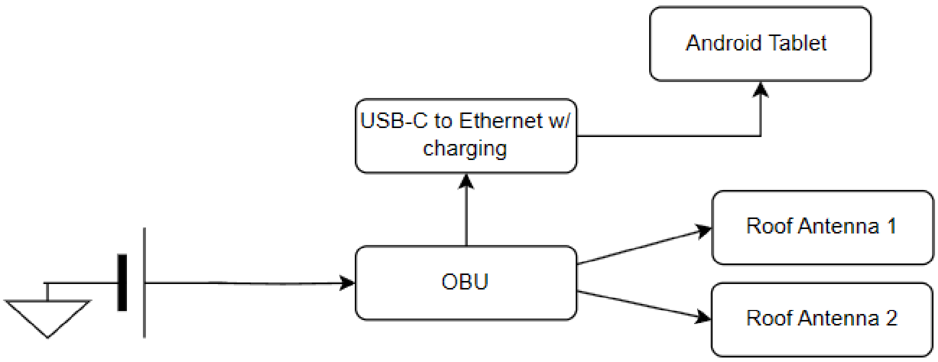

Figure 6

Prototype Deployment Plan

ROAD COMMISSION for OAKLAND COUNTY

Data Flow Diagram:

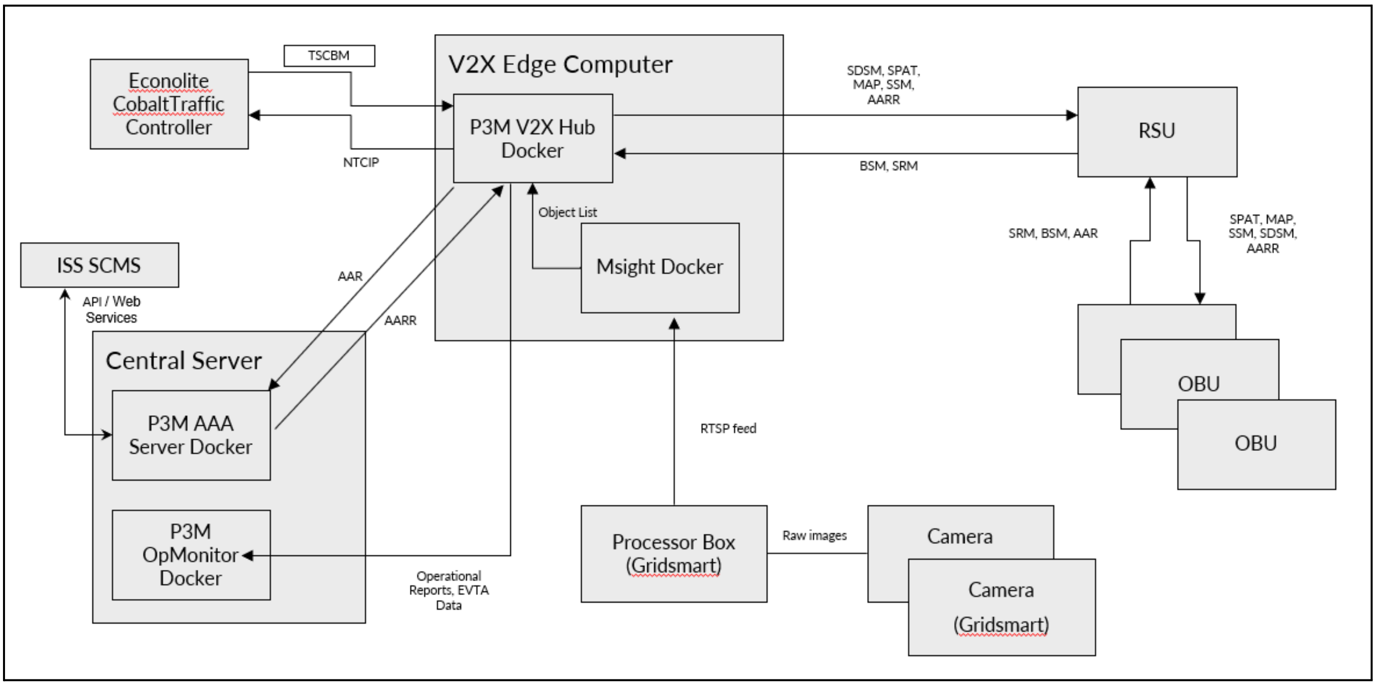

Figure 7

Network Architecture

An extensive design review cycle with RCOC IT was established to determine the best approach to gaining access at the intersection that was securely isolated with multiple firewalls. The approach agreed is shown in Figure 8 and summarized as follows:

VPN tunnel established to the P3M AWS servers. Edge device updates will be achieved by a SSH connection into the edge box. The V2X system will be non-operational during these updates but there will be no disruption to the traffic controller or signalization.

Limited allowance to external internet servers through a TMC proxy server and a whitelist of Internet access points. These services are needed for security credential top offs (ISS) and for software updates, security patches, and bug fixes after we deploy (e.g. GitHub).

Network Diagram Removed for Security

Figure 8

Subcomponents / Sub Systems

The following table shows the sub systems with considerations for their requirements with respect to the enrollment in the Security Credential Management System (SCMS).

Intersection Sub System: Assume 1 required at each intersection unless otherwise noted

Name	Vendor	Requirement
RSU	Cohda	MK6 CV2X standard compliant (NTCIP), FCC certification Antennae and mounting hardware included in the kit P3M software downloaded into the RSU *ISS enrollment for Security Credentials* Periodic "top off" for new certificate uploads.
PoE Injector	Transition Networks	SI-IES-1200-LRT Unmanaged Hardened Poe+ Injector – Poe Injector (Din Rail Mountable) Required for powering RSU.
Power Supply PoE Injector	Mean Well	MDR-40-48Power supply that converts 120VAC to the fixed voltage for the PoE injector.
Traffic Controller	Econolite	NTCIP Compliant.
V2X Edge Computer	Neousys	Nuvo-9166GC; CPU/GPU P3M V2X Hub and Plug in software downloaded UM CEE MSight algorithm container downloaded
Camera	Gridsmart	FE3; (2) cameras at most intersections. Follow manufacture installation and setup including gel filled ethernet cable for moisture ingress.
Processor Box	Gridsmart	GS3; Required to support the Gridsmart cameras in setup and for IOO evaluation using the Gridsmart App.
Network-Managed Power Distribution Unit	Netio	NETIO PowerPDU 4KS
Layer 2 Unmanaged Switch	Trendnet	TRENDNET TI-G80
PoE+ Surge Protector	Citel	CITEL MJ8-POE-A

Name	Vendor	Requirement
Power cables	Hardware	(4) Required C14 to C13 short connections to the PDU.
Outdoor cabling	Misc.	Cat5e cabling including patch and incidental grounding cables.

Vehicle Sub System: Assume 1 required in each vehicle unless otherwise noted

Name	Vendor	Requirements
OBU	Cohda	MK6 CV2X standard compliant (NTCIP), FCC certification Antennae included in the kit; GPS (1) roof mount , CV2X (2) P3M software downloaded into the OBU *ISS enrollment for Security Credentials* Periodic "top off" for new certificate uploads
Wi-Fi Vehicle Antenna	Mobil Mark	MMXF502-00003HV3HV00-BLK-180 Magnetic mount, added adhesive 3M pad for robustness
HMI Tablet	Samsung	Galaxy Tab Active3 8.0" 64GB
Tablet Holder	TACKFORM	TFEP-SR18-TAB
USB-C to Ethernet	Belkin	AVC002btBK USB-C to Ethernet power supply for tablet
Ethernet Cable 15'	Misc.	Cat 8 Ethernet Cable, 15ft Heavy Duty High Speed Internet Network Cable

Other Sub System Elements

Name	Vendor	Requirements
Authentication AAA	AWS	AWS hosted P3M software running
Operational Monitor	AWS	AWS hosted P3M software running Dashboard user interface to allow analysis
Security Credential Management System Portal	ISS	Enable IEEE 1609.1, 1609.2 and 1609.3 standards conformance

Security / SCMS

A production SCMS operated by Integrity Security Solutions (ISS) will be deployed as part of RCOC project. The SCMS provides message security for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. Benefits of the SCMS include:

- Ensuring integrity—Users can trust that the message was not modified between sender and receiver.
- Ensuring authenticity—Users can trust that the message originates from a trustworthy and legitimate source.
- Ensuring privacy—Users can trust that the message appropriately protects their privacy.
- Achieving interoperability—RSUs and OBUs from different suppliers will be able to talk to each other and exchange trusted data without pre-existing agreements.

Suppliers of C-V2X RSUs and OBUs deployed in the Oakland County ecosystem will enable ISS SCMS security certificates for broadcast by PSID type and SSP, from the RCOC network. The devices will:

- Enable IEEE 1609.1, 1609.2 and 1609.3 standards conformance including misbehavior and revocation functions in conjunction with proper behavior of ISS SCMS back-office (certificate top-off of OBUs and RSUs).

- Enable subsequent security stack requirements revisions/updates to be integrated and tested within the supplier firmware build and supplied to RCOC within 45 days of release changes for a minimum of 36 months after supplier selection as indicated within this specification document.
- Enable security profiles to be implemented for messages by PSID and in specific instances SSP as outlined in the image below (Figure 9).
- Support a valid, functional, and appropriate certified hardware security module (HSM). The devices shall successfully utilize security certificates and HSM which integrates, stores, and utilizes established ‘methods/protocol’ to process device security enrollment, revocation, misbehavior detection, re-enrollment (in specific cases where device certificates no longer are being updated and the device requires to be ‘renewed’ in the SCMS enrollment registry) directly with ISS SCMS development, staging and production environments using IPv6 network connectivity (no IPv4 Internet Access) between the SCMS and the field devices when the device configuration is enabled for ‘secure’ message certificated usage by PSID.
- Implement an HSM and unit processor/memory size adequately, to not impact or degrade under radio performance load and drop packets, mis-align timestamps or not allow up to a minimum of 30 equipped OBUs simultaneous connections within radio range to a single deployed and operable RSU.
- Be functional and certified with an internal/embedded HSM and meets criteria for secure message broadcast certificates configurable by PSID and maintains certificate currency, update requests (i.e., security update ‘top-off’, 2- week rotation request for RSUs and 45 day rotation-request for OBUs) with the SCMS so that the devices installed within the network do not expire or drop current certificates for broadcasting/receiving messages that are secured during field deployment and functional device use.
- Support a configuration setting that toggles between enabling/disabling forwarding of specific PSID message types to an endpoint destination with security to be included in the message(s) forwarded including BSM, Signal Request Message with full SPDU (i.e., security header turned on).

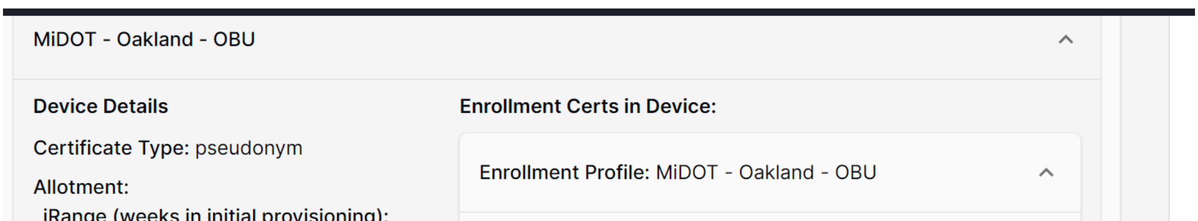

Figure 9

8 Procurement

For the Stage 1 Planning Grant, the prototype demonstration required the procurement of the following elements:

- C-V2X infrastructure deployed at 5 intersections strategically selected for safety, vulnerable user traffic, equity, and availability of the required infrastructure to support the technology (e.g. advanced traffic controllers, network connectivity, etc.).
- C-V2X technology deployed in 10 county-owned vehicles. The system in the vehicles will include C-V2X on-board units (OBUs), Driver Displays, and antennae.
- Updates at the Traffic Management Center or a secure VPN tunnel outside the TMC to allow data storage and analytics.

This section details the goals, the approach followed, and the results of the Procurement Plan for RCOC SMART Grant project's Prototype Demonstration. This document does not cover the procurement of contractors, project partners, or engineering support services, including bench-testing software or hardware.

Procurement Strategy

This is a compressed project of 12 months duration. The team's goal was to have a prototype demonstration deployed and gather data before the Stage 2 SMART Grant application was released in summer 2024. This drove the procurement strategy of using vendors the team had direct development experience with and that had already been tested for interoperability in the ATCMTD Smart Intersections Project in Ann Arbor, MI.

Through team meetings there was an established responsibility for who was ordering what. For example, RCOC took responsibility for all components inside the cabinet except for the Edge computer and the RSU power supply, which was deemed the responsibility of P3M.

Name	Vendor	Qnty.	Lead Time (wks.)	Requirement / Part Number
Camera	Gridsmart	9	2*	FE3; (2) cameras at all intersections except one. * IOO purchased through their distributor
Ethernet Cable 15'	Misc.	10	2	Cat 8 Ethernet Cable, 15ft Heavy Duty High Speed Internet Network Cable
HMI Tablet	Samsung	10	1	Amazon order, Active TAB 3
Layer 2 Unmanaged Switch	Trendnet	5	3	TRENDNET TI-G80
Power Distribution Unit	Netio	5	3	NETIO PowerPDU 4KS Network-Managed
OBU	Cohda	10	6	MK6
PoE Injector	Transition Networks	5	2	SI-IES-1200-LRT Unmanaged Hardened Poe+ Injector - Poe Injector (Din Rail Mountable)
PoE+ Surge Protector	Citel	5	3	CITEL MJ8-POE-A
Power cables	Hardware	20	2	(4) Required C14 to C13 short connections to the PDU at each intersection
Power Supply PoE Injector	Mean Well	5	2	MDR-40-48

Prototype Deployment Plan

ROAD COMMISSION for OAKLAND COUNTY

Name	**Vendor**	**Qnty.**	**Lead Time (wks.)**	**Requirement / Part Number**
				Power supply that converts 120VAC to the fixed voltage for the PoE injector
Processor Box	Gridsmart	5	2*	GS3; * IOO purchased through their distributor
RSU	Cohda	5	6	MK6; Ordered the KIT with antenna and mounting hardware
Security Credential Management System Portal	ISS	1	1	Requires an initial portal be opened for the jurisdiction and then a device enrollment process. There is prototype enrollment and a production enrollment option. Device permissions and the technical coordination time are not included in the time estimate.
Software Development Kit	Cohda	1	1 day	CWP-SFTWA-RL19-WW01901
Tablet Holder	TACKFORM	10	2	TFEP-SR18-TAB
Traffic Controller	Econolite	5	4	NTCIP Compliant
USB-C to Ethernet	Belkin	10	2	Amazon order; AVC002btBK
V2X Edge Computer	Neousys	5	6	Nuvo-9166GC; CPU/GPU

Name	Vendor	Qnty.	Lead Time (wks.)	Requirement / Part Number
Wi-Fi Vehicle Antenna	Mobil Mark	10	8	MMXF502-00003HV3HV00-BLK -180 Required going through a distributor, Westward Sales

9 Testing

The primary task was software and hardware integration, and the team conducted a phase of Layout Testing to validate the integration in a similar environment to the production environment. The layout testing serves as a key quality gate before equipment installation at the actual intersections. The end-to-end testing builds an intersection "twin" on the bench to evaluate the physical and networked connections of all the system components. The software is exercised for the first time in the connected IT environment with the traffic management center servers. The team followed the following steps for Layout Testing.

Layout Testing Prerequisites

Prior to beginning the Layout Testing, ensure that the following prerequisites have been completed:

1. Layout testing architecture diagram (hardware, cabling, power) is confirmed
2. All parts kitted and labeled
3. VPN is established between RCOC network and cloud
4. University of Michigan integration testing has been completed
5. Confirm camera or direct intersection feeds
6. Confirm MAP survey reference point
7. Confirm with ISS the security profiles for test devices
8. ISS Portal set up and test devices are enrolled with proper security profiles

Layout Testing Objectives:

1. RSU is powered on, configured, and connected to the network
2. OBU is powered on, configured, and connected to the network

3. Edge device is powered on, configured, and connected to the network
4. Gridsmart Camera is powered on, configured, and connected to the network
5. Traffic Controller is powered on, configured, and connected to the network with the correct firmware version
6. P3M Tablet is powered on and connected to the OBU
7. OBU is enrolled with SCMS certs with proper permissions
8. RSU is enrolled with SCMS certs with proper permissions
9. OpMonitor is deployed and accessible
10. AAA Server is deployed and accessible
11. Clocks are synchronized across devices
12. RSU is broadcasting accurate SPaT and MAP
13. OBU is broadcasting accurate BSM
14. OpMonitor logging expected operational events
15. VRU Detection is functioning with limited alerts (prior to live learning data)
    a. MSight is sharing object detection reports with V2X Hub
    b. V2X Hub is generating, encoding, and broadcasting SDSMs via Wi-Fi and C-V2X spectrums
    c. OBU is receiving and decoding SDSMs
    d. P3M Tablet is displaying an alert
16. EVTA is functioning as expected
17. Signal Priority is functioning as expected for one intersection
18. Vehicle trajectory is logged in OpMonitor EVTA module
19. RSU can be remotely power cycled
20. Edge processor can be remotely power cycled
21. OBU firmware can be remotely updated
22. RSU firmware can be remotely updated
23. OBU can refresh SCMS certificates
24. RSU can refresh SCMS certificates
25. Signal Priority is functioning as expected with the addition of a 2nd intersection
26. OBU broadcasts SRM to request signal priority
27. V2X Hub receives and processes SRM

28. ATC processes signal priority correctly
29. Operational Events/SPaT are logged in OpMonitor

Layout Test Environment:

Layout Test Stand Used

Figure 10

The team performed layout testing at the RCOC Electrical Building in Waterford. The team used a bench setup and a mobile cart with all the equipment to simulate the production traffic cabinet environment. Exposure outside was required for RSU GPS signal reception.

10 Site Selection

Intersections

The following process was used to select (5) intersections from over 1400 in the county for the prototype demonstration.

Step 1: Identified and prioritized selection criteria

Intersection Considerations	Category	Scaling (1 low -5 high)
Intersection in disadvantaged area	Equity	5
Strong wireless connection for backhaul	Existing Infrastructure	5
Room in conduit for cabling & RSU mounting pole close to controller	Existing Infrastructure	5
Intersection is under RCOC jurisdiction	Traffic/Safety	5
Large number of pedestrians/cyclists	Traffic/Safety	5
Large number of accidents/ fatality hot spots	Traffic/Safety	5
Room in cabinet	Existing Infrastructure	4
Heavy traffic flow intersection (esp. with test fleet)	Traffic/Safety	4
Intersections with high speeding, red light violations	Traffic/Safety	3
Multiple intersections selected along the same corridor	Strategic/Partnership	3
Camera is installed	Existing Infrastructure	2
Site Surveys completed	Existing Infrastructure	2
Simple road geometry (helps reduce MAP file points and payload size)	Existing Infrastructure	2
Controller type compatibility	Existing Infrastructure	2
Corridor is near an OEM / Supplier	Strategic/Partnership	1
Route includes school buses	Strategic/Partnership	1
Proximity to first responder base locations	Strategic/Partnership	1
Community open-minded to test new technology	Strategic/Partnership	1

Step 2: Aggregate data to visualize how each site meets the criteria above.

Sample screenshot from intersection mapping tool

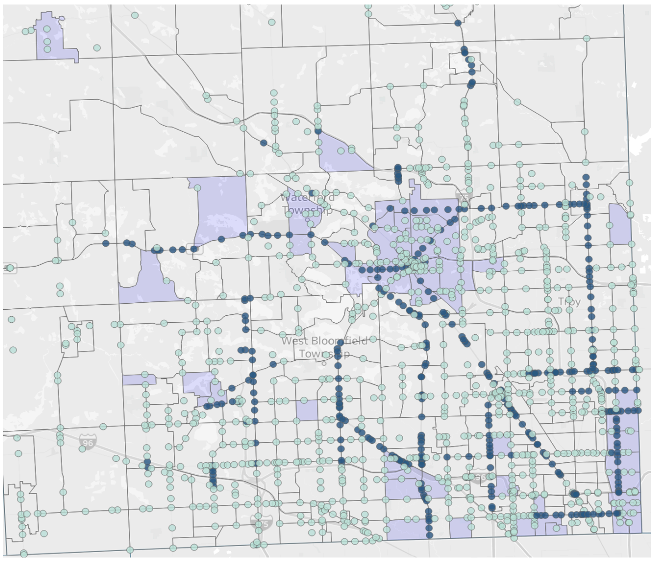

Figure 11

Dataset	Source	Comments
Crash Types/Location	SEMCOG	2017-2021, within 250ft of an intersection
RCOC Jurisdiction	RCOC	
Disadvantaged Community Indicator	Census Data	Criteria from the government climate and economic screening tool.
Pedestrian Score	Walkscore.com	
Traffic Counts	SEMCOG	
Financial Impact of Crashes	National Safety Council	Costs of motor related Injuries matched to SEMCOG crash data.
Salt Routes	RCOC	
Truck Routes	SEMCOG	
Bike Lane Locations	SEMCOG	
Gridsmart Locations	RCOC	

Pedestrian scores are from https://www.walkscore.com. Disadvantaged indicators are from https://screeningtool.geoplatform.gov/. Information is from Census data

Step 3: Team meetings to refine the list and selection criteria

Multiple review meetings with the RCOC traffic engineering department helped narrow the list further. Intersections with planned construction, with older cabinets, or with no room in conduit were excluded.

CO.	ROAD .1	ROAD .2	CITY .1	Controller	Pedestrian Score	Disadvantaged	Notes	Selection Preference
30	Southfield	10 Mile	Southfield	SCATS	61	Yes	Large intersection. Plazas on 2 corners.	No - no room in cabinet
903	Southfield	Filmore	Southfield	SCATS	57	Yes	Smaller intersection on larger Road. In front of Synagogue	Old cabinet - signal in flash during the weekday
129	Southfield	10 1/2 Mile	Southfield	SCATS	51	Yes	Smaller intersection on larger Road. Small Plaza on 1 corner.	No - no room in cabinet
24	Greenfield	Mt Vernon	Southfield	SCATS	78	No	Smaller intersection on larger Road. Plaza on 1 corner	
31	Greenfield	10 Mile	Southfield	SCATS	76	Yes	Large intersection, Plazas on 2 corners.	
115	Greenfield	10 1/2 Mile	Southfield	SCATS	74	Yes	Plaza on 1 corner	
354	Greenfield	Providence	Southfield	SCATS	73	No	No crosswalk on greenfield. Plazas on 2 corners	
199	Greenfield	9 Mile	Southfield	SCATS	69	Yes	Large intersection. Plaza on 1 corner. Office building on 1 corner	No - no room in cabinet
1392	12 Mile	600' e/o M-1 (Woodw	Royal Oak	Centracs	67	No	Not an intersection. **Crosswalk with lights**	No - would need pole to install Gridsmart

Figure 12

Step 4: Final Selection

The final (5) are shown below.

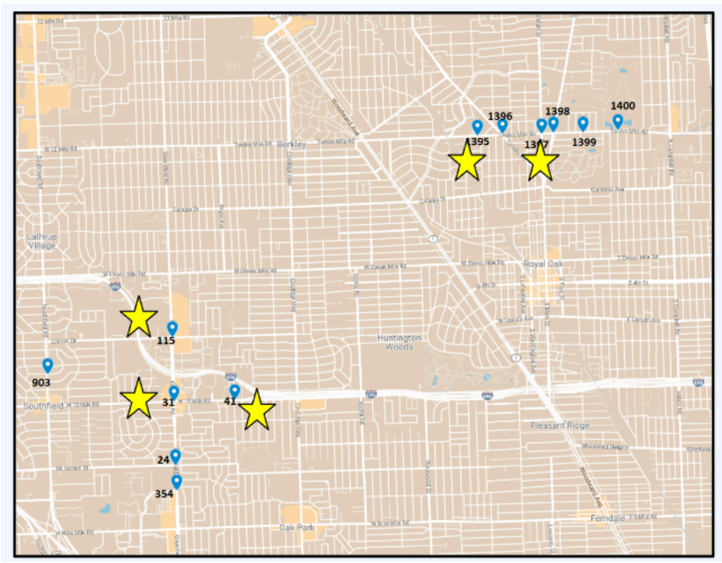

Figure 13

Pictures of all intersections are included in the Appendix "Installation Guidelines"

11 Vehicle Selection

The ten vehicles selected for the prototype demonstration were RCOC fleet pickup trucks. The make/model was shared for vehicle installation preparation with Brandmotion, the vehicle equipment installer. An on-site visit identified the following installation decisions:

- The preferred tablet mounting was a passenger seat mount with a flexible cable that allowed minimal distraction with the existing 2-way radio and was robust to emergency stops.

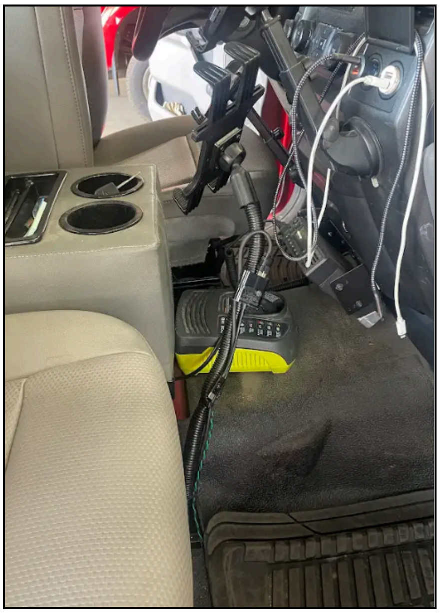

Figure 14

- OBU will be mounted on the back vertical panel.

Figure 15

- Fuse usage for key on power (no constant drain or leakage source)
- Various alternatives for the roof mount antenna were considered given the mixture of steel and aluminum roofs. A 3M adhesive plus silicone was agreed for the 2 added RF antennas. A minimum of 24-inch separation was targeted between antennas.

Figure 16

12 Intersection Deployment

Preparation

After agreement with RCOC on the intersections targeted, the following steps were followed to prepare to deploy the technology.

1. The vendor drafting the Installation Guideline (Integral Blue) was given physical samples of all new parts being installed and participated in the layout testing. This gave them hands-on experience with the exact system components, making their installation instructions very accurate.
2. Site visit to inspect the cabinets and identify possible signal obstructions (existing signs, trees, buildings, etc.).
3. The recommendations were consolidated into a report and reviewed with RCOC. The support of the Customer was critical on items like rearranging existing equipment to make more room for the new parts.
4. The Installation Guideline report and the Proposed Site Inspection report are key project artifacts shared with RCOC.

Installation

After RCOC installed the hardware at the intersection, the following steps were followed on site to verify the technology while the install team was still on site.

Local Validation Checks:

1. Visual inspection of devices for installation craftsmanship, placement of devices in the cabinet, and orientation/height of the RSU on the pole.
2. Visual confirmation that devices boot and exhibit normal LED status light behavior.
3. Local ping responses from all existing and new devices on-site through the new TRENDNET Ethernet switch.
4. Gateway ping responses from the “field” interface of RCOC’s firewall through the new TRENDNET Ethernet switch.

Remote Validation Checks

1. After local validation checks are performed, P3Mobility and RCOC will perform remote validation checks from P3Mobility’s AWS instance and RCOC’s TOC.
2. P3M tests of each network port expected to be available via port forwarding.
3. P3M remote login to the RSU via SSH.

4. P3M remote login to the Edge Processor via SSH.
5. P3M remote login to the PDU via HTTP.
6. P3M remote access to Gridsmart camera feed(s) via VLC or equivalent RTSP client.
7. RCOC remote access to Gridsmart cameras via Gridsmart application.
8. RCOC remote visibility of traffic signal controller in central management software.
9. RCOC remote login to the PDU via HTTP.

Any failure experienced when performing the above tests will be locally investigated before leaving the site until either the issue is resolved or determined to be caused by something outside of the local cabinet/pole.

13 Maintenance and Operations

Maintenance

Preventative Maintenance

The project team's assumption was no hardware preventative maintenance would be required in this prototype demonstration duration of ~9 months. This would include things like sending up a bucket truck to clean the lens of the cameras and confirm alignment, check for moisture intrusion.

The project team's assumption was that software preventative maintenance in the installed Edge device running a Linux operating system would encompass daily automated checks for the latest security updates. Upon manual review (minimum bi-weekly) of recommended updates and upgrades, any applicable upgrades will be pushed as applicable.

Emergency Maintenance

The project team considered "emergency maintenance" as part of the prototype deployment. Intersections by their function are subject to traffic box damage from accidents, lightning strikes and power outages driven by storms. The proper approach of having spare parts on hand had to be balanced with the project budget. The following approach was agreed upon for the main items:

- Edge Device: One extra at P3M vendor being used for development.
- RSU: One extra at P3M vendor being used for development.
- OBU: One extra at P3M vendor being used for development.

- Other parts like a POE injector, or a surge protector are readily available from RCOC distributors.

As part of the deployment, P3M will outfit a company-owned eleventh vehicle with the same hardware. In the case of a RCOC fleet vehicle damage, the OBU, antenna, or tablet could be reallocated if needed.

Planned Maintenance

Edge Device Software Updates: By the network connection achieved (Secured VPN tunnel to the AWS cloud) edge device updates will be achieved by a SSH connection into the edge box. Updates to the V2XHub plugins can be made without disabling the rest of the system. Only updates to the V2XHub core (not anticipated) will require a shutdown of the V2XHub system, but in all cases, there will be no disruption to the traffic controller or signalization. Updates expected include:

1. V2X Hub Software
2. Object Detection Software
3. Security Patches

RSU Software Updates: The P3M Edge device will SSH into the RSU for updates. The V2X system will be non-operational during these updates, but there will be no disruption to the traffic controller or signalization.

OBU Software Updates: The OBU has by design a radio transceiver that includes Wi-Fi. OBU updates will be made while the car is stationary in the garage with a laptop computer and network connection.

OpMonitor Software Updates: OpMonitor updates will be made in the AWS cloud and will not disrupt any operations at the intersections.

Tablet Software Updates: If needed, the tablet would be removed from the vehicle and updated by a technician and returned.

Operations

Monitoring of the V2XHub plugins

The V2XHub plugins are application-specific software components built in accordance with the architectural specifications of the USDOT V2X Hub. They are enabled at each intersection based on whether the Smart Road services that they support are offered at that location. Any fault condition in the software is detected immediately by the OpMonitor and reported in real-time to an operator via an email notification.

The P3M Operations Monitor (OpMonitor) provides the monitoring capabilities the design team and the IOO RCOC will use during the deployment for recognizing anomalous conditions. Monitoring of the V2XHub plugins and RSU: when periodic keepalive reports from any of these components are not received, the OpMonitor issues an email notification to an operator. This triggers an investigation that may require an SSH connection to the edge or the RSU, depending on the content of the notification. If an SSH connection cannot be established, a remote reboot via the PDU can be carried out.

14 Project Management Plan

Project Management Plan

The key input to the Project Management Plan was the SMART Grant application charter and high-level statement of work that defined the prototype scope and budget allocation. The project management plan for the prototype demonstration encompassed the following elements and was the basis for how the work would be coordinated for this specific workstream. Effort was made to "right-size" the project governance with the limited hours and budget for both our customer RCOC as well as the partners supporting.

Project Processes

- Scope Management
- Communication Management
- Schedule Management
- Risk & Issue Management

- Cost Management
- Quality Management
- Procurement Management (not covered here, see separate section)

Project Documents

- Responsibilities Matrix (RASIC)
- Risk Log
- Open Actions Log
- Change Log
- Timing Plan
- Planned vs. Actual Budget Spreadsheet
- Lessons Learned Register

Scope Management

The following sections will highlight the approaches taken and, where appropriate, examples.

After the formal project award, a series of contracting meetings were held to onboard the various project partners that would be critical for the prototype demonstration. During this discovery process, we realized a gap in local support for the installation guidelines which added another partner organization. We established a *project partner approval process* with RCOC for their awareness of who is on the team and the scope of that partner's responsibilities. To reduce the risk of confusion regarding who is responsible for what, we created a RASIC chart as shown below. Names are redacted, but the tasks are accurate.

RASIC (Responsible, Approve, Support, Inform, Consult)

Key Tasks Prototype Demonstration	Team 1	Team 2	Team 3	Team 4	Team 5
Provide SCMS certificates		R			
Provide OBU S/W and configuration instructions		R			
Configure C-V2X OBUs		R		S	
Enroll C-V2X OBUs in SCMS	I	R			
Install C-V2X OBUs & Antennas in Vehicles	A	S		R	
Procure Vehicle Displays (HMIs) & Brackets				R	
Configure Vehicle Displays (HMIs)		R		S	
Install Vehicle Displays (HMIs)	A	S		R	
Procure C-V2X RSUs		R			
Configure C-V2X RSUs		R	I		
Enroll C-V2X RSUs in SCMS		R	I		
EDGE and RSU installation and wiring instructions	A	S	R		
Install C-V2X RSUs	R		S		
Procure intersection edge devices		R			S
Provide edge device s/w & configure instructions		R			R
Configure intersection edge devices		R			S
Install intersection edge devices	R	S	S		
Procure intersection sensors and sensor processor	R				
Configure intersection sensors / object detection	R		I		S

Key Tasks Prototype Demonstration	Team 1	Team 2	Team 3	Team 4	Team 5
Install intersection sensors / object detection	R	I			A
Provide monitoring software (Op Monitor, AAA)		R			
Configure maintenance software (AWS)		R			
Install monitoring and maintenance s/w	I	R			
FCC site registration	S	S	R		
Network plan, drawings, and IT approvals	A	S	R		I
Network execution	A	S	R		I
Data evaluation	A	R			S
Layout testing	S	R	S	S	S
Configuration management list	I	R		I	S
Prototype Concept of Operations	A	R	I		S
Procure cable, PoE, switches, routers	R		I		
Run cable, PoE, switches, routers at intersections	R		S		
Operations and Maintenance	R	S	S	S	S

Communication Management

While the weekly reviews were planned to be virtual, an onsite “face-to-face” kickoff event was held at the customer site to review the prototype demonstration plan and allow the team to meet each other. As part of this event, a risk brainstorming session generated items for the initial project risk register. Mitigation actions were moved to the open issues list to track. A subset of the risk registers for “fleet vehicle installation and performance” is shown below for illustrative purposes.

Risk Identification	Probability	Mitigation Strategy
Newer vehicles could have aluminum roofs affecting the magnetic mount RF antenna planned.	H	**Mitigate:** Identify an adhesive pad and silicone agent to use in these cases.
Snowplow / work trucks have aggressive car wash profiles causing damage to external antennae.	M	**Avoid:** Use pickups instead.
Work trucks might have pressure washes INSIDE the vehicle cabs which could impact OBU robustness.	L	**Avoid:** Use pickups instead.
Fleet trucks might have 2-way radios & roof mount antenna already installed which could cause interference or degraded CV2X performance.	H	**Mitigate:** Install guidelines to give max spacing.
The accuracy of the information coming to the OBU might not be accurate enough for sensitive performance use cases due to no RTK corrections.	L	**Accept:** GPS corrections out of scope for this project, not included in the OBU hardware.
Window mount suction cup holders for the HMI tablet can come loose in an accident or loosen with temperature swings.	H	**Mitigate:** Fixed mount tablet holder planned.
The driver is distracted by too many alerts.	L	**Watch:** VRU use case designed w/ 3 levels of alerts. Setup a driver interview after 30-45 days to review this.

A weekly call with RCOC was a critical part of the prototype demonstration preparation. Open items were assigned and tracked as well as a milestone list of key items for the next 4-6 weeks. This was also the forum for our change control process with the customer. An example of a change request was changing from a heads-up display in the vehicle to an Android tablet due to an incompatibility discovered in testing. Meeting notes documented the decision.

P3M as the overall project responsible, held separate internal technical review meetings and weekly meetings with the key project partners for intersection audits and install guidelines, vehicle installation, and object detection software development.

For Cost Management, a monthly progress report format was agreed that included the budget breakdown in the main categories as well as accomplishments, next steps, and escalation of critical issues. These monthly reports were valuable and were the foundation of generating the USDOT Quarterly Report content.

Schedule Management

The project plan required a schedule where the detailed sequence of events was mapped out for internal control. For customer meetings a simplified milestone list proved most valuable with key dates aligning the different parties (layout testing starts, data management plan due, etc.).

Quality Management

The quality management for the demonstration utilized the following tactics:

- Sequence of testing gates from software verification to bench testing, to system layout testing. The system layout test was a mock-up of a physical intersection "twin" in a garage.
- Intersection signoff based on an established readiness checklist.
- Monitoring of intersection data using the OpMonitor server for suspicious performance.

Note: The data management plan was a heavy influencing factor on the privacy and security aspects of connection to the traffic management center servers.

15 Lessons Learned

Prior Project Lessons Learned

The project team recognized the value of the lessons learned artifacts from prior CV pilots for RCOC prototype demonstration and did a thorough review which is summarized below.

Category / Tag	Lesson Learned Description	Applicable to RCOC?	Reference Link for More Info
SCMS Challenges in deployment:	Certificate top off issues - recommend the SCMS auditing tool review error codes and times stamps Certificate deactivation -initial top off period too short, download more than a few weeks at a time. RSU application requested multiple certificates due to networking issues and was locked out. Issue fixed on the SCMS backend. Local Certificate Chain File (LCCF) Implementation - Device vendors and deployment agencies should ensure that the processing of the ancillary files associated with the SCMS, such as the Local Certificate Chain File (LCCF) are tested fully. It is also recommended that vendors stay up to date on software updates for applications and libraries within their device.	Yes	Intelligence Transportation Systems - ITS Deployments (dot.gov)
5.9GHz interference	HamWAN radios are not designed to co-exist with V2X communications and hence pose an interference hazard. OTA updates during periods of interference took much longer. It took the FCC involvement with a "Secure Your Equipment notice" to address. The lesson learned is to monitor for potential interference by means of random wireless monitoring (sniffer) surveys in the CV Pilot area. In addition, an early and complete radio spectral analysis should be conducted for areas for deployment, to include the full CV2X spectrum and adjacent channels.	Quote received by a 3rd party engineering consultant to do this work. Budget does not allow this added work for stage 1.	Intelligence Transportation Systems - ITS Deployments (dot.gov)
Cost, cellular modems	THEA relied on cellular modems for the communications between the controllers and the TMC and ran into budget issues underestimating the bandwidth needs (to 20 gigabytes at a cost of $100 a month for each RSU)	No - wireless backhaul already exists at 5 test sites	Intelligence Transportation Systems - ITS Deployments (dot.gov)
Transient protection	Thunderstorms with lightning took out many RSUs due to inadequate grounding (painted surfaces, fastener corrosion). LL is to make sure you have extra SIM cards and / or RSU's to reduce downtime at intersections after a lightning strike. White Paper on the issue: https://www.its.dot.gov/pilots/thea_rsu.htm	Yes - shared with Integral Blue	Intelligence Transportation Systems - ITS Deployments (dot.gov)

Category / Tag	Lesson Learned Description	Applicable to RCOC?	Reference Link for More Info
Testing at other pilot sites	Interoperability testing among different pilot groups proved very valuable (pre-meetings and a formal test plan and test readiness review were developed to ensure that protocols and schedules were documented in advance). The testing allowed the participants to test applications using devices and equipment that they generally lack access to and take advantage of other supporting resources at the STOL testbed such as a DSRC sniffer.	No - Out of scope. After evaluation consider Macomb Co. and Ann Arbor.	Intelligence Transportation Systems - ITS Deployments (dot.gov)
GPS Accuracy	V2V applications like Forward Collision Warning (FCW) were used to assess the reception and processing of BSMs. The devices' GPS accuracy was sometimes a factor in whether an alert was reported, since the host vehicle needed to classify the remote vehicle in the same lane for FCW alerts. GPS coverage was good throughout the testing, with 8-11 satellites usually in view. Initial testing for some devices encountered issues with triggering alerts, but after updating lane width configurations in the devices, consistency was greatly improved.	No - Different use cases, RTK corrections out of scope.	
Demonstration / Demo's	Ensure the vehicles are tested on the selected roadway prior to the event to ensure there is adequate sky visibility to allow the ASD to acquire GNSS signals.	Yes - Add to vehicle test plan.	Intelligence Transportation Systems - ITS Deployments (dot.gov)
	The roadway used for the demonstration was smaller than ideal to safely perform all of the maneuvers which forced "tuning" the applications being demonstrated to operate at slower speeds which under normal circumstances, would lead to too many false alarms.	No - Different use cases.	
	There are risks involved in driving members of the general public when trying to trigger the ASD safety applications. For best results, it is recommended to utilize professional drivers or provide adequate training prior to the demonstrations.	Yes - Create a training pamphlet to help educate.	
	The issue of repeatability and variability in driver behavior is likely to remain a challenge in both application testing as well as performing "tuning" adjustments aimed at different driving conditions.	Yes - Get driver logs / feedback.	
Integrating and testing large disparate systems	A Systems Engineering Management Plan (SEMP) is needed to help the team understand what they will do technically to successfully prosecute the project.	We did not create.	
	Documented traceability of requirements through architecture to design testing and to physical implementation is critical for maintaining a large disparate system.	We did not create.	Intelligence Transportation Systems - ITS Deployments (dot.gov)

Category / Tag	Lesson Learned Description	Applicable to RCOC?	Reference Link for More Info
	Not having requirements specifications for software, firmware and hardware that will be procured outside the development team adds cost and schedule risks.	Yes - used off-the-shelf hardware to meet standards, used prior knowledge to source edge from SIP.	
	Testing concepts based on individual products is no substitute for testing on large systems. A good practice to follow before starting a project is to ensure your team has a good understanding of testing principles (based on IEEE 829 or ISO 29119-3).	Yes - layout (aka end-to-end) testing w/ the network planned.	Referred to Connected Vehicle Deployment Technical Assistance (CVDTA) Program
	Using an independent verification and validation (IV&V) team can greatly improve documentation quality.	Not possible	
Pooled Vehicle Study (UDOT, WSP et al.) CV Pooled Vehicle Study for Interoperability.	MAP files not compliant to CTI4501	Yes	ITSA Webinar
	Intersection geometry change post deployment (CIMMS algorithm)	Not for Stage 1	ITSA Webinar
	Data (storage & volume) costs that were underestimated	Yes - will need to be estimated for Stage 1 and factored into Stage 2 business cases.	ITSA Webinar

RCOC Project Lessons Learned

RCOC project team's "open issue list" was also the source of "things gone right" and "things gone wrong" collectively called for our "lessons learned". After the prototype demonstration phase, a formal review of this list with the customer and partners is required before project closeout. As of this writing, here are a few example lessons learned from the prototype demonstration:

Category / Tag	Lesson Learned	Description
Gridsmart Data Logging	Thing Gone Wrong	Timing delays in getting VRU use case working were driven by the amount of time it took to store weeks'

Category / Tag	Lesson Learned	Description
		worth of data at the targeted intersections for machine learning. Passing this amount of data through the VPN to AWS cloud was cost prohibitive and the remote hard drives plugged into the Gridsmart processor storing the data proved unreliable.
FCC Approvals	Thing Gone Wrong	FCC approvals added delays in getting device certified OBU/RSU parts. FCC requires approval to operate CV2-X at the ITS 5.9GHz and the Intersections need to be registered.
Network Connectivity to the Intersection	Thing Gone Wrong	The degree of difficulty and the amount of time to get approved network solutions implemented for intersection connectivity was underestimated and resulted in delays to the prototype demonstration.
Mapping Tool	Thing Gone Right	The creation of a visual mapping tool with agreed priorities to help in the intersection selection was critical to narrow down the test intersections with all the data sources (traffic safety, volumes, controller technology, which jurisdictions control, etc.) and stakeholder opinions.