Document Title: Draft Implementation Report

Project Title: Leading in Economically Sustainable Safety with C-V2X Technology in Oakland County Michigan

Recipient Name: Road Commission Oakland County (RCOC)

Fiscal Year of Award: DOT-SMART-**FY22-01**

Period of Performance: August 15 2023 to February 15 2025

Organization(s) Preparing the Implementation Report: Road Commission for Oakland County, P3Mobility

Date Submitted: June 15, 2025

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1. Executive Summary

Project Title: Leading in Economically Sustainable Safety with V2X Technology in Oakland County, Michigan
Lead: The Road Commission for Oakland County (RCOC)
Location: Oakland County, Michigan
Public Partners: University of Michigan, Oakland County Local Governments, Lawrence Technical University (LTU), Southeastern Michigan Council of Governments (SEMCOG)
Private Partners: P3Mobility, The Mannik & Smith Group (MSG), Integral Blue, AECOM, Brandmotion, Operis, OpenVia, Poco Labs, Bridgeport Consulting

This project was to design and prototype a scalable, interoperable, and financially sustainable Connected Vehicle (V2X) system to enhance roadway safety and mobility across Oakland County, Michigan. The goals and objectives of this project included:

- Developing a scalable business model for V2X deployment that reduces reliance on public funding by incorporating private partnership and investment as well as subscription-based services.
- Piloting a hybrid approach using C-V2X in the 5.9 GHz band and U-NII bands and Networked V2X over cellular networks to address spectrum constraints and extend coverage.

Stage 1 Results:

- The project developed a financially sustainable model that offers V2X services (e.g. signal priority) on a paid subscription basis. This model enables funding for deployment and O&M of the system beyond grant funding. The V2X Authorization Server, deployed during Stage 1, supports this model by managing vehicle subscription accounts for V2X services. The project team also developed Financial Models and Deployment, Community Engagement, and Workforce Development Plans. Stage 2 will focus on executing these plans.
- The project successfully deployed a prototype of interoperable Direct V2X technology that utilizes SCMS-enrolled devices to securely deliver SPAT, Signal Priority and VRU Alerts with C-V2X hardware at 5 intersections and in 10 vehicles.
- To address limitations in the 5.9 GHz ITS band, the project utilized the 802.11p (formerly DSRC) protocol in the U-NII bands to broadcast V2X messages with comparable performance to C-V2X protocol in the ITS band.
- VRU Alerts were tested and presented several challenges, including ineffective camera systems, training data limitations, sensor blind spots, and high false-positive rates due to environmental factors. These challenges prevented full deployment of VRU Alerts in the vehicles. However, RCOC remains committed to this use case, and Stage 2 will evaluate alternative sensor technologies, such as LiDAR and radar, to enhance detection accuracy.

Stage 2 Recommendations:

- For Stage 2, the project will expand V2X deployment across Oakland County with a focus on maximizing safety, efficiency, and sustainability. A public-private partnership will be established to recruit fleet vehicles as paid subscribers for V2X services, creating a recurring revenue stream to fund long-term operations. Signal priority and pre-emption will be provided at as many intersections as possible to improve mobility for key user groups. To reduce cost and deployment complexity, cellular-based Networked V2X will be deployed to extend system coverage to any location with network connectivity. Network V2X was previously limited by latency and security challenges, but recent developments suggest Networked V2X may now be viable for broader applications. RCOC will continue to analyze these approaches to shape the scope and strategy of Stage 2.

2. Introduction and Project Overview

2.1. Project Overview

The "Leading in Economically Sustainable Safety with V2X Technology in Oakland County, Michigan" project, led by the Road Commission for Oakland County (RCOC), aims to achieve a large-scale deployment of Vehicle-to-Everything (V2X) technology. Stage 1 of the project included prototyping and planning activities, setting the foundation for a broader deployment in Stage 2. Key themes for both Stage 1 and 2 of the projects include:

- **Economic Sustainability**: Developing a sustainable model for V2X deployment that leverages private partnership and investment to support infrastructure expansion and maintenance. This includes delivering a financial model and business plan with clearly defined business case scenarios to help infrastructure owners and operators (IOOs) understand how public-private partnerships can create value while mitigating risks.
- **Alignment with USDOT Vision and Orders**: Supporting the USDOT's vision as outlined in the "Saving Lives with Connectivity: A Plan to Accelerate V2X Deployment" document released on August 16th, 2024. The project also aligns with USDOT order "Ensuring Reliance Upon Sound Economic Analysis in Department of Transportation Policies, Programs, and Activities" which prioritizes the utilization of user-pay models.
- **Building on Previous USDOT Projects**: Utilizing frameworks, lessons learned, and insights from other V2X and connected vehicle pilots.
- **Adherence to Standards:** Following SAE, IEEE, and ITE V2X standards and incorporating an interoperable Security Credential Management System (SCMS).
- **Bandwidth Solution**: Developing and evaluating a solution for the reduction in the allocated 5.9 GHz ITS band by deploying Direct V2X[1] use cases that utilize C-V2X in the 5.9 GHz ITS band and 802.11p (formerly DSRC[2]) or 802.11ac (WiFi 5) or 802.11g (WiFi 3) in the Unlicensed National Information Infrastructure (U-NII) or 2.4 GHz Industrial, Scientific, and Medical spectrum (ISM) bands. Additionally, Networked V2X use cases via traditional cellular networks, utilizing V2X message standards and SCMS, will also be evaluated.
- **Stakeholder Engagement**: Engaging with the community, industry, and workforce to improve the adoption and acceptance of V2X technology.

2.1.1. Real-World Issues and Challenges

The at-scale implementation addresses several critical challenges:

1. **Transportation Safety:** Approximately 40,000 lives are lost annually in the U.S. due to traffic incidents. By deploying V2X technology, the at-scale implementation aims to reduce crashes and fatalities, particularly among vulnerable road users.

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[1] For this document, the term "V2X" refers to the broad definition of Vehicle-to-Everything communication. "Direct V2X" refers to peer-to-peer communication and "Networked V2X" refers to communications that rely on a third-party cellular network.

[2] DSRC stands for Dedicated Short-Range Communications. Typically this term is used interchangeably with IEEE 802.11p. Since this project uses 802.11p over U-NII bands, it is no longer "dedicated" in the FCC sense of that term. This document will use the term 802.11p for clarity.

2. **Funding for V2X Infrastructure:** Traditional funding sources are insufficient for the long-term expansion and maintenance of transportation technology. The at-scale implementation introduces a sustainable business model that attracts private investment.
3. **Regulatory and Spectrum Challenges:** The reduction of dedicated spectrum for transportation and the withdrawal of mandates for connected vehicle technology has hindered progress. This project introduces innovative solutions to utilize the remaining spectrum effectively.
4. **Community Engagement and Workforce Development:** The next phase of the project will implement plans prepared in the Stage 1 to educate the public and prepare the workforce for the adoption and maintenance of new transportation technologies.

2.1.2. Geographic Area and Jurisdiction

The at-scale implementation for Stage 2 of the project will be in Oakland County, Michigan. The county is in southeast Michigan, 20 miles north of the City of Detroit, and has a population of 1.3 million. This county includes 36 census tracts designated as Historically Disadvantaged Communities, which will be a focus for the at-scale deployment. Oakland County is home to 64 of the global 100 OEM/Tier 1 suppliers, and accounts for over 40% of Michigan's GDP. RCOC manages the region of 900 square miles with over 1500 traffic signals. RCOC has been on the cutting edge of ITS technologies and were one of the first agencies to deploy adaptive traffic control systems, video detection, and connected vehicle technology. RCOC's successful track record with ITS and strategic location to the OEM and Tier 1 automotive supply base make it a strategic hub for V2X.

During Stage 1 the project team conducted extensive analysis of potential deployment locations for Stage 2. The effort included analysis of crash and traffic rates, disadvantaged communities, VRU risk, existing infrastructure, and presence of vehicles that will be equipped with Direct V2X RSUs. The team identified 112 intersections (Figure 1) that best met the selection criteria. Two corridors (Woodward Avenue and Telegraph Road) contain most of these intersections. These roads are jointly maintained by RCOC and MDOT and require coordination to deploy Direct V2X technology. MDOT is a new project partner for Stage 2 to support this coordination. Additionally, neighboring Macomb County has an existing Direct V2X deployment, so RCOC will deploy at several intersections along a shared corridor, which runs between Oakland County and Macomb County, so that V2X interoperability can be demonstrated.

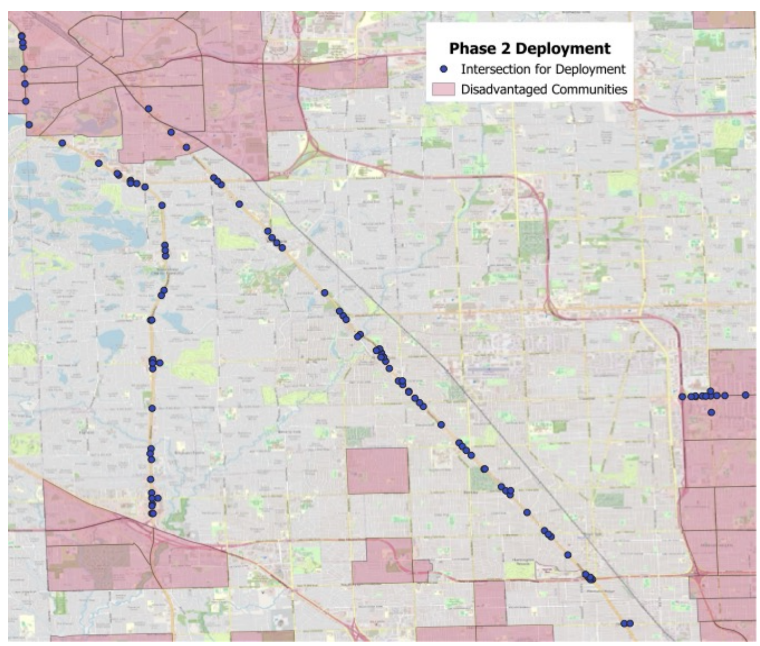


Figure 1: 112 Direct V2X Deployment Sites planned for Stage 2.

Towards the end of Stage 1, the project team identified that Networked V2X technology could significantly enhance the impact of the Stage 2 deployment. Historically, Networked V2X has been unable to deliver the low latency necessary for safety-critical applications and lacked the Security Credential Management System (SCMS) integration required for interoperability within the broader V2X ecosystem. However, recent industry developments suggest that these limitations are being addressed, making widespread deployment of Networked V2X more feasible in the near future. Networked V2X would be ideal for use cases that relay on SPAT, MAP, TIM, or SRM messages such as Signal Priority, Signal Preemption, Red-Light Violation Warning and traveler alerts. By leveraging cellular networks to transmit these messages, it would be possible to impact a wider area at a lower cost, since RSUs and OBUs would not be required for every intersection or vehicle. If Networked V2X can be deployed in a reliable and interoperable manner, the Stage 2 deployment could include all signalized intersections across the county. The team has identified over 600 initial targets for deploying the Networked V2X solution if that is feasible. Subscription services would be facilitated by the V2X Authorization Server at all locations.

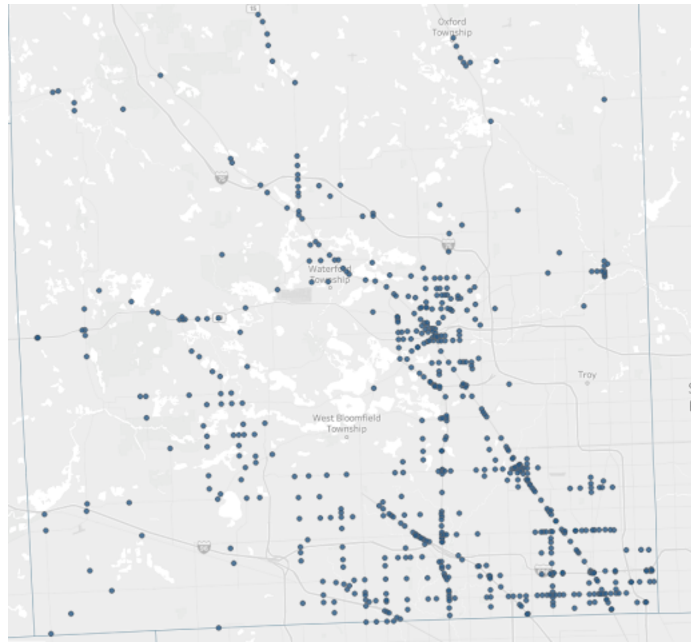


Figure 2: 616 Network V2X Deployment Sites planned for Stage 2

The 112 deployment sites were chosen to be the most impactful for achieving the key themes of the project. In response to the FY22 Stage 1 SMART Grant Notice of Funding Opportunity's goal of addressing equity, 25 of the 112 Direct V2X deployment sites are in disadvantaged communities, pursuant to the Department of Transportation's HDC locator tool.

2.1.3. Technologies Being Deployed

The project has deployed the following technologies:

1. **Connected Vehicles**: This technology enables vehicles to communicate with other vehicles, roadside infrastructure, and traffic management systems. This communication provides real-time data and alerts to drivers and automated systems. The specific technology elements include:

    - V2X Roadside Units (RSUs): Devices installed at intersections and along roadways to communicate with OBUs in connected vehicles. The RSUs can support communication via C-V2X, 802.11p and WiFi protocols.

- Advanced Traffic Controllers: Traffic signal controllers equipped with V2X capabilities to manage signal operations based on real-time data.
- Edge Computing Devices: High-performance computers installed at intersections to process data locally and reduce latency.
- Enhanced V2X Hub and Plug-ins: Open-source USDOT platform which has been enhanced to facilitate the integration of various V2X applications and services including the ability to monetize certain V2X services.
- On-Board Units (OBUs): Devices installed in vehicles to enable V2X communication. The OBUs can support communication via C-V2X, 802.11p and WiFi protocols.
- Human Machine Interface: Driver display within the vehicle that provide drivers with real-time alerts and information.
- Upgraded Antennae: Hardware components that facilitate the wireless transmission and reception of V2X data.
- Security Credential Management System (SCMS): Ensures secure and authenticated communication between vehicles and infrastructure.
- V2X Authentication Server: Manages access and subscription services for V2X applications enables an economically sustainable model.

2. **Intelligent Sensor-Based Infrastructure**: This technology integrates advanced sensors and computing devices into the transportation network to enhance safety and support connected vehicle technology. The specific technology elements include:

    - Cameras and AI-based VRU Detection Models: Cameras and AI-based VRU Detection Models for detecting and analyzing traffic conditions, including vehicle movements and vulnerable road users (VRUs).
    - Dual-Mode RSUs: Utilize 802.11P in the U-NII bands for additional communication bandwidth required to support sensor data sharing messages.

2.1.4. Goals and Desired Outcomes for At-Scale Implementation

The following goals and outcomes were identified for each program goal area. These impacts are further discussed in section 4.1: Impacts of At-Scale Implementation.

Goals	Desired Outcomes
Reduce Congestion and Delays for Commerce and the Traveling Public	● Reduced travel time for commercial vehicles with V2X freight signal priority ● Reduced congestion for commercial vehicles and the traveling public with V2X freight signal priority ● Reduced delays for school buses with V2X signal priority
Improve the Safety and Integration of Transportation Facilities and Systems for	● Reduced number of VRU crashes and near misses with V2X VRU driver alerts

Goals	Desired Outcomes
Pedestrians, Bicyclists, and the Broader Traveling Public	● Reduced number of pedestrian and bicyclist incidents in school zones and work zones from V2X Informational Messages ● Reduced number of crashes with authorized vehicles with V2X traffic signal priority and pre-emption ● Reduced red-light running incidents from Red-Light Violation Warning and Traffic Signal Countdown applications
Improve Access to Jobs, Education, and Essential Services, Including Health Care	● Reduced delays for school buses with V2X signal priority ● Reduced operating time for emergency vehicles with V2X maintenance signal priority ● Reduced operating time for municipal maintenance vehicles with V2X maintenance signal priority
Connect or Expand Access for Underserved or Disadvantaged Populations and Reduce Transportation Costs	● Cost Savings from V2X Technology
Contribute to Medium- and Long-Term Economic Competitiveness	● Revenue generation from subscription services
Improve the Reliability of Existing Transportation Facilities and Systems	● Improved transit and school bus on-time reliability ● Improved remote monitoring and uptime features
Promote Connectivity Between and Among Connected Vehicles, Roadway Infrastructure, Pedestrians, Bicyclists, the Public, and Transportation Systems	● Increase number of Connected Vehicle compatible intersections ● Increase number of Connected Vehicles ● Improved interoperability using V2X industry standards ● Increased communication bandwidth by leveraging the U-NII Wi-Fi spectrum ● Accelerated realization of benefits of the V2X system by leveraging infrastructure sensors
Incentivize Private Sector Investments or Partnerships	● Improved financial sustainability of the V2X system by introducing a model that focuses on generating funds and attracting private investment to support the deployment, operations, and maintenance of the V2X system ● Accelerated deployment of the V2X system with a model that attracts private investment ● Accelerated deployment of V2X equipped vehicles by collaborating with OEMs and fleet providers
Improve Energy Efficiency or Reduce Pollution	● Reduced fuel consumption with V2X traffic signal priority and pre-emption

Goals	Desired Outcomes
	● Reduced pollution with V2X traffic signal priority and pre-emption
Increase the Resiliency of the Transportation System	● Improved cybersecurity with the introduction of the SCMS into the V2X system
Improve Emergency Response	● Improved response time for emergency vehicles with V2X emergency vehicle pre-emption ● Reduced number of crashes with emergency vehicles with V2X emergency vehicle pre-emption

2.1.5. Additional Information

The project is designed to be scalable and replicable, with a prototype demonstration at five intersections and deployment in ten county-owned vehicles. The lessons learned from this prototype will inform a broader, multi-year deployment plan across Oakland County, aligning with the USDOT's national V2X deployment strategy. The project will also involve significant workforce development efforts to prepare residents for jobs in the evolving transportation technology sector. This project represents a forward-thinking approach to addressing critical transportation challenges through innovative technology and sustainable business practices, ultimately aiming to improve safety, efficiency, and quality of life for all residents of Oakland County.

2.2. Impacted Communities

The map in section 2.1.2 shows which communities will be directly impacted with an at-scale implementation of Direct V2X. If Networked V2X becomes feasible, the impacted communities would change and encompass most of the county's geographic area.

2.2.1. Connecting or Expanding Access for Underserved or Disadvantaged Populations

In response to the FY22 Stage 1 SMART Grant Notice of Funding Opportunity's goal of addressing equity, 25 of the 112 Direct V2X deployment sites are in disadvantaged communities, pursuant to the Department of Transportation's HDC locator tool. Key benefits to these communities include:

- Improved Safety: Implementing technology that reduces traffic accidents in high-risk areas.
- Reduced Congestion: Improving traffic flow, leading to shorter travel times and reduced emissions.
- New Economic Opportunities: Creating jobs related to the deployment and maintenance of the technology, as well as workforce development programs to train residents.

2.2.2. Meaningful Involvement of Community Stakeholders

During Stage 1 of the project, a Community Engagement Advisory Board was established to gather input from key community stakeholders and develop a community engagement plan to be executed in Stage 2. By involving local stakeholders in the planning process, the project aims to deliver tangible benefits where they are most needed. This approach not only improves safety and efficiency but also fosters community support, ensuring that the project meets the diverse needs of Oakland County's residents.

The Advisory Board included representatives from diverse backgrounds:

- Government: RCOC, Michigan Department of Transportation (MDOT), Oakland County, City Administrators, Local traffic engineers.
- Educational Institutions: Faculty from Lawrence Technical University.
- Community Organizations: Leaders from various community groups and associations.
- Residents: Local citizens providing insights into community concerns and needs.

The Advisory Board met regularly over several months to create the following framework for community engagement:

- **Stakeholder Identification**: The board identified key stakeholders, including residents, local government officials, transit organizations, and professional associations that would have an interest in the safety of their community and the deployment of technology to improve safety.
- **Messaging**: Developed a detailed plan for engaging the community, focusing on clear, concise messaging about the benefits of the technology.
- **Communication Strategies**: Outlined multiple communication channels such as social media, public meetings, workshops, and flyers to reach a broad audience. These channels will help to discuss the project, gather feedback, and answer community questions, ensuring transparency and responsiveness.
- **Focus on Institutions Engaged in Workforce Development**: The plan emphasizes prioritizing engagement and deployment with organizations focused on workforce development. This was meant to ensure that young people and the future workforce are being exposed to the technology and understand its benefits.
- **Surveys and Feedback Forms**: Ongoing collection of input from residents and local businesses to address their transportation needs and concerns.

2.3. Deployment Scale

The table below compares the scale of Stage 1 and Stage 2.

Item	Stage 1	Stage 2 (as planned)	Stage 2 (with Networked V2X)
Number of Intersections with V2X deployed	5	112 (see Figure 1 in section 2.1.2)	20-50 sites with Direct V2X 600+ sites with Networked V2X (see Figure 2 in section 2.1.2)
Site Selection Criteria	Based on existing infrastructure and VRU traffic	Existing infrastructure, traffic counts, crash counts, Disadvantaged Communities	Direct V2X: Prioritizing VRU safety Networked V2X: All sites with adequate network connectivity
Number of OBUs deployed and Vehicle Type	10 RCOC owned maintenance pick-up trucks	1000 RCOC maintenance trucks, RCOC snowplows, local maintenance vehicles, local emergency vehicles (police and fire),	500 Direct V2X OBUs in public vehicles

		local maintenance vehicles, MDOT emergency and maintenance vehicles	Networked V2X Mobile App available for all other vehicles
SCMS Utilized	Yes	Yes	Yes
V2X Use Cases	Signal Priority, VRU Alerts, Fleet Intelligence	Signal Priority, VRU Alerts, Fleet Intelligence, Signal Pre-emption, Red-Light Violation Warning, Work Zone warnings, Weather Alerts	Signal Priority, VRU Alerts, Fleet Intelligence, Signal Pre-emption, Red-Light Violation Warning, Work Zone warnings, Weather Alerts
V2X Communication Methods	5.9 GHz ITS band, 802.11p in U-NII bands	5.9 GHz ITS band, 802.11p in U-NII bands	5.9 GHz ITS band, 802.11p in U-NII bands, Licensed Cellular Spectrum

2.4. Project Activities Summary

2.4.1. Project Partners

The following organizations were partners on the project:

Partner	Description
Road Commission for Oakland County (RCOC)	Lead organization responsible for overall project management and implementation. RCOC manages road infrastructure and traffic operations within Oakland County.
P3Mobility	Digital infrastructure project development firm providing consulting services and a software platform which enables a user pay model for subscriptions in the V2X ecosystem. Key project partner for developing the business model and financial plan.
The Mannik & Smith Group (MSG)	Engineering firm specializing in transportation infrastructure. Responsible for planning and gathering data related to traffic safety and efficiency.
Integral Blue	Specializes in advanced traffic signal and intelligent transportation systems (ITS). Provides technical expertise in the design, installation, and maintenance of traffic management solutions, including systems integration and the deployment and integration of V2X technology at intersections.
AECOM	Global infrastructure consulting firm providing engineering, design, planning, and management services. Supports the creation of the plan to deploy at-scale in Stage 2.
Brandmotion	Developer and distributor of automotive retrofit safety technology. Partnered on the development of the workforce development program including training for V2X technology installation and maintenance.
Operis	Specialist in financial modeling and advisory services for large infrastructure projects. Provides expertise in developing financial models, risk assessment, and economic viability for attracting private investment and ensuring economic sustainability.
OpenVia	Leading infrastructure management and investment firm specializing in the operation and maintenance of transportation infrastructure. Contributes expertise in structuring private investment in infrastructure projects.
Oakland County Local Government	Involves various local government entities supporting strategic planning
Lawrence Technical University (LTU)	Educational institution contributing research and technical expertise. Involved in workforce development and community engagement efforts.
Southeastern Michigan Council of Governments (SEMCOG)	Regional planning organization supporting data collection

University of Michigan	University of Michigan Transportation Research Institute supplied the VRU detection software (Msight) used for Vulnerable Road User detection.
Poco Labs	Michigan-based market research firm specializing in the automotive industry. Poco Labs supported the industry stakeholder engagement activities for the with interviews with OEM, fleet, and Tier 1 automotive stakeholders. The insights gathered from this activity were inputs to the Business and Financial Plan and the County-wide Deployment Plan which will be executed on in Stage 2 of the project.
Bridgeport	Michigan-based communications consultant that led the creation of the Community Engagement Plan.

2.4.2. Prototype

The prototype includes 5 intersections (Figure 3) and 10 RCOC vehicles that are configured with V2X technology. The prototype demonstration phase validated the feasibility and benefits of V2X technology, preparing RCOC for a larger-scale deployment in Stage 2. The key activities of the prototype include:

- **System Architecture Design**: Developed the system architecture for the prototype, integrating V2X technology with existing traffic management infrastructure and ensuring robust security through the Security Credential Management System (SCMS).
- **Technology Selection and Procurement**: Selected and procured critical hardware components, including Roadside Units (RSUs) and On-Board Units (OBUs), ensuring compliance with industry standards and project requirements.
- **Installation of RSUs and OBUs**: Deployed RSUs at five strategically selected intersections and installed OBUs in ten county-owned vehicles. These installations were chosen based on safety, traffic volume, and infrastructure readiness.

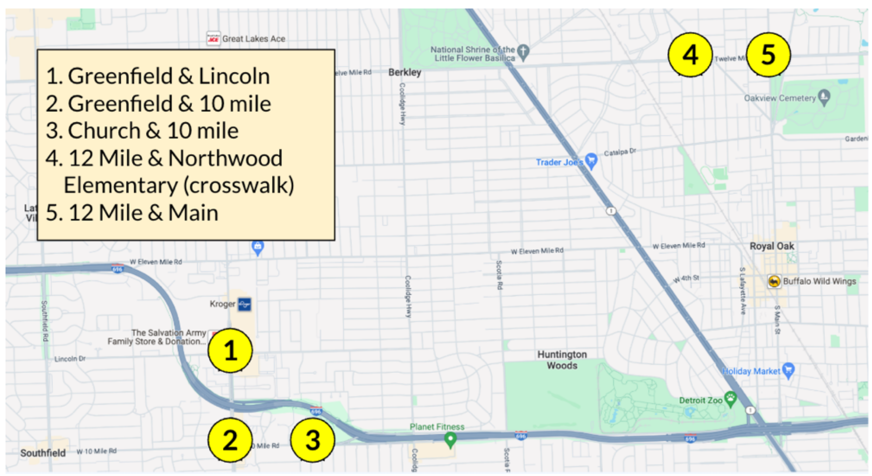


Figure 3: Five prototype intersections for Stage 1

- **Initial Testing and Validation**: Conducted comprehensive testing of the installed RSUs and OBUs to ensure effective communication, system functionality, and data accuracy. Validated the system's ability to provide real-time alerts and enhance traffic safety.
- **Data Collection and Analysis**: Implemented monitoring tools to collect performance data on safety improvements, traffic flow, and signal priority effectiveness. Analyzed the collected data to assess the impact of the V2X technology.

2.4.3. Planning Deliverables

Stage 1 of the project led to the creation of the following deliverables:

- **County Wide Deployment Plan:** This document identifies the technology deployment plan for Oakland County hopefully supported by a Stage 2 SMART grant. This document is influenced by RCOC's mission and priorities, lessons learned from Stage 1, and a fiscally sustainable acquisition, installation, and maintenance plan suitable for RCOC to deploy V2X technology across the county.
- **Community Engagement Plan:** This document identifies the plan to engage and educate the wider community on the benefits of V2X technology for Stage 2.
- **Business and Financial Plan:** This document identifies the business and financial plan to create an economically sustainable deployment for Stage 2. This includes a financial model that demonstrates the cost and benefit determination for the Stage 2 project. This document also presents options for preferred project and investment structure for a privately financed deployment of infrastructure, which will expand upon the Stage 2 grant funding.
- **Workforce Development Plan:** This document identifies the plan to educate RCOC and the wider community workforce on deploying and maintaining V2X technology for Stage 2.
- **Project Evaluation Plan:** This deliverable is a report that focuses on how the performance of Stage 1 of the project will be evaluated and how the performance of Stage 1 can be used to estimate benefits of the system during at-scale deployment in Stage 2. An in-depth analysis of RCOC's transportation network and costs for upgrades was used to determine the optimal deployment locations and V2X use cases for a scaled Stage 2 deployment.
- **Data Management Plan:** The data management plan is a summary of the types of information being collected and stored. It identifies qualitative and quantitative data sets, their formats, methods of collection, and storage. The plan documents how data security and privacy are addressed and what access and achieving is planned.

2.5. Public Resources and Presentations

RCOC and the project team have actively disseminated information about the V2X project through various public resources and presentations. The team was highly motivated to not only communicate internally but also externally to support the growing ecosystem and educate the community with the following activities:

Public Resources

- Public website for project information[3]
- Updates will be added to ITSA JPO Lessons Learned Database upon project closure
- Project materials are shared as per the Data Management Plan

Presentations and Outreach

- October 2023 press conference with Deputy Assistant US Secretary of Transportation and Chief USDOT Scientist Robert Hampshire, PhD in Oakland County.

[3] https://www.rcocsustainable-safety.org/

- April 2024 Intelligent Transportation Society of America Conference in Phoenix, AZ
    - Presentation: Financially Sustainable C-V2X Deployments in Oakland County, Michigan – to discuss the motivation and goals of the project
    - Presentation: Expanding the C-V2X Spectrum for Safety Critical Applications – to discuss how U-NII band WiFi is being used in the project.
- Press release[4] from the City of Southfield, MI to garner support for a public discovery of the project and technology
- July 2024 Michigan Department of Transportation (MDOT) Transportation Career Day at Lawrence Tech University with news segments from
    - ABC Channel 7 Detroit[5]
    - NBC Channel 4 Detroit
- News radio WWJ interview with CEO and founder of project partner, P3Mobility, to discuss the project
- Michigan Senator Gary Peters staff debriefing
- September 2024 presentation to ITS-Rocky Mountain Chapter
- December 2024 presentation to ITS-Texas Chapter
- January 2025 presentation to ITS Michigan Chapter

2.6. Deviations from Original Proposal

The project workstreams drove the desired outcomes that were outlined in the Stage 1 Narrative for location, community, workforce, technical merit, and project readiness with emphasis on the economically sustainable model. There were a few deviations from the original proposal:

1. The Stage 1 prototype deployment timing had a delay from the baseline plan of approximately 6 months. The main factors causing this were:
    a. The network and firewall configuration did not allow full access between the traffic cabinet, the traffic management center and the cloud. Workarounds proved difficult and time consuming.
    b. Training data collection for the VRU detection system was manual and error-prone leading to delays in training the AI models. (These items are discussed further in section 4 on challenges and lessons learned.)
2. The grant application originally intended to focus only on direct C-V2X communication in the 5.9 GHz ITS band. The approach expanded to demonstrate the use of 802.11P communication in the U-NII bands to overcome the reduction in FCC spectrum. The approach will also continue to expand to include Networked V2X over cellular spectrum. The project team plans to evaluate the feasibility of Networked V2X by demonstrating and testing Networked V2X use cases in the prototype demonstration after Stage 1 concludes.
3. The original proposal called for the installation of C-V2X OBUs and tablet displays in 10 RCOC fleet vehicles. The OBUs were installed, but the tablets were not installed at the

[4] https://www.cityofsouthfield.com/news/city-southfield-partners-rcoc-ltu-and-p3mobility-launch-new-road-safety-technology

[5] https://drive.google.com/file/d/1wDZt-NP2zYSnQfGof-Z2S7UYP-4eFiwE/view?usp=sharing

conclusion of Stage 1 due to challenges with providing reliable VRU alerts (These challenges are discussed further in section 4 on challenges and lessons learned). The project team will consider installing the tablets after Stage 1 concludes based on the performance of the system.

3. Proof of Concept or Prototype Evaluation Findings

3.1. Summary

Statutory Area	**Finding**
Reduce Congestion And Delays For Commerce And The Traveling Public	Traffic Signal Priority reduced the average time through an intersection by approximately 10%. It was configured to minimize disruptions to non-equipped vehicles and the signals will get back in sync within 1 cycle.
Improve The Safety And Integration Of Transportation Facilities And Systems For Pedestrians, Bicyclists, And The Broader Traveling Public	Demonstrated that VRU alerts could be delivered to a driver via C-V2X communications.
Improve Access To Jobs, Education, And Essential Services, Including Health Care	Traffic Signal Priority reduced the average time through an intersection by approximately 10%. This can be applied to transit and emergency vehicles.
Connect Or Expand Access For Underserved Or Disadvantaged Populations And Reduce Transportation Costs	Analyzed crash cost data for Oakland County and how a reduction in crashes could save significant money for RCOC and other parties.
Contribute To Medium- And Long-Term Economic Competitiveness	Demonstrated a V2X Authorization Server to offer V2X Services (e.g. commercial signal priority) on a paid subscription basis.
Improve The Reliability Of Existing Transportation Facilities And Systems	Demonstrated automatic and remote restart of V2X components without requiring a technician to visit the site.
Promote Connectivity Between And Among Connected Vehicles, Roadway Infrastructure, Pedestrians, Bicyclists, The Public, And Transportation Systems	Deployed 5 C-V2X RSUs and 10 C-V2X OBUs. Also, demonstrated V2X communications in the U-NII bands using 802.11p protocol.
Incentivize Private Sector Investments Or Partnerships	Engaged with private investors and fleets to build a financial model

Improve Energy Efficiency Or Reduce Pollution	Simulated how traffic signal priority could reduce fuel consumption for equipped vehicles.
Increase The Resiliency Of The Transportation System	SCMS system was deployed for secure V2X messaging.
Improve Emergency Response	Traffic Signal Priority was effective and can be expanded to include Emergency Vehicle Preemption in Stage 2 to improve emergency response.

3.2. Analysis of Project Evaluation and Data Management Plan

The table below summarizes the performance metrics submitted as part of the Project Evaluation and Data Management Plan. Each metric will be discussed in detail in the subsequent sections.

Evaluation Question	***Performance Measure***	***Performance Measure Target***	***Result***
Cooperative Perception: Can the system detect a potential conflict with a VRU?	Time between alert and point of potential conflict.	Alert is received with an acceptable response time. The acceptable response time will vary for each intersection approach and will be calculated while considering speed limit of the approach and ITE guidelines for driver human reaction times and deceleration	End to end latency of SDSMs averages 1.8 seconds due to limitations in the sensor.
Signal Priority: How much time can be saved for a vehicle with signal priority?	Intersection traversal time	5% improvement from baseline	Approximate 10 second reduction in travel time through an equipped intersection. This average considers all scenarios regardless of whether TSP is granted or not.
Signal Priority: Can signal disruption be minimized with signal priority?	Number of cycles for signal to recover after Signal Priority event	Signal timing recovers in less than 3 cycles	With a timing adjustment as a percentage of cycle length set to 10%, simulation and field testing has shown a full signal recovery in less than 2 cycles.
Unlicensed Wi-Fi: Can a V2X message be reliably delivered over unlicensed Wi-Fi (adjacent to ITS spectrum)?	Packet throughput over a set time	Packet throughput over unlicensed Wi-Fi is equivalent to packet throughput over the ITS spectrum	Packet throughput using the U-NII bands meets or exceeds throughput in the ITS spectrum.

Unlicensed Wi-Fi: How far can a message be reliably delivered over unlicensed Wi-Fi compared to ITS spectrum?	Packet loss over a distance	Packet loss over unlicensed Wi-Fi is equivalent to packet loss over the ITS spectrum at 100 meters from RSU	Packet loss performance using the U-NII bands meets or exceeds packet loss performance in the ITS spectrum up to 400 meters from RSU.
Unlicensed Wi-Fi: Is access to unlicensed Wi-Fi spectrum secure and protected?	Packet throughput	Packet throughput is not impacted while non-authorized users attempt to access the unlicensed Wi-Fi spectrum	The originally described evaluation question was demonstrated with different criteria. Security was demonstrated in the U-NII band by encrypting 802.11p messages with SCMS. For other 802.11 protocols, there was a WiFi network password protection mechanism where only an entity enrolled in SCMS could access the network encryption key.
Financial Sustainability: How will vehicles be authorized for revenue generating V2X subscription services in accordance with IOO policies?	Accurate authorization of V2X services for a vehicle	100% authorization accuracy	100% authorization accuracy was achieved.
Financial Sustainability: What cost savings can be potentially realized through signal priority/preemption?	Average time for vehicle to pass through a specific route	5% improvement from baseline	Approximately $0.25 cost savings for each pass through a TSP enabled intersection. Percentage improvement is dependent on additional factors that were not possible to control.
Overall System: Does the system provide value to the users?	Qualitative feedback from users	Net positive feedback	Pending – As the system is rolled out to RCOC fleet vehicles, the team can obtain feedback from multiple stakeholders including: TMC staff, drivers, fleet managers, etc.

3.2.1. Cooperative Perception: Can the system detect a potential conflict with a VRU?

The system successfully generated and transmitted SAE J3224 SDSMs based on data from cameras that was processed by an AI VRU detection algorithm. The messages were processed in the vehicle and used to display alerts about potential conflicts to a driver in a test vehicle.

VRU Detection System Overview

The project incorporated an edge-cloud system architecture that used cameras at the intersection along with the Msight VRU detection software created by the University of Michigan Transportation Research Institute. The system used Gridsmart camera processor boxes RTSP streams as the input. All intersections utilized two cameras except one small intersection where only one was deployed. The first phase captured thousands of images that were stored, manually labeled, and then used to train a YOLOv11 detection model for object classification.

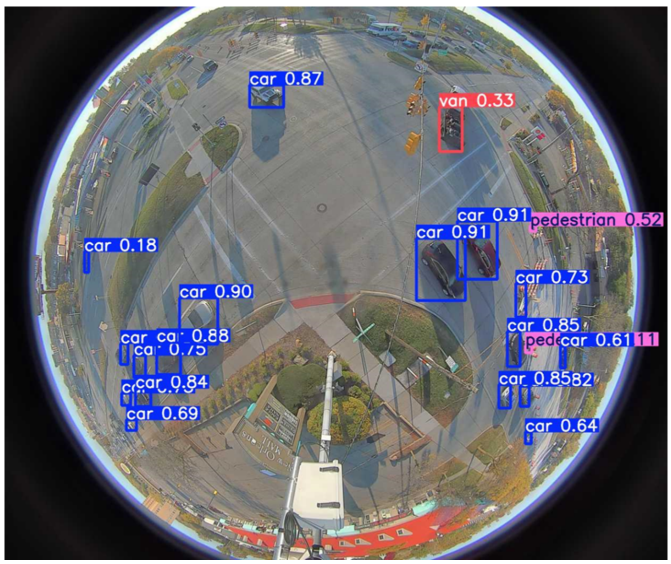


Figure 4: Example output from a YOLO detection model

The detection model identifies objects of interest in the image, the localization module determines their precise 3D coordinates, the fusion module integrates data from multiple sensors to enhance accuracy and reliability, and the tracking module continuously monitors their trajectories over time.

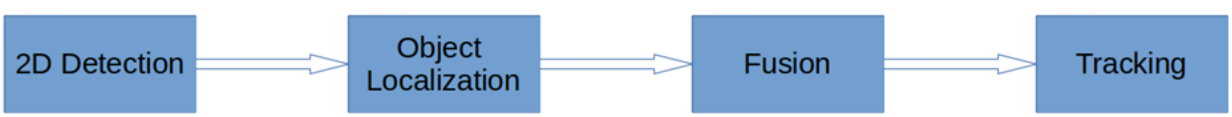
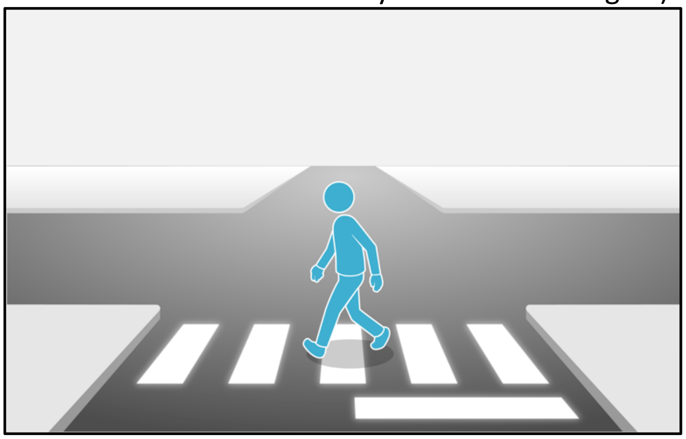


Figure 5: AI VRU Detection Process Flow

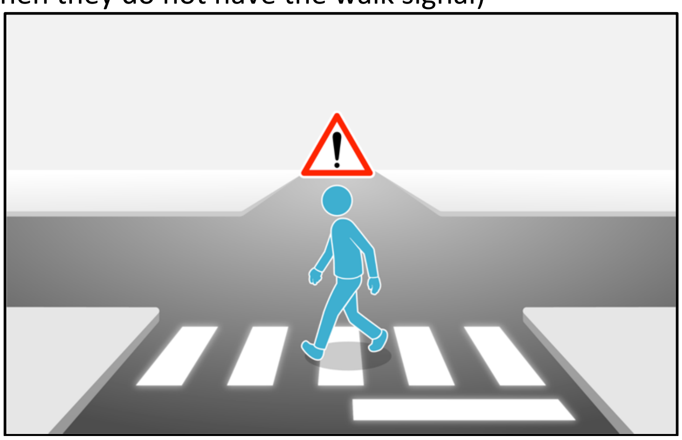
The detected VRUs were fed into the P3Mobility V2X Hub where they were formatted as SAE J3224 SDSMs then forwarded to the RSU for broadcast.   On the vehicle side, the OBU running a P3Mobility application processed the SDSMs along with the MAP and SPaT message. If a VRU is present, an alert was designed to be displayed to the driver showing the estimated VRU location relative to the vehicle. The VRU display logic added significant complexity over a generic VRU alert but pushed the boundaries to show what was possible.

There were three main levels of alert based on the location of the detected VRU, the location of the vehicle, and the traffic signal status. The prototype did not classify different types of VRUs (e.g. pedestrian, bicycle, scooter).

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)



Level 2: Provides an alert that a VRU is in a crosswalk they are not permitted to be in. (e.g. A pedestrian crossing when they do not have the walk signal)



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 was supplemented with an audio warning alert to further warn the driver.

Testing

Bench testing was a pre-requisite to live intersection testing with a test vehicle. The team used simulated objects (Obj_Sim) being fed into the system to debug the lane logic and MAP issues. The Obj_Sim was also used effectively to show stakeholders how the HMI/ tablet would look in a safe controlled environment. Model performance was evaluated every release by the project team based on a standard validation image set. Actual intersection performance was evaluated by plotting the detected VRUs against actual images and using driver reported performance. As the diversity of data improved, or false negatives / false positives were captured and shared, the performance incrementally improved.

Figure 6: Example of plotting VRU Detection output against the real-world for validation.

VRU Detection Model Performance

The UM Msight team developed multiple detection models as part of this project. The first two models were trained on a dataset comprising 6,958 images, with 745 images reserved for evaluating model performance. The third model was built using the pre-trained weights of the second model, and a data engine was incorporated to enhance the VRU detection performance. It should be noted that images in this dataset were from both Oakland County intersections and Ann Arbor, MI intersections to increase the evaluation context. The results are evaluated using

Average Precision (AP), a metric in object detection that measures the area under the precision-recall curve. AP was calculated using center distance thresholds (2, 5, 10, 20, and 50 pixels) rather than the traditional IoU. The reported AP values represent the mean AP (mAP) across these thresholds, providing a robust evaluation of detection accuracy at varying tolerances.

The overall VRU detection performance improved from 41% to 48%. Lower average precision versus a vehicle was expected due to the smaller pedestrian cross section size especially in the top-down view. Other contributing factors included a minimum annotated training data set and the lack of camera specific intrinsic parameters to use in the calibration (for example, distortion coefficients of the fisheye lenses).

Model Version 1 Performance

Class	**AP**	**Class**	**AP**	**Class**	**AP**
Car	59.701	**Truck**	20.626	**Bus**	56.711
Trailer	0.000	**Motorbike/Cycler**	28.423	**Pedestrian**	41.093
Van	0.052	**Pickup**	37.190		

Model Version 2 Performance

Class	**AP**	**Class**	**AP**	**Class**	**AP**
Car	95.259	**Truck**	35.304	**Bus**	81.879
Trailer	33.401	**Motorbike/Cycler**	32.530	**Pedestrian**	43.631
Van	1.188	**Pickup**	47.636		

Model Version 3 Performance

Class	**AP**	**Class**	**AP**	**Class**	**AP**
Car	85.712	Truck	**28.432**	**Bus**	76.589

Trailer	31.204	Motorbike/Cycler	**40.512**	**Pedestrian**	48.123
Van	1.672	Pickup	**42.789**		

End to End Latency

To determine the latency of the IP Camera/RTSP stream, we compared the GPS coordinates from the on-board OBU to the positions being reported by the VRU detection system and measured the delay between the two. All tests were performed in sets of opposite directions to account for any positional inaccuracy or "skew" from the VRU detection system. Both systems times were synced via GPS.

The team identified an average end to end latency of 1.76 seconds which is much higher than the acceptable threshold of 300ms which indicates adequate performance.

The time for the camera to capture and stream the data is the largest contributor to latency. This project used Gridsmart fish-eye cameras and processors processing box which the team discovered are meant for traditional vehicle counting and not real-time VRU detection. Integration and optimization efforts need to be taken with camera and computer vision suppliers as part of a Stage 2 plan.

As noted in Section 1.6 Deviations from the Original Proposal, the tablets intended to display the alerts were not installed in any vehicles besides the test vehicle at the time of this report. The latency demonstrated increases the risk of false alerts. The project team will install the tablets after Stage 1 concludes based on the improved performance of the system achieved.

Step	**Nominal Time (ms)**	**Comments**
IP Camera + RTSP Server	1,636.3	
Detection	14.739	Total Inference time is 50.346 ms
Pub/Sub	7.975	
Fusion	1.198	
Pub/Sub	0.89	
Tracking	25.545	
POM processed	25.5	

SDSM generated	0.3	Total V2X Hub processing time 81.2 ms
RSU to OBU transmission	55.4	
Total	**1,767.9**	

3.2.2. Signal Priority: How much time can be saved for a vehicle with signal priority?

This project included the deployment of traffic signal priority (TSP) where equipped and enrolled vehicles would make a request as they approached the intersection which could be granted by signal extensions of the requested phase or reductions of opposing phases. TSP is more benign than emergency vehicle preemption which has a more aggressive controller response and is more disruptive to traffic patterns. This use case required extensive reviews and approvals from the RCOC traffic engineers to ensure the implementation aligned with their guidelines and operational objectives. At the time of this report, four intersections had TSP fully implemented and tested as part of this project. The project faced delays equipping the 10 RCOC maintenance trucks, so widespread TSP data was not available at the time of this report submission. Data collection will continue after the official end date of Stage 1 and prior to Stage 2.

The key considerations for TSP were:

- The approach to TSP was conservative for this first pilot with a maximum timing adjustment as a % of cycle length set to 10%.
- No turning and no vehicle classes are differentiated
- The max adjustment is 10 sec with a target to return to timing in 1-2 cycles.
- Provide at least two cycle-time of “Lockout” preventing additional priority requests to allow the intersection traffic to stabilize
- There were no changes to the existing intersection event plans. Split timing extensions were applied to the priority phase while split timing reductions were applied to all active phases. No phase or pedestrian walk signal skipping were used.
- Timing adjustments are made only to green intervals
- “Estimated Time of Arrival”, “Estimated Time of Departure”, and “Time to Live” are provided by the SRM (signal request message) and continuously updated as the vehicle approaches
- Adjustments to the Econolite controller TSP sub-menus were documented in updated Timing Plans for proper configuration control. See example below.

4. PREEMPTOR/SCP - 3. SCP STRATEGY PLAN

SCP (TSP / EVP) STRATEGY PLAN: 1

COORD PTN IN FREE 120
ALT SEQUENCE . . . .
TIME TO LIVE 120
MAX UPDATE % 0

SCP PHASE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
ENABLE	NO	YES	NO	YES	NO	YES	NO	YES								
MAX QUEUE COMP		0		0		0		0								
OBSTRUCTING PHS		0		0		0		0								
RECOVER CYCLE		0		0		0		0								
PREEMPT RECOVER		NO		NO		NO		NO								
ADVANCE WARNING		0		0		0		0								

4. PREEMPTOR/SCP - 4. SCP SPLIT PATTERN

SCP (TSP / EVP) SPLIT PATTERN: 1

PHASE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
MAX RTDN	1	8	0	0	1	8	0	0								
SPLT GRN	13	41	0	27	13	41	0	27								
MAX EXTN	0	9	0	9	0	9	0	9								

SCP (TSP / EVP) SPLIT PATTERN: 2

PHASE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
MAX RTDN	1	7	0	1	1	7	0	1								
SPLT GRN	13	38	0	30	13	38	0	30								
MAX EXTN	0	9	0	9	0	9	0	9								

SCP (TSP / EVP) SPLIT PATTERN: 3

PHASE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
MAX RTDN	1	8	0	0	1	8	0	0								
SPLT GRN	13	41	0	27	13	41	0	27								
MAX EXTN	0	9	0	9	0	9	0	9								

SCP (TSP / EVP) SPLIT PATTERN: 4

PHASE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
MAX RTDN	1	8	0	0	1	8	0	0								
SPLT GRN	13	41	0	27	13	41	0	27								
MAX EXTN	0	9	0	9	0	9	0	9								

SCP (TSP / EVP) SPLIT PATTERN:

PHASE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
MAX RTDN																
SPLT GRN																
MAX EXTN																

Figure 7: RCOC Timing Sheet Updates

The traffic signal operations personnel at RCOC decided that the timing plans for signal priority should be specifically designed such that the maximum signal timing offset allowable from a signal priority request can always be recovered with adjustments to the following phases before completing a full cycle. A different, or more aggressive timing policy would have much different results and could result on more significant time savings.

The following steps were taken to bench test TSP before testing in the field:

1. Traffic signal controller database images were uploaded to the bench system with modifications based on TSP parameters
2. Bench emulation generated the SPM files and controller behavior reports with a variety of approach times.

3. Virtual Simulations (VSIMs) created for a variety of approaches to the intersection - see example figure below.

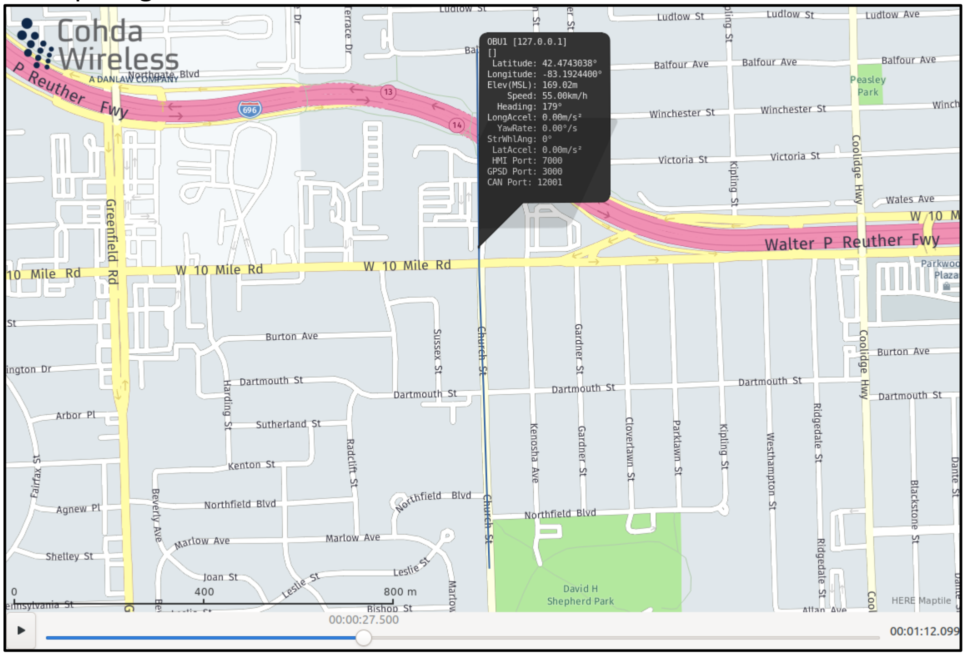


Figure 8: Example of a simulated vehicle trajectory to test TSP

After completing bench testing, the team moved onto field testing to demonstrate TSP with a test vehicle.

Field testing prerequisites included:

- Full system production SCMS enrollment (RSU, OBU)
- NTCIP 1211 traffic controller image updated with the parameter changes agreed upon by RCOC.
- P3Mobility OpMonitor configured to store test data

Field testing confirmed bench simulation showing both phase extension outcomes:

1. TSD (time of service desired) can be met by extending the priority phase
2. TSD (time of service desired) cannot be met by extending the priority phase. Reductions are applied to opposing phases to return to the priority phase sooner. Extensions are then applied on the next cycle to replace the opposing phase reductions that were applied to get an early return (most common behavior based on parameter settings).

Field Testing Example Results:

<u>Scenario:</u>

- Vehicle approached the intersection on the minor street (Phase 4/8).
- SRM sent at the beginning of the MAP vehicle lane with ETA to the intersection of 18s.
- 7.5s of green remains for phase 4/8.

<u>Results:</u>

- Maximum allowable extension of 9s (10% cycle time) is insufficient to get the vehicle through the intersection, so extension is not granted.
- Phases 1/5 reduce their green time by 1s (maximum allowed as per timing sheet).
- Phases 2/6 reduce their green time by 8s (maximum allowed as per timing sheet).
- Phases 4/6 become green 9s early due to reductions of opposing phases.

Reporting:
SPaT messages are saved to the online dashboard throughout a TSP request. This gives an in-depth view of the actions of the controller throughout the request and allows a traffic engineer to review how the TSP timing parameters are affecting the controller in the field. The team found it valuable to be able to display the controller responses in a manner that allowed a variety of stakeholders to understand what was happening. This information was accessed in real time using the SPaT Priority tab of the OpMonitor.

SPaTPriority

Sent at	Ph1	Min	Max	Ph2	Min	Max	Ph3	Min	Max	Ph4	Min	Max	Ph5	Min	Max	Ph6	Min	Max	Ph7	Min	Max	Ph8	Min	Max
2025-01-28 17:02:40.201	🔴	63	203	🔴	203	203	🔴	0	0	🟢	3	143	🔴	63	203	🔴	203	203	🔴	0	0	🟢	3	143
2025-01-28 17:02:40.301		0	0	🔴	202	202	🔴	0	0	🟢	2	142	🔴	62	202	🔴	202	202	🔴	0	0	🟢	2	142
2025-01-28 17:02:40.389	🔴	61	201		0	0	🔴	0	0	🟢	1	141	🔴	61	201	🔴	201	201	🔴	0	0	🟢	1	141
2025-01-28 17:02:40.503	🔴	59	199	🔴	200	200	🔴	0	0	🟡	35	35	🔴	60	200	🔴	200	200	🔴	0	0	🟡	35	35
2025-01-28 17:02:40.601	🔴	58	198	🔴	198	198	🔴	0	0	🟡	34	34	🔴	58	198	🔴	199	199	🔴	0	0	🟡	34	34
2025-01-28 17:02:40.688	🔴	57	197	🔴	197	197	🔴	0	0	🟡	32	32	🔴	57	197	🔴	198	198	🔴	0	0	🟡	33	33
2025-01-28 17:02:40.800	🔴	56	196	🔴	196	196	🔴	0	0	🟡	31	31	🔴	56	196	🔴	196	196	🔴	0	0	🟡	32	32
2025-01-28 17:02:40.988	🔴	55	195	🔴	195	195	🔴	0	0	🟡	30	30	🔴	55	195	🔴	195	195	🔴	0	0	🟡	30	30
2025-01-28 17:02:41.100	🔴	53	193	🔴	194	194	🔴	0	0	🟡	29	29	🔴	54	194	🔴	194	194	🔴	0	0	🟡	29	29
2025-01-28 17:02:41.200	🔴	52	192		0	0	🔴	0	0	🟡	28	28	🔴	53	193	🔴	193	193	🔴	0	0	🟡	28	28
2025-01-28 17:02:41.288	🔴	51	191	🔴	192	192		0	0	🟡	27	27	🔴	52	192	🔴	192	192	🔴	0	0	🟡	27	27
2025-01-28 17:02:41.400	🔴	50	190	🔴	190	190	🔴	0	0	🟡	26	26	🔴	51	191	🔴	191	191	🔴	0	0	🟡	26	26
2025-01-28 17:02:41.501	🔴	49	189	🔴	189	189	🔴	0	0		0	0	🔴	50	190	🔴	190	190	🔴	0	0	🟡	25	25
2025-01-28 17:02:41.588	🔴	48	188	🔴	188	188	🔴	0	0	🟡	23	23	🔴	48	188	🔴	189	189	🔴	0	0	🟡	24	24
2025-01-28 17:02:41.700	🔴	47	187	🔴	187	187	🔴	0	0	🟡	22	22	🔴	47	187	🔴	187	187	🔴	0	0	🟡	23	23
2025-01-28 17:02:41.888	🔴	46	186	🔴	186	186	🔴	0	0	🟡	21	21	🔴	46	186	🔴	186	186	🔴	0	0	🟡	21	21
2025-01-28 17:02:42.000	🔴	44	184	🔴	185	185	🔴	0	0	🟡	20	20	🔴	45	185	🔴	185	185	🔴	0	0	🟡	20	20
2025-01-28 17:02:42.102	🔴	43	183	🔴	183	183	🔴	0	0	🟡	19	19	🔴	43	183	🔴	184	184	🔴	0	0	🟡	19	19
2025-01-28 17:02:42.188	🔴	42	182	🔴	182	182	🔴	0	0	🟡	17	17	🔴	42	182	🔴	182	182	🔴	0	0	🟡	18	18
2025-01-28 17:02:42.301	🔴	41	181	🔴	181	181	🔴	0	0	🟡	16	16		0	0	🔴	181	181	🔴	0	0	🟡	17	17
2025-01-28 17:02:42.400	🔴	40	180	🔴	180	180	🔴	0	0	🟡	15	15	🔴	41	181		0	0		0	0		0	0
2025-01-28 17:02:42.489	🔴	39	179	🔴	179	179	🔴	0	0		0	0		0	0	🔴	180	180	🔴	0	0	🟡	15	15
2025-01-28 17:02:42.600	🔴	38	178	🔴	178	178		0	0	🟡	14	14	🔴	39	179		0	0	🔴	0	0	🟡	14	14
2025-01-28 17:02:42.701	🔴	37	177		0	0	🔴	0	0	🟡	13	13		0	0	🔴	178	178	🔴	0	0	🟡	13	13
2025-01-28 17:02:42.791	🔴	36	176	🔴	176	176	🔴	0	0	🟡	11	11	🔴	37	177	🔴	177	177	🔴	0	0	🟡	12	12
2025-01-28 17:02:42.902	🔴	35	175	🔴	175	175	🔴	0	0	🟡	10	10	🔴	35	175	🔴	175	175	🔴	0	0	🟡	10	10
2025-01-28 17:02:43.088	🔴	34	174	🔴	174	174	🔴	0	0	🟡	9	9	🔴	34	174	🔴	174	174	🔴	0	0	🟡	9	9
2025-01-28 17:02:43.200	🔴	32	172	🔴	173	173	🔴	0	0	🟡	8	8	🔴	33	173	🔴	173	173	🔴	0	0	🟡	8	8
2025-01-28 17:02:43.301	🔴	31	171	🔴	171	171	🔴	0	0	🟡	7	7	🔴	32	172	🔴	172	172	🔴	0	0	🟡	7	7
2025-01-28 17:02:43.390	🔴	30	170	🔴	170	170	🔴	0	0	🟡	5	5	🔴	31	171	🔴	171	171	🔴	0	0	🟡	6	6
2025-01-28 17:02:43.501	🔴	29	169	🔴	169	169	🔴	0	0	🟡	4	4	🔴	29	169	🔴	170	170	🔴	0	0	🟡	5	5
2025-01-28 17:02:43.601	🔴	28	168	🔴	168	168	🔴	0	0	🟡	3	3	🔴	28	168	🔴	168	168	🔴	0	0	🟡	4	4
2025-01-28 17:02:43.688	🔴	27	167	🔴	167	167	🔴	0	0	🟡	2	2	🔴	27	167	🔴	167	167	🔴	0	0	🟡	3	3
2025-01-28 17:02:43.900	🔴	26	166	🔴	166	166	🔴	0	0	🟡	1	1	🔴	26	166	🔴	166	166	🔴	0	0	🟡	1	1
2025-01-28 17:02:43.989	🔴	24	164	🔴	165	165	🔴	0	0	🔴	655	10...	🔴	25	165	🔴	165	165	🔴	0	0	🔴	655	10...
2025-01-28 17:02:44.101	🔴	23	163	🔴	163	163	🔴	0	0	🔴	654	10...	🔴	24	164	🔴	164	164	🔴	0	0	🔴	654	10...

Figure 9:"This table shows a section of SPaT data during a TSP request. You can review the duration of each signal state and compare it to the unmodified event plan to review what changes have been made. It also allows for review of the accuracy of the min signal time provided by the controller throughout the request.

TSP Time Saving Results

Based on evaluations with the test vehicle, TSP provides an approximately 10 second reduction in travel time at an intersection on average each time a vehicle passes through an intersection.

This reduction is based on the probability of having the TSP request granted based on the current signal status. For example:

- For a perfectly timed green extension the vehicle saved a full cycle of ~ 70 seconds by not stopping at a red light.
- If the vehicle did have to stop at the red light, the savings range from 0 sec to ~ 9 seconds from reductions to the opposing green phases.

This reduction is unique to each intersection because timing plans and speed limits vary by each location. Additionally, it is important to note that time savings on this conservative approach were minimal given how the agency wanted this first intersection deployed as the TSP implemented was as non-destructive as possible.

3.2.3. Signal Priority: Can signal disruption be minimized with signal priority?

The traffic signal operations personnel at RCOC decided that the timing plans for signal priority should be specifically designed such that the maximum signal timing offset allowable from a signal priority request can always be recovered with adjustments to the following phases before completing a full cycle. Both bench and field testing confirmed at the pilot intersection that the maximum signal timing offset allowable from a signal priority request can always be recovered with adjustments to the following phases before completing a full cycle. This same review will be done at the other 4 intersections as they roll out this use case functionality. Every intersection might have different timing patterns based on its geometry.

The team has performed testing to generate “Purdue” files. These files show the controller correctly receiving a signal priority request and accepting or rejecting the request based on the timing plan provided. These files show that the controllers will continue to behave as expected according to the timing plans and not be adversely affected by signal priority requests. This is an important part of demonstrating the limits to how much signal priority can disrupt the normal signal rotation at an intersection.

Summary of Testing Alternative Communication Bands and Protocols

The team has successfully broadcast SAE J3224 Sensor Data Sharing Messages (SDSMs) in non-5.9 GHz bands. Due to the reduction in the dedicated ITS band, organizations like ITS America[1] believe it is unlikely that SDSMs will "fit" in the ITS band. This project aimed to identify alternative spectrum where these messages could be broadcast. The team evaluated standard C-V2X protocol in the 5.9 GHz ITS band and compared that to 802.11ac (WiFi 5) and 802.11p (formerly DSRC) in the 5 GHz U-NII bands; along with 802.11g (WiFi 3) in the 2.4 GHz Industrial, Scientific, and Medical spectrum (ISM) band. The team took the following test approach:

- SAE J3224 Sensor Data Sharing Messages (SDSM) were used to evaluate performance of the U-NII bands.
- For evaluating WiFi, the team utilized the existing WiFi module on each Cohda MK6 model RSUs and OBUs with both RSU's and OBU's using omnidirectional antennas. The RSU to broadcast messages over the U-NII and ISM bands. OBUs, when in range, received broadcast messages.
- For evaluating 802.11p the team utilized the existing 802.11p radios on the Cohda MK6 model RSUs and OBUs; both RSUs and OBUs were equipped with omnidirectional antennas.
- C-V2X baseline performance in the 5.9 GHz ITS band was evaluated with existing C-V2X protocol radios on the Cohda MK6 devices.
- To create consistent repeatable test scenarios, the team used a utility to simulate detected objects instead of using real-world output of a VRU detection system.
- A test vehicle was parked at various locations on or near the street and data logs were post processed.
- A power transmission level of 20 dBm EIRP was used for WiFi and 802.11p protocols. It is worth noting that higher transmission power levels (e.g. 30 dBm) are available that are compliant with FCC regulations. In future testing the team would like to evaluate system performance of higher and lower power levels in addition to different antenna configurations and robust measurement of data throughput with different power levels.

This approach resulted in successful transmission and receipt of SDSMs over the U-NII and ISM bands. In particular, 802.11p protocol showed equivalent range performance to C-V2X in the 5.9 GHz ITS band. This testing was successful and valuable to gain confidence in one option to help address the reduction of bandwidth in the 5.9 GHz ITS band.

Since the goal of this Stage 1 project was feasibility of a prototype, detailed scientific testing was not in-scope. Additional testing is recommended to provide comprehensive evaluation with respect to range, message payload size, protocol data throughput, and packet loss rate under various external conditions and system configurations. A larger real world testing dataset should be collected before determining the mean performance for scaled V2X use.

Future testing should include evaluating combinations of different antenna, transmit power levels, channel, channel width (e.g. 10 MHz, 20MHz, 80MHz, etc.), channel contention (e.g. heavy use vs low use), and the environment conditions (e.g. precipitation, foliage, season, urban, suburban, rural). ISM and U-NII bands offer more channels to evaluate with various tradeoffs in RF range and data throughput performance.

Overall, this pilot was one small step towards the longer-term vision of a multi-band (ITS, U-NII, ISM, Cellular) and multi-protocol (C-V2X, 802.11p, 802.11ac/ax/be, LTE, 5G) approach for V2X communication. The ideal V2X approach should optimize low latency communication for safety critical data with the flexibility and situational awareness to use alternate communication methods while exiting areas of 5.9 GHz ITS band coverage. Specifications and standards will be needed to support the approach.

3.2.4. Unlicensed Wi-Fi: Can a V2X message be reliably delivered over unlicensed Wi-Fi (U-NII bands adjacent to ITS spectrum)?

To evaluate the potential for using increased payload size in 802.11 protocols on U-NII bands the team injected arbitrary object-actor count payloads of increasing size on both ITS and U-NII bands. The team observed that 802.11ac broadcasts in the U-NII band exceeded the performance of the ITS band both in terms of perception object count and transmission rate. 802.11ac can accommodate more objects in a SDSM because it has a larger packet size and is able to serialize messages over multiple packets to increase the object counts that can be transmitted. With the 5.9 GHz ITS band, the transport is dictated by IEEE 1609.3 and does not allow for message fragmentation.

5.9 GHz ITS Band Results

The team observed that an SDSM containing approximately 80 objects was the maximum that could be transmitted over the ITS band due to the maximum packet size for ITS transmissions. This test was performed with simple objects. In the future as more optional data elements in the SDSM are populated, the number of objects that fit in the SDSM would decrease. The maximum throughput was 80 objects at 10hz in the ITS band. The ITS largest payload is 1,400 bytes with special non-protocol handling being required.

802.11p Results

802.11p shares the same limitations as ITS with a maximum payload of 1400 bytes and transmission rate of 10hz.

802.11ac/802.11g *Results*

The WiFi protocol was stressed to send a payload of 3,272 bytes - the 802.11ac/g protocol fragmented packets to seamlessly deliver the larger payloads. Stress testing was stopped at 100 perception objects - but this should not be taken as a limitation of payload size, it is simply where the stress test ended.

Tests show that RSUs can transmit and OBUs can receive 100 object SDSMs at a rate of 30Hz over U-NII band WiFi. The higher refresh rate of 30Hz is significant because it provides object data at a higher frequency that better meets requirements of autonomous vehicles.

3.2.5. Unlicensed Wi-Fi: How far can a message be reliably delivered over unlicensed Wi-Fi compared to ITS spectrum?

Packet loss seems very consistent for both 802.11p in the U-NII bands and C-V2X in the ITS band up to 400m. Initial tests seem to show that 802.11p performs better with minor obstructions such as foliage. It is also worth noting that the current RSUs are broadcasting with a lower transmit power over 802.11p than C-V2X. 802.11p signals are currently being transmitted at 20dBs, and ITS signals are being transmitted at 24dBs due to technical limitations of the RSU

Packet Loss Rate with Clear LOS

Distance (m)	ITS 5.9 GHz (SPaT)	ITS 5.9 GHz (MAP)	802.11p (SDSM)
	Packet Loss (%)		
~ 25	1	0	3
~ 150	1	0	0
~ 225	1	2	3
~ 300	1	0	0
~ 400	6	37	9

Packet Loss Rate with overhead tree branches on approach

Distance (m)	ITS 5.9 GHz (SPaT)	ITS 5.9GHz (MAP)	802.11p (SDSM)
	Packet Loss (%)		
~ 50	1	1	1
~ 100	0	0	1
~ 150	2	3	2
~ 200	16	40	4
~ 250	62	98	40

3.2.6. Unlicensed Wi-Fi: Is access to unlicensed Wi-Fi spectrum secure and protected?

The originally described test where packet loss would be measured while unauthorized users attempted to access the U-NII band WiFi network was found not to be feasible or realistic. The team took two alternate approaches to demonstrate the WiFi network was secure and protected.

First, the team demonstrated that access to the WiFi network was restricted only to OBUs and RSUs with shared security keys. In the future these keys, access and authorization may be directly integrated into a SCMS framework. Only devices enrolled in Security Credential Management System (SCMS) would be able to access the network. This creates a de-facto dedicated spectrum band wide enough to support the broadcast of these messages with the low latency required for safety critical applications.

The team also analyzed potential interference and channel contention from other WiFi users in the area. This testing was performed in the field by measuring packet rates of WiFi traffic in the channels that may be used for sending V2X data over U-NII. Below is a summary of a sample observed WiFi traffic at the field-testing site for a limited sample period; more testing is required to understand the threshold of channel activity that negatively impacts the use of a channel for V2X use. This data is meant solely as a reference point for future testing. As the team continues to test the performance of U-NII band WiFi, it will include an analysis of interference from peer WiFi traffic to ultimately determine the optimal configuration and channel use.

Frequency	2412	2427	2437	2442	2452	2457	2462	5180	5220	5260	5560	5745	5765	5785	5825
Transmission Rate pkts/sec	56.4	15.4	38.3	28.1	19.6	38.5	84.2	47.7	174	13.0	10.5	16.0	12.4	104	6.3

3.2.7. Financial Sustainability: How will vehicles be authorized for revenue generating V2X subscription services in accordance with IOO policies?

The P3Mobility V2X Authorization Server was deployed during the RCOC SMART Grant project to demonstrate how specific vehicles could be authorized for V2X services in accordance with IOO policies. The system was used to authorize and manage accounts for vehicles for accessing signal priority services at equipped intersections. This capability allows RCOC to define and enforce policy-based access rules, such as limiting signal priority to specific vehicle types, subscriber accounts, locations, or times of day. The implementation demonstrated that a user-fee model for V2X services is technically viable and aligned with public-sector objectives, laying the groundwork for a financially sustainable system that can scale beyond grant funding.

3.2.8. Financial Sustainability: What cost savings can be potentially realized through signal priority/preemption?

TSP can lead to cost savings by improving fuel efficiency, reducing vehicle wear-and-tear, and increasing operational efficiency. By minimizing stops and delays at intersections, TSP helps reduce fuel consumption and limits the strain on vehicle components such as brakes and engines. More efficient routes also mean less time spent on the road, which can reduce labor costs or allow the same number of vehicles to cover more ground without expanding fleet size.

The project faced delays equipping the 10 RCOC maintenance trucks, so widespread TSP data was not available at the time of this report submission Data collection will continue after the official end date of Stage 1 and prior to Stage 2. However, we can use industry data to estimate the cost savings from TSP. Section 3.2.2 indicated that the average time savings each time a vehicle passed through an intersection was 10 seconds. When Using the American Transportation Research Institute’s reported hourly operating cost of $91.27 for trucking, we can estimate the potential cost savings to be $0.25 for each TSP intersection that a vehicle passes through regardless of if TSP is granted or not.

These cost savings scale with the number of equipped vehicles and intersections, and while the per-vehicle savings may seem modest, the aggregate benefits across a fleet and entire signal network can be substantial as shown in the table below.

Item	**Cost Savings**
1 vehicle passing through 1 equipped intersection	$0.25
1 vehicle passing through a 10 equipped intersection corridor, twice per day	$5.07
1 vehicle passing through a 10 equipped intersection corridor, twice per day for 5 weekdays	$25.35
1 vehicle passing through a 10 equipped intersection corridor, twice per day for 5 weekdays for 1 year	$1,318.34

Cost Savings from V2X Fleet Intelligence

Additionally, the project team demonstrated that another method of financial sustainability might come from the availability of V2X data known as V2X Fleet Intelligence. V2X Fleet Intelligence combines vehicle trajectory data with traffic infrastructure data to give a more complete view of a driving scenario. Data elements include:

- location
- heading
- approach type (ingress, egress or "in intersection")
- lane
- distance to stop bar
- traffic signal phase servicing the lane
- traffic signal state
- location of VRU with highest alert level
- PED signal state of VRU in with highest alert level (if VRU is in a crosswalk)

This capability could reduce operating costs for an IOO by helping to make better operational decisions without having to pay for data. This changes the current paradigm where IOOs are paying data aggregators for access to vehicle data to help them make decisions. Additionally, the capability could be offered on a paid basis to the following customers:

- Fleet managers for better understanding their driver’s behavior
- Insurance companies / risk departments looking to offer preferred pricing based on driving patterns
- Researchers trying to understand driving behavior and/or traffic flow models
- OEM / AV engineers looking to gain trust in the V2V data availability

Future integration into the vehicle CAN bus could provide an even richer data set.

While Stage 1 showed the feasibility of combining vehicle and infrastructure data, the project team needs to consider the challenges of acquiring large amounts of data including – data storage costs and the respect for the privacy and ownership of the data.

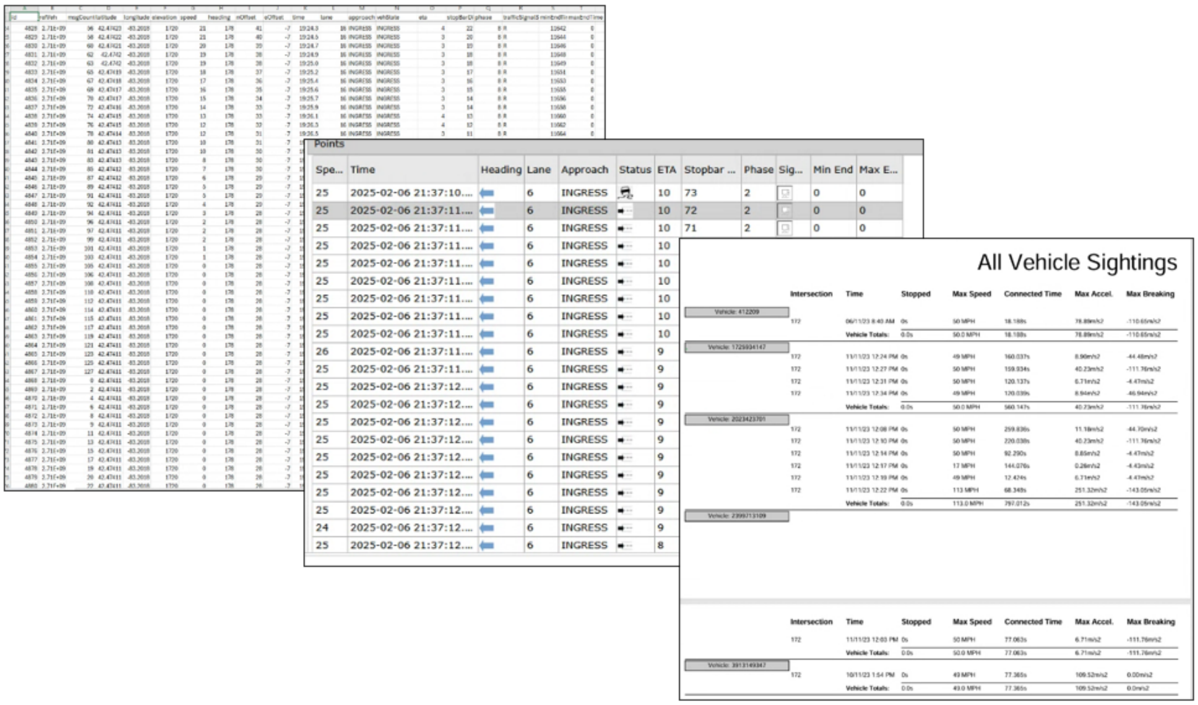


Figure 10:: Unfiltered raw data all the way to a summarized dashboard

3.2.9. Overall System: Does the system provide value to the users?

The system demonstrated clear value to users by demonstrating reduced travel times for equipped vehicles through traffic signal priority, enhancing safety through VRU alerts, and offering a scalable framework for subscription-based services. These capabilities, when deployed at scale, are expected to deliver broad operational efficiencies for vehicles while enabling IOOs to generate sustainable revenue and support ongoing system maintenance. It is important to note that there is a learning curve associated with the system, and successful implementation requires internal expertise or support from experienced private sector contractors.

3.3. Analysis of Goals from Grant Application

The proof-of-concept and prototype developed during Stage 1 have largely met the original goals outlined in the Stage 1 project proposal. The primary goals were to enhance traffic safety, improve traffic efficiency, and establish a financially sustainable model for V2X technology deployment in Oakland County which Stage 1 has laid the groundwork for.

- **Reducing Traffic-Related Fatalities and Injuries**: One of the key objectives was to reduce traffic accidents, particularly those involving vulnerable road users (VRUs). The Stage 1 prototype demonstrated that VRU alerts and signal priority are possible, but that further technology validation is required for success.
- **Reducing Traffic Congestion or Improving Travel-Time Reliability**: The project aimed to enhance traffic efficiency through the deployment of V2X technology. The implementation of signal priority demonstrated improved traffic flow with minimal impact to overall traffic.
- **Providing the Public With Access to Real-Time, Integrated Traffic, Transit, and Multimodal Transportation Information to Support Informed Travel Decisions:** This was not targeted as part of Stage 1, but Stage 2 will include providing SPAT, MAP and SDSM information to equipped vehicles so that they can better respond to driving situations.
- **Reducing Barriers to, or Improving Access to, Jobs, Education, and Essential Services:** This was not targeted as part of Stage 1, but Stage 2 will target providing Emergency Vehicle Preemption and Transit Signal Priority to provide better access to jobs, education and essential emergency services.
- **Financial Sustainability**: Establishing a technology framework that enables a financially sustainable model was central to the project's objectives. Stage 1 laid the technical groundwork for this with the V2X Authorization Server. Stage 1 also analyzed financial models and business plans that show how financial sustainability could be achieved with user fee-based models.

4. Anticipated Costs and Benefits of At-Scale Implementation

4.1. Impacts of At-Scale Implementation for USDOT Goal Areas with Baseline Data

The following sections detail the impacts of at-scale implementation for USDOT program goal areas with current baseline data and target level of impact.

4.1.1. Reduce Congestion and Delays for Commerce and the Traveling Public

Impact	Baseline Data	At-Scale Target
Reduced travel time for commercial vehicles with V2X freight signal priority	Travel time data will be gathered before enabling signal priority in Stage 2.	10% reduction in travel times for equipped vehicles. This is based on proposed changes to traffic controller parameters.
Reduced congestion for commercial vehicles and the travelling public with V2X freight signal priority	Data will be gathered before enabling signal priority in Stage 2 using metrics such as Travel Time Index (TTI)	5% improvement in congestion using identified metrics.

Reduced delays for school buses with V2X signal priority	Travel time and delay data will be gathered before enabling signal priority in Stage 2.	10% reduction in travel times for equipped vehicles. This is based on proposed changes to traffic controller parameters.

4.1.2. Improve the Safety and Integration of Transportation Facilities and Systems for Pedestrians, Bicyclists, and the Broader Traveling Public

Impact	Baseline Data	At-Scale Target
Reduced number of VRU crashes and near misses with V2X VRU driver alerts	Historical VRU crash statistics are available for each intersection. Near-miss data is not currently available.	VRU crashes are low probability, random events, so instead of measuring final output, Stage 2 will measure the number of VRU Alerts generated.
Reduced number of pedestrian and bicyclist incidents in school zones and work zones from V2X Informational Messages	Historical crash statistics are available across the county. Near-miss data is not currently available.	VRU crashes are low probability, random events, so instead of measuring final output, Stage 2 will measure the number of VRU Alerts generated.
Reduced number of crashes with authorized vehicles (e.g., emergency, snowplows, etc.) with V2X traffic signal priority and pre-emption	Historical authorized vehicle crash statistics are available for each intersection.	Zero crashes with authorized vehicles while V2X traffic signal priority and pre-emption are activated.
Reduced Red-Light running incidents from Red-Light Violation Warning and Traffic Signal Countdown applications measured by drivers taking an action after receiving an alert.	None currently	75% of the time an alert is issued the driver stops before entering the intersection

4.1.3. Improve Access to Jobs, Education, and Essential Services, Including Health Care

Impact	Baseline Data	At-Scale Target
Reduced delays for school buses with V2X signal priority	Travel time and delay data will be gathered before enabling signal priority in Stage 2.	10% reduction in travel times for equipped vehicles. This is based on proposed changes to

		traffic controller parameters.
Reduced operating time for emergency vehicles (e.g. ambulances) with V2X maintenance signal priority	Baseline data not available but will be captured in Stage 2.	10% reduction near deployment sites.
Reduced operating time for municipal maintenance vehicles (e.g. snowplows, garbage trucks) with V2X maintenance signal priority	Baseline data not available but will be captured in Stage 2.	10% reduction near deployment sites.

4.1.4. Connect or Expand Access for Underserved or Disadvantaged Populations and Reduce Transportation Costs

Impact	Baseline Data	At-Scale Target
Cost savings from V2X Technology	SEMCOG has provided comprehensive crash cost data for the County (average of $1.2B annually)	A proportional reduction in crash costs at equipped intersections based on the equipped vehicle rate (e.g. if 10% of vehicles are equipped, expect a 10% reduction)

4.1.5. Contribute to Medium- and Long-Term Economic Competitiveness

Impact	Baseline Data	At-Scale Target
Revenue generation from subscription services	None currently	Revenue generation from subscription services to cover V2X system O&M.

4.1.6. Improve the Reliability of Existing Transportation Facilities and Systems

Impact	Baseline Data	At-Scale Target
Transit and school bus on time reliability	Baseline data not available but will be captured in Stage 2 as partners are onboarded.	10% improvement in transit and school bus on time reliability
Remote monitoring and uptime features (e.g. auto restart before sending a truck out)	Baseline data not available.	Reduced number of physical trips to an intersection.

4.1.7. Promote Connectivity Between and Among Connected Vehicles, Roadway Infrastructure, Pedestrians, Bicyclists, the Public, and Transportation Systems

Impact	Baseline Data	At-Scale Target

Increase number of Connected Vehicle compatible intersections	14 previously deployed C-V2X RSUs in the county	With Direct V2X: 112 Intersections are connected vehicle compatible With Network V2X: 500 intersections are connected vehicle compatible
Increase number of Connected Vehicles	0 documented deployed C-V2X compatible vehicles in the county	1,000+ connected vehicles operating in the county with Direct or Network V2X
Improved interoperability using V2X industry standards (e.g., IEEE, SAE, ITE)	None since system was not previously in place.	System is interoperable with 3 other deployments in Michigan (MDOT, Macomb County, Ann Arbor).
Increased communication bandwidth by leveraging the U-NII Wi-Fi spectrum to complement 5.9 GHz ITS band V2X communications	5.9 GHz ITS band bandwidth is 30 MHz and SDSMs do not fit.	SDSMs are reliably broadcast in U-NII bands.
Accelerated realization of benefits of the V2X system by leveraging infrastructure sensors to generate V2X cooperative perception messages	None since system was not previously in place.	VRU crashes are low probability, random events. Stage 2 will measure the number of VRU Alerts generated.

4.1.8. Incentivize Private Sector Investments or Partnerships

Impact	Baseline Data	At-Scale Target
Improved financial sustainability of the V2X system by introducing a model that focuses on generating funds and attracting private investment to support the deployment, operations, and maintenance of the V2X system	None since system was not previously in place.	Negotiation of a term sheet with a P3 partner achieved during Stage 2 so that cash or in-kind investment is made to expand the deployment and cover ongoing operations and maintenance after Stage 2.

Accelerated deployment of the V2X system with a model that attracts private investment	None since system was not previously in place.	Negotiation of a term sheet with a P3 partner achieved during Stage 2 so that cash or in-kind investment is made to expand the deployment or cover ongoing operations and maintenance after Stage 2.
Accelerated deployment of V2X equipped vehicles by collaborating with OEMs and fleet providers	None since system was not previously in place.	At least one non-publicly owned fleet signing an agreement to deploy V2X technology in its vehicles.

4.1.9. Improve Energy Efficiency or Reduce Pollution

Impact	Baseline Data	At-Scale Target
Reduced fuel consumption with V2X traffic signal priority and pre-emption	Not available	Since data is not readily available, the team plans to demonstrate a 10% reduction in fuel consumption with vehicle simulations of signal priority.
Reduced pollution with V2X traffic signal priority and pre-emption	Not available	Since data is not readily available, the team plans to demonstrate a 10% reduction in pollution metrics with vehicle simulations of signal priority.

4.1.10. Increase the Resiliency of the Transportation System

Impact	Baseline Data	At-Scale Target
Improved cybersecurity with the introduction of the SCMS into the V2X system	None since the system was not previously in place.	Zero successful cybersecurity attacks or bad actors due to V2X security.

4.1.11. Improve Emergency Response

Impact	Baseline Data	At-Scale Target

Improved response time for emergency vehicles (e.g., fire, police, ambulance etc.) with V2X emergency vehicle pre-emption	Baseline data not available but will be available in Stage 2 as further engagement occurs with emergency vehicle operators.	10% reduction in response time near deployment sites.
Reduced number of crashes with emergency vehicles (e.g., fire, police, ambulance etc.) with V2X emergency vehicle pre-emption	Historical authorized vehicle crash statistics are available for each intersection.	Zero crashes with emergency vehicles while V2X emergency vehicle pre-emption is activated.

4.2. Costs

4.2.1. Costs of Prototype

The total project is expected to come in just slightly under the $2 million project budget. Much of the work was for planning and design for the prototype and the at-scale implementation. The 5 intersection and 10 vehicle prototype cost about $550,000, excluding the technical project management. This breaks out into a per intersection cost of $80,000 and a per vehicle cost of $15,000. These per unit costs include some re-work, over engineered designs, and lessons learned and do not include the volume pricing and economies of scale that are expected in Stage 2 pricing. The prototype intersections also used existing cameras and required little to no modifications, whereas Stage 2 may require new cameras, changes to the controller, or changes to the cabinet.

4.2.2. Costs of At-Scale Implementation

Stage 2 technology deployment costs vary for each intersection depending on the existing infrastructure at the intersection and what modifications are required. For example, some intersections require larger cabinets to support new equipment, while other intersections may not require VRU detection systems due to low volumes of pedestrian traffic. The cost of these modifications is broken down below:

#	Item	Cost Per Intersection
1	Direct V2X Hardware and Installation	$26,700
2	VRU Detection System and Installation	$36,700
3	Traffic Controller Upgrade	$4,900
4	Traffic Cabinet Upgrade	$24,300

Maintenance costs are shown in the following table:

#	Item	Cost Per Intersection Per Year
1	Direct V2X Hardware Maintenance	$1,641
2	VRU Detection System Maintenance	$483

The following table breaks down the installation and maintenance costs for vehicles.

#	Item	Cost Per Vehicle

1	V2X Hardware	$2,155
2	Installation	$495
3	Maintenance	$435 per year (assumes 1 repair per year)

The total cost for 112 intersections and 1000 vehicles to be equipped with Direct V2X technology in Stage 2 and maintained over the course of the project is expected to be $9.27 million.

Stage 2 also includes $5.7 million in cost for non-technical items or one time only technical items such as:

- Stage 2 Project Management Consultant
- Workforce Development Execution
- Community Engagement Execution
- Procurement Management
- V2X Integration and Testing
- Interoperability testing with MDOT and Macomb County
- Traffic Operations Center Network Configuration Changes
- Adaptive Signal Timing Integration

If the evaluation of Networked V2X confirms that it is feasible for an at-scale deployment, the deployment costs would be greatly decreased. The table below shows the comparison of estimated costs between Direct and Network V2X. The primary costs for Networked V2X would be the configuration required to connect the intersection to the network and to upgrade the traffic controller to provide the required data. VRU Detection systems would not be required at Networked V2X locations because VRU alerts would not be a supported use case. Additionally, since no additional equipment would go into the cabinet, traffic cabinet upgrades would not be required.

#	Item	Direct V2X Cost Per Intersection	Networked V2X Cost Per Intersection
1	Hardware and Installation	$26,700	$5,629
2	VRU Detection System and Installation	$36,700	Not required
3	Traffic Controller Upgrade	$4,900	$4,900
4	Traffic Cabinet Upgrade	$24,300	Not required
	Total	$92,600	$10,529

4.3. Cost-Benefit Analysis

The most meaningful quantified benefit is the cost reduction from avoiding crashes. The table below shows the costs for type of injuries from crashes[6].

Type of Injury / Crash	Total Cost
Fatal	$13,111,000
Disabling Injury	$1,066,000
Injury Detected at Scene	$232,000
Injury Possible	$126,000
No Injury (Property Damage)	$17,500

The data below shows the total cost of injuries from crashes within 250 ft of an intersection in Oakland County[7]. These are the crashes likely to be avoided with V2X technology.

Year	Cost of Crashes
2017	$1,408,677,500
2018	$1,244,583,500
2019	$1,389,649,000
2020	$914,641,000
2021	$1,207,976,000
Annual Average	$1,233,105,400

For this 5-year period there were 76,572 crashes within 250 ft of an intersection, or, on average, 15,314 crashes per year. The average cost of a single crash is $80,519. This implies that if V2X technology prevented just 187 crashes over the 3-year grant period, the value of the benefits would exceed the $15 million cost of the project. This target reduction of 187 crashes represents only 0.4% of the crashes that happen each year. **The benefits of crash reduction far exceed the cost of deployment**.

5. Challenges and Lessons Learned

The following sections identify major lessons learned during Stage 1 of the project. The lessons here will be used to improve in Stage 2 and be beneficial to other V2X deployments across the county.

5.1. Sustainable Business Model

- **Vehicle Adoption:** A key lesson learned during the financial modeling of the project was the importance of securing many committed, subscribed users to ensure the success of the financial model. The subscription-based approach relies on vehicle adoption to generate sufficient revenue to fund the deployment, operations, and maintenance of the V2X system. Without a critical mass of users, the system risks falling short of its financial sustainability

[6] https://injuryfacts.nsc.org/all-injuries/costs/guide-to-calculating-costs/data-details/
[7] Injury / Crash Data from 2017-2021 provided by SEMCOG

goals. This challenge can be addressed through regulatory mandates that require certain vehicles to equip V2X technology to ensure a pool of subscribed users. Alternatively, if Networked V2X was deemed feasible, mobile phones as a means of accessing V2X services could broaden participation. While mobile device integration offers a more accessible entry point for users, it may not provide the same level of financial return as dedicated V2X hardware subscriptions. Balancing user adoption with revenue generation remains a critical consideration for future deployments.

- **Upfront Capital:** One of the key financial challenges identified during the project is the high upfront investment required for V2X deployment, which can deter both public and private sector stakeholders. The initial costs associated are significant, making it difficult to justify without a clear long-term return on investment. Public-private partnerships can help mitigate some of these risks by distributing costs between government agencies, private technology providers, and fleet operators, but securing commitments from all stakeholders remains a complex process. Ensuring financial viability will require strategic funding sources, such as grants, debt, and private sector contributions, alongside scalable business models that allow for phased investment and deployment to align costs with realized benefits.
- **User Value Perception:** The success of a V2X subscription-based financial model is highly dependent on user adoption, making it critical to demonstrate clear value to potential subscribers. Many fleet operators may hesitate to commit to subscription fees if they do not immediately perceive a significant return on investment, such as improved safety, reduced travel time, or cost savings. Educating potential users on the tangible benefits of V2X technology will be essential in driving adoption.

5.2. Technical Suitability / Integration with Incumbent Systems

- **Infrastructure Sensors**: During Stage 1 existing cameras that were meant for vehicle detection were repurposed to use for VRU detection. Ultimately, it was determined that the current architecture could not reliably support the VRU alert use case. Latency and unstable frame rates were observed which are not optimal for VRU detection. The cameras were also prone to blind spots and dirty lenses which led to poor performance. Additionally, these cameras require a large processor inside the space-starved cabinets. Stage 2 will mitigate these issues by including a more extensive procurement and analysis process for sensors that can be used for both VRU and vehicle detection without large space requirements. Stage 2 will focus on the use of alternative sensors such as radar and LiDAR or combinations of camera plus other sensors.
- **VRU False Positive Detection**: Another challenge faced was false positive detections, where the system mistakenly alerted the driver of non-existent VRUs. These false positives were triggered by complex real-world scenarios, such as changes in environmental conditions (e.g. changing seasons, falling leaves, etc.). False positives not only decrease the accuracy of the system but also increase computational overhead and potential distractions in driver decision-making processes. To address this, the following strategies were implemented: Enhance the training dataset with diverse scenarios to improve model robustness to environmental changes. Introduce post-processing filters to validate detections. In the future, the project will explore incorporating additional sensor data (e.g., radar) to reduce ambiguity.

- **Infrastructure Sensor Blind Spots**: Another issue with VRU Alerting was the presence of blind spots in the camera coverage. These blind spots occurred due to the placement and limited field of view of the cameras, which caused VRUs to be not detected in those areas. To minimize blind spots, the team attempted to train the model with situations where a VRU was in the blind spot. Unfortunately, the improvements were minimal due to the limited amount of training data of this specific situation. In Stage 2 the project will explore using alternate sensors that don't have blind spots, adjusting the positioning and angles of existing cameras to maximize coverage, or installing additional sensors at strategic points to cover previously undetected areas.
- **AI VRU Detection Models**: The AI VRU detection model in Stage 1 required a large volume of training data to calibrate the AI models. Collecting, storing, and transferring the data was an underestimated cost that is not feasible for an at-scale deployment. Additionally, the model was unable to differentiate types of VRUs. Stage 2 will include the procurement of a system that requires less training data and is able to differentiate between types of VRUs.
- **Traffic Controllers**: RCOC uses multiple models of traffic controllers. Some models provide the inputs to V2X SPAT messages better than others. Stage 1 required unexpected traffic controller upgrades to a newer model or different manufacturer. Stage 2 will deploy at locations that do not require upgrades or for critical locations the upgrade will be planned in advance.
- **Adaptive Traffic System**: The SCATS system, widely used in Oakland County, is currently incompatible with V2X technology. In Stage 2, the planning process will include updates to the controllers operating system to ensure compatibility with V2X.
- **Roadside Unit (RSU)**: The RSUs in Stage 1 demonstrated adequate signal strength and performance and can continue to be used for Stage 2. Stage 2 will include demonstrating how 1 RSU can be used to accommodate 2 intersections in a close area and to support signalized Michigan Left Turns[8].
- **Network Approach**: Stage 1 results demonstrated that an edge device could support multiple intersections when Sensor Data Sharing Messages were not broadcast. Stage 2 will consider a "hub" approach where 1 edge device will support multiple intersections for locations with very low volumes of VRU traffic. This will reduce deployment costs for Stage 2.
- **Remotely Managed Power Strips:** Stage 1 activities encountered instances where the RSU or edge device needed to be power cycled, but mobilizing RCOC staff to intersections is laborious and expensive. The team successfully demonstrated remotely managed power strips with individual outlet control and rules-based power cycling to reduce this risk. This approach will be continued in Stage 2 to enhance operational efficiency and reduce maintenance costs.
- **802.11p in U-NII Band Performance:** 802.11p performance in the U-NII WiFi bands appears to be satisfactory for V2X communications based on signal strength and packet loss. Stage 2 will evolve this concept with a deeper evaluation of signal congestion and software-selectable channels for optimum performance, ensuring reliable communication in various conditions.

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[8] https://en.wikipedia.org/wiki/Michigan_left

- **MAP File Limitations:** 802.11P in the U-NII bands can effectively deliver SAE J2735 MAP messages without the granularity restrictions imposed by the MTU IEEE 1609.3, making it a viable option for automated vehicle functionality that requires more detailed MAP data, which could otherwise result in MAP message sizes too large for the WSMP MTU.
- **SCMS Enrollment:** The SCMS provider (ISS) changed the process for device enrollment from a manual process to a more automated process that requires an SSH session from the device to the ISS server. This might be easily accommodated if a cellular SIM card was added to the RSU. However, if the device is deployed without a cellular SIM card and within an IOO's secure network, network security changes are required to bypass IOO firewalls. This was not communicated by the SCMS provider or hardware vendor and caused delays in getting the devices enrolled.
- **SAE J3224 and J2735 Mismatches:** The team identified a discrepancy in how SAE J3224 and J2735 handles X or Y coordinates offset from a reference point. J2735 defines the X-axis as east to west and the Y-axis as north to south. J3224 is the inverse. This was resulting in J3224 SDSMs indicating objects were in an incorrect position. In the short term, the team was able to account for this in the V2X Hub. In the long term, the appropriate SAE teams will be alerted of the discrepancy.
- **GPS Wander on OBU:** During testing, vehicles parked in clear, unobstructed environments (away from potential urban canyons) exhibited GPS position drift by several meters, which was significant enough to falsely indicate that the vehicle was in an incorrect lane. This positional inaccuracy could pose challenges for lane-specific V2X applications that rely on precise vehicle location data for safety-critical functions. In future stages, this issue could be mitigated through the implementation of Real-Time Kinematic (RTK) positioning and RTCM (Radio Technical Commission for Maritime Services) message corrections.

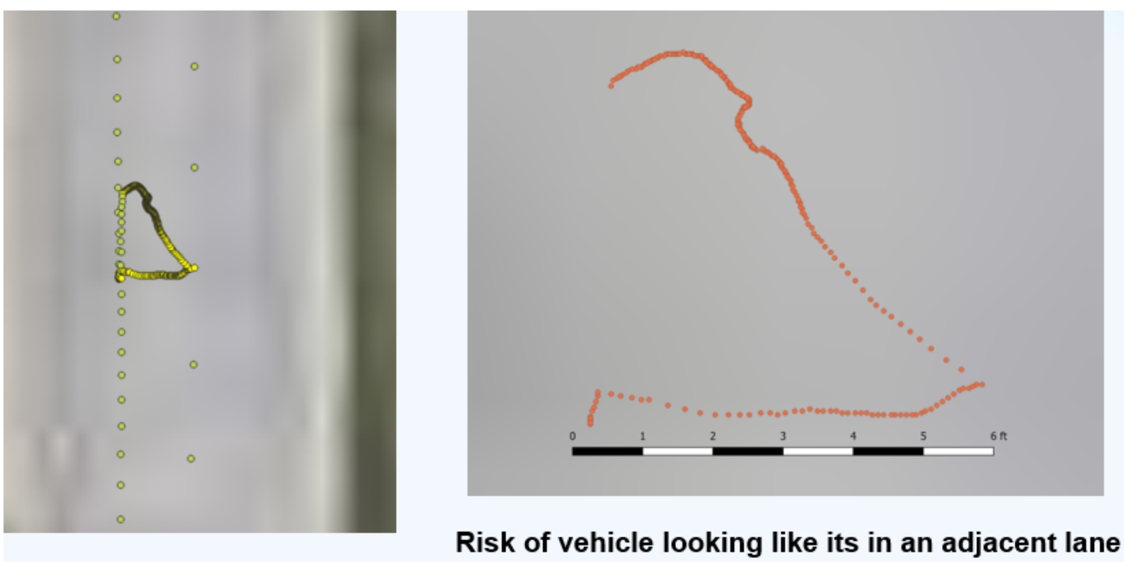

Figure 11: The image above shows the GPS location of a stationary vehicle. The GPS shows the vehicle drifting over 6ft from its actual location. This caused unexpected behavior because the system thought the vehicle was in the other lane.

- **VRU Detection Plotting for Visual Analysis:** The project team learned the importance of plotting the detection data over a map view of the intersection. This technique allowed the team to visually analyze the performance of the detection model and identify issues such as distortion, inaccurate in object positioning, and blind spots. This helped the team iterate on the model and ultimately improve performance. The figures below show examples of these plots.

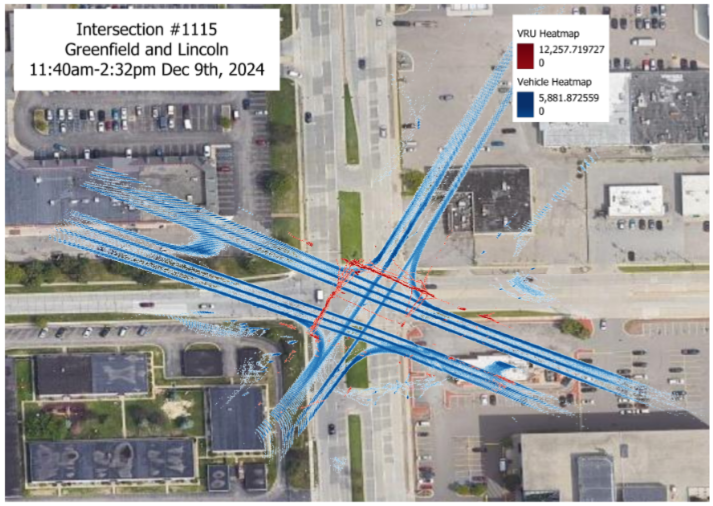

Figure 12: VRU detection data plot that shows a rotated output that indicates a configuration issue with the model.

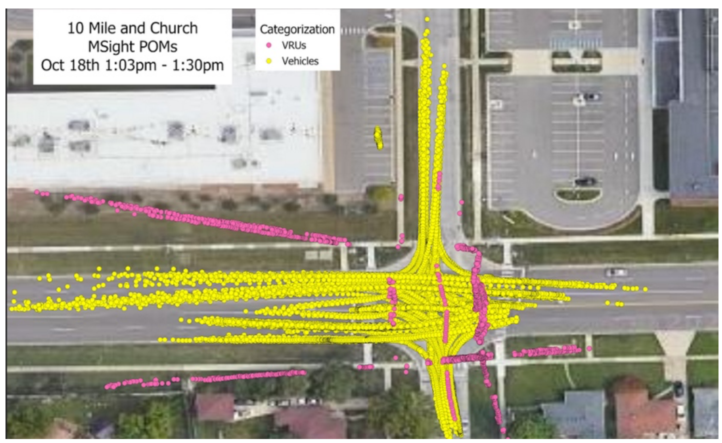

Figure 13: VRU Detection data plot that shows a distortion in the northwest direction.

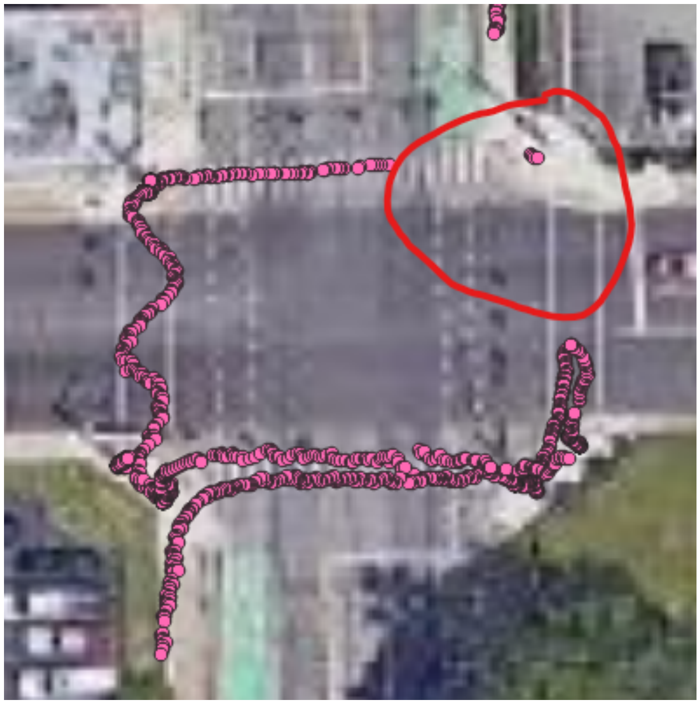

Figure 14: VRU Detection data plot that shows a blind spot in the northeast corner of the intersection due to a smudge on the camera lens.

- **Health Monitoring:** The team actively monitored the health of the RSU and V2X software to ensure system reliability and performance. Continuous system monitoring allowed the team to quickly identify and diagnose potential issues. Without proactive health monitoring, these issues could have gone undetected, leading to extended downtime and reduced system effectiveness. This approach was essential for maintaining system integrity and will be a standard practice in Stage 2 to ensure consistent and reliable operation. Stage 2 will aim to automate some of the manual health monitoring processes that are already in place.
- **Incomplete MAP Files:** The team discovered that sidewalks were not being included in the MAP files due to limitations in the USDOT mapping tool, which did not export sidewalk data to the JSON format. This omission resulted in false VRU (Vulnerable Road User) alerts being displayed to drivers when individuals were walking in valid sidewalk areas, incorrectly identifying them as potential hazards. The team addressed this issue by manually editing the JSON files to include the missing sidewalk data, which resolved the false alerts.

5.3. Workforce Capacity

- **Explaining the Technology:** The complexity of the technology and, therefore the difficulty in communicating with the public is a key challenge. Stage 1 piloted a V2X driving simulator successfully, and an improved version is planned for Stage 2.
- **Contracting Installation Work**: RCOC's internal staffing resources for installing V2X intersection equipment were limited during Stage 1. Partnering with experienced contractors such as Integral Blue was essential to achieve timely and accurate installation. This

contractor-based installation model will continue in Stage 2 to support scalability and technical consistency across the expanded deployment.

- **Trouble-shooting equipment:** The RCOC staff had limited diagnostic tools at the time of installation to properly verify V2X hardware installation. For example, RSUs with non-typical connectors require testing equipment to ensure Ethernet cables are terminated correctly. This was not initially available and caused rework at the intersection. This will be accommodated in the budget and plan for Stage 2.

5.4. Legal, Policy, and Regulatory Requirements

- **FCC Approvals:** Currently, there are three approval layers to a V2X deployment currently. There is an FCC license and waiver to deploy C-V2X, FCC site registration for RSU, and device level FCC certification from the manufacturer. Device level certification delayed the RSU/OBU shipments. This certification criteria will be included in the Stage 2 procurement process.
- **Contracting:** In general, the procurement and contracting process took longer than anticipated, and this will be accounted for in the Stage 2 project schedule.
- **Government Vehicle Drivers:** There are restrictions on who can drive certain types of government vehicles, even from a parking lot to a garage bay. This could impact vehicle installations and will be accounted for in Stage 2 planning activities and schedule.

5.5. Partnerships

- **Intersection Ownership:** Municipal infrastructure intersects with and incorporates elements across a mixture of state, county, and local jurisdictions, requiring extremely involved collaboration and coordination when installing and maintaining new technology components. For example, even within a specific infrastructure owning agency, the agency may require coordination (or even permission) from its IT department to facilitate external access or processing of data from the local traffic / ITS network.
- **RCOC Field Staff:** The availability of RCOC field staff is not guaranteed and often cannot be subjected to the requirements of a project schedule as agency field staff have other, higher priority duties that take precedence. Stage 2 should include an MOU between partners and RCOC for pre-approved (but communicated) access to cabinets and permission to install devices to minimize burden on RCOC field staff.
- **Private Partners:** The project included many private partners, each of which played very specific roles in the project. The coordination between this large number of partners is a complex exercise that requires truly excellent and generalized (as opposed to just engineering) program management skills. This requirement was handled well in Stage 1, but there may be a need in Stage 2 to introduce program management and team communication technologies to assist with the increased size of the task in the larger deployment.

5.6. Procurement and Budget

- **On-Board Unit (OBU)**: OBUs chosen for Stage 1 were robust and performed well, but the high cost was identified as a barrier to adoption by local commercial fleets. In Stage 2, the team can use the Stage 1 OBUs in heavy-duty vehicles (snowplows) and explore lower-cost OBU options for more widespread deployment in light-duty vehicles.

- **Vehicle Antenna**: The prototype included two roof-mounted antennas to utilize 5.9 GHz and U-NII band communications. Stage 2 will optimize the setup and reduce to a single 5-in-1 antenna.
- **Testing During Procurement Selection**: Stage 1 used existing cameras and experienced limitations. Stage 2's plan includes sensor requirements and a vendor benchmarking review before procurement. Benchmarking will include an assessment of sensors being used in other Michigan pilots and the country.

5.7. Data Governance

- **Data Storage and Retention Policies:** V2X systems generate massive volumes of data, including real-time signal data, vehicle trajectory, and system health logs. In Stage 1, the project team learned that storing all this data indefinitely in the primary operational system is not feasible, as it can quickly strain storage capacity and degrade overall system performance. As a result, Stage 2 will implement defined data retention and archiving policies that align with the operational and analytical needs of the system. Data required for immediate decision-making or diagnostics will be retained in the live environment for a limited period, while less time-sensitive or historical data will be periodically offloaded to an archival storage solution. These policies will help maintain system performance and ensure that critical data remains available for evaluation, compliance, and continuous improvement purposes.

5.8. Internal Project Coordination

- **Shared Collaboration Area:** Key documents and deliverables were emailed between team members due to the lack of a unified repository. Stage 2 needs an externally accessible shared folder for the full team where living can be retrieved along with storing project deliverables. For collaborative software integration, GitHub was used successfully.
- **Nearby Deployment Coordination:** Stage 1 was solely focused on Oakland County. During the stakeholder discovery evaluation, the project team agreed to realize the potential benefits of coordinating with nearby connected vehicles and infrastructure pilots (Macomb County, Ann Arbor, MDOT M1 corridor). Stage 2 will include coordination and interoperability testing with nearby projects.
- **Improved Bench Testing:** Testing configuration changes was a very manual process in Stage 1 and bench testing missed several issues that were caught after deployment. Stage 2's schedule and budget include time for up-front testing to reduce delays and re-work.

5.9. Community Impact

- **Wider Community Outreach:** Most engagement during Stage 1 occurred through professional or technical channels via the advisory board. Stage 2 needs to include a clear strategy to assess and communicate how V2X benefits (e.g., safety improvements, reduced delays) will be distributed across different neighborhoods, especially those identified as underserved or disadvantaged.

5.10. Public Acceptance

- **Experiential Outreach:** At the July 2024 MDOT Transportation Career Day at Lawrence Technological University, the project team observed strong enthusiasm and receptiveness among students who interacted with a V2X driving simulator. The simulator allowed participants to experience the real-time safety benefits of V2X applications, such as red-light violation warnings and pedestrian alerts. This event highlighted the effectiveness of hands-on demonstrations in helping the public understand and support the technology. As a result, Stage 2 will incorporate similar experiential outreach activities to build broader community engagement and trust.

5.11. Cybersecurity

- **Security / Network Design:** Municipal networks have different security requirements from each other, and even within an infrastructure owning agency, network security requirements for a traffic / ITS network may differ from the requirements applied to the enterprise network, affecting the ability to remotely access and manage infrastructure devices or send / receive data from external parties. Similarly, devices being installed may be subject to security assessment and in some cases, such as in the example of edge processor deployments, may constitute a security risk. RCOC / P3M access via VPN was agreed upon early in the project but the functional requirements were not worked out until much later and ran into many roadblocks, such as AT&T restrictions. Proposals for additional network changes have been received, and the work will be incorporated at the beginning of Stage 2 as a dependency for other design elements.
- **Edge Computer Risk:** The addition of an edge computer triggered a series of risk questions from the RCOC IT department. Many were satisfactorily addressed in the prototype deployment, but some will need to be revisited in the system design phase of Stage 2.
  - Examples of questions addressed in Stage 1: Ubuntu OS security patches and updates, long-term support plan, limited whitelist approvals for trusted domains agreed.
  - Examples of concerns that will need to be addressed in Stage 2: multifactor authentication on SSH, additional security recommendations to reduce whitelisted exposure, managing the large footprint of devices.

6. Deployment Readiness

6.1. Project Readiness for At-Scale Implementation

The following sections describe the requirements for successful implementation, key obstacles demonstrated progress, uncertainties, and risk mitigations for each topic area.

6.1.1. Legal, Policy, and Regulatory Requirements

Requirement / Risk / Uncertainty	Progress / Mitigation	Impact

Final ruling from FCC on V2X	This was previously tracked as a risk but was resolved with the FCC's final ruling on November 21, 2024.	N/A
V2X standards are still evolving (e.g. SAE, IEEE, ITE)	Team members participation in standards organizations and committees to inform and learn.	Low
Lack of standards for signal priority and preemption which created challenges when a corridor traverses intersections managed by different city, county, and state level jurisdictions	Outreach and inclusion of MDOT and Macomb County in the Stage 2 project.	Low

6.1.2. Procurement and Budget

Requirement / Risk / Uncertainty	Progress / Mitigation	Impact
OBU pricing is currently too high to incentivize non-subsidized adoption	Evaluation of a low-cost OBU for mass market adoption. Optimize antenna configuration.	High
Clarity on how domestic procurement requirements apply to ITS projects	Work with SMART Grant Program office to navigate the Buy America / Build America, Buy American acts.	Medium

6.1.3. Partnerships

One of the primary goals of this project was to explore how private financing from infrastructure investors could support the deployment of V2X technology. Although not a requirement for Stage 2 deployment, establishing the framework of a public-private partnership will support the long-term expansion and maintenance of the V2X system. Stage 1 has made significant progress towards establishing the framework.

Various partnership models for this project were analyzed, each with a different level of complexity, speed of execution, allocation of risks and responsibilities, and value for money. A Revenue Support Model, which typically has been applied in digital infrastructure projects, is considered one of the better options. Under this procurement structure a public-private partnership entity (PPP) would be established to lead all the aspects of DBFOM and the commercialization of the V2X system by incentivizing the adoption of subscription V2X services by commercial fleets. The impact level of this requirement is high.

An alternate model of public agency led deployment is also being explored to establish the agency in a revenue collection role. The success of the public agency in either model is dependent on the number of subscribed users and the involvement of a partner who can bring (or require) those users to the ecosystem. With the absence of a mandate to require vehicles to be equipped with C-V2X technology, the project team has been focusing on identifying fleet operators as the ideal candidate to provide first users. It is important to emphasize that a mandate to deploy V2X in all OEM production vehicles would position agencies across the country (or their private sector designee) to be able to collect revenue without having to also incentivize adoption of the technology. This would result in a much more immediate and faster growing revenue stream than would otherwise be the case.

6.1.4. Technology Suitability / Integration with Incumbent Systems

Requirement / Risk / Uncertainty	Progress / Mitigation	Impact
More robust and proven VRU detection systems are required	During Stage 2, RCOC will perform validation testing as part of the procurement process to compare how VRU detection systems from multiple vendors meet requirements.	High
Challenges with technology integrations	Include validation testing as part of procurement process and include a contingency budget to handle additional support required from vendors.	Low
Driver display in the vehicle is not optimized	Evaluate alternative display options to determine which option best fits each vehicle. Encourage OEMs to adopt V2X and take ownership of driver display.	Medium

6.1.5. Data Governance

Requirement / Risk / Uncertainty	Progress / Mitigation	Impact
Protections in place to protect data privacy	RCOC completed the Data Management Plan tool (DMPTool) inputs. No sensitive data was collected or used by this project. All technical system data was anonymous and did not include any personally identifiable information (PII), or confidential business information. All external web services that were requested were approved by RCOC IT staff. Some future use cases that support private financing will require user consent for data to be shared with a 3rd party. RCOC recognizes the management of this in a transparent and	High

	empathetic manner is essential for an at-scale deployment.	

6.1.6. Workforce Capacity

Requirement / Risk / Uncertainty	Progress / Mitigation	Impact
Scaling the project will require a skilled workforce capable of installing, maintaining and operating the V2X system.	Workforce development initiatives, including training programs and upskilling, will be essential to ensure that the necessary expertise is available.	High

6.1.7. Internal Project Coordination

Requirement / Risk / Uncertainty	Progress / Mitigation	Impact
Coordinating across different departments and stakeholders within the project team is crucial to reduce cost and schedule overruns.	Build upon successful processes from Stage 1, including: a project schedule, open issues list, risk log, RASIC chart, cross-functional team meetings, shared repository, documented change control process, and an expanded steering committee.	Medium

6.1.8. Community Impact

Requirement / Risk / Uncertainty	Progress / Mitigation	Impact
Agencies and stakeholders will expect clear, transparent evidence that the deployed V2X system is delivering value. Without a well-defined framework to measure outcomes it may be difficult to justify further	The project team has defined a set of initial performance metrics in Stage 1, focusing on quantifiable outcomes such as travel time savings, system uptime, VRU alert counts, and successful signal priority events. These metrics have been aligned with broader USDOT goals, such as improved safety and system efficiency. In Stage 2, a structured performance measurement plan will be developed to collect, analyze, and report on system impacts using both quantitative (e.g., time savings, incident reduction) and qualitative (e.g., community feedback, user satisfaction) data. This will also include defining tools and processes for community engagement metrics to ensure the public's	Medium

investment or public buy-in.	perspective is captured and incorporated into ongoing improvements.	

6.1.9. Public Acceptance

Requirement / Risk / Uncertainty	Progress / Mitigation	Impact
Gaining public support and ensuring positive community impact are key to the project's success.	Stage 1 benefited from a 10-person advisory board from a variety of public and private disciplines to draft the Stage 2 community engagement plan. The recommended mitigation, based on the advisory committee's experience, includes prioritizing engagement with key stakeholders and targeted messaging through appropriate channels.	Medium

6.1.10. Cybersecurity

Requirement / Risk / Uncertainty	Progress / Mitigation	Impact
Unauthorized access to the RCOC IT network could allow a malicious actor to access traffic signal systems, sensitive data, or infrastructure.	In Stage 1, strict firewall rules, segmented networking, and security procedures were implemented to isolate the V2X system from the broader RCOC network. These protections limited exposure and ensured that only authorized devices and users could access the system. In Stage 2, this approach will be expanded with the design of a secure network architecture to support countywide deployment.	High
Bad actors could attempt to spoof V2X messages to mislead vehicles, trigger false signal priority events, or interfere with driver alerts, undermining the safety and reliability of the system.	Stage 1 addressed this threat through the integration of the Security Credential Management System (SCMS), which enables message authentication and ensures that only trusted devices participate in the V2X ecosystem. All SPAT, MAP, SRM, and other safety messages are cryptographically signed and validated by receiving devices. In Stage 2, this framework will be continued to the full deployment area, with enhanced validation procedures and monitoring of certificate usage to detect and respond to anomalies.	Medium

6.2. Understanding Maintenance and Operating Requirements

The maintenance requirements for the V2X equipment deployed in Stage 2 are well known. However, if the system is expanded beyond the Stage 2 deployment locations or requires a new technology there are unknowns. To better understand the requirements for sustaining this project, continued engagement with the private sector is essential. First, private infrastructure investors and consumer adopters are key to the economically sustainable approach, ensuring that ongoing operations and maintenance (O&M) are adequately funded, even as technology evolves. This financial backing will enable the project to adapt to future technology changes without incurring technical debt. Next, engaging with automotive OEMs is critical for understanding future technology needs. OEMs were engaged during Stage 1 and have expressed interest in testing their vehicles with the infrastructure both in the remaining months of Stage 1 and into Stage 2. They have not yet committed to expanded involvement in Stage 2, but an increased engagement process will be undertaken to include them in the project and financial structure for future stages. Their input remains vital for understanding upcoming advancements and aligning the project's infrastructure with future developments.

6.3. Impacts on Jobs

At-scale implementation will create numerous high-quality jobs in technology installation and system maintenance. RCOC has existing long and positive relationships with unions[9] and will continue to utilize labor agreements for this project. To mitigate potential negative impacts, Stage 2 of the project will include workforce training programs to upskill employees, preparing them for the evolving demands of the V2X ecosystem and ensuring long-term job stability.

7. Wrap-Up

The RCOC project team is deeply appreciative of the opportunity provided by USDOT to further develop V2X technology within Oakland County. The Stage 1 SMART process, particularly the early data collection and evaluation plan milestones, along with the 12-month timeline, pushed the team to be as efficient and effective as possible.

For the at-scale implementation, several notable changes are planned:

- **Alignment with MDOT and Macomb County**: RCOC will work closely with MDOT and Macomb County to establish V2X technology along higher-traffic corridors that span multiple jurisdictions. The communication plan for the at-scale project will emphasize awareness and two-way communication with nearby V2X deployments to ensure both understanding of the technology and interoperability.
- **Networked V2X Evaluation:** After the conclusion of Stage 1, Networked V2X will be evaluated to determine its potential to increase the overall impact of the deployment while reducing costs. By leveraging existing network connectivity to traffic cabinets, Networked V2X could be deployed across a much broader area without the need for extensive hardware investments in RSUs and OBUs. The evaluation will focus on assessing reliability,

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[9] Agreements are in place with The Clerical Technical Group of the Technical, Professional, and Office Workers Association of Michigan (TPOAM), Skilled Foremen Association of the Technical, Professional and Office workers Association of Michigan, The International Union of Operating Engineers (IUOE) Local 324.

latency, SCMS integration, and the overall scalability of this technology. Multiple potential providers of Networked V2X capabilities will be evaluated.

- **Enhanced Technology Benchmarking**: While Stage 1's use of existing cameras and processors provided invaluable insights, more work is needed to benchmark other detection systems. This will enable RCOC to define the right set of requirements for a formal procurement process.
- **Expansion of Team and Partnerships**: To support the at-scale deployment, RCOC will intentionally and judiciously expand the team, adding critical expertise in areas such as infrastructure investment, community engagement, network infrastructure, and cybersecurity. This will ensure that the deployment is comprehensive and meets the highest standards of safety and efficiency.

These adjustments are designed to build on the successes of Stage 1 while addressing the challenges and opportunities identified as the project moves toward full-scale implementation.

Recommendations to other communities embarking on the path of deploying V2X technology include:

- **Start with a Clear Vision and Scalable Plan:** Define your goals clearly from the outset and develop a plan that allows for scalable growth, ensuring that initial deployments can be expanded effectively as technology, funding, and community needs evolve.
- **Leverage Public-Private Partnerships:** Establishing strong public-private partnerships can bring in necessary resources, expertise, and innovation, making the project more robust and scalable.
- **Focus on Interoperability:** Ensure that your V2X systems are designed for interoperability with existing infrastructure and neighboring jurisdictions. Validate interoperability claims from vendors prior to making large procurement decisions.
- **Conduct Due Diligence on Assets and Network Architecture**: At the outset of planning, thoroughly assess your existing assets and network architecture. Understanding your current infrastructure capabilities and limitations will help you plan more effectively and avoid costly surprises during implementation.

By following these principles, communities can position themselves for successful V2X deployments that enhance transportation safety, efficiency, and sustainability.