Leading in Sustainable Safety with V2X Technology in Oakland County Michigan

Evaluation Plan

Recipient Name: Road Commission Oakland County (RCOC)

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Document Approval

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1 Introduction and Project Overview

Project Description

This Stage 1 Planning Grant's overall goal is to build an economically sustainable safety model and prototype deployment of Cellular-Vehicle-to-Everything (C-V2X) technology. The Project recognizes that government funding cannot be the only source of monies to support the expansion and operations of digital infrastructure. This project will create a blueprint for building digital infrastructure that supports private investment and generates the revenue needed to finance ongoing operations and maintenance. In addition to the Evaluation Plan, the blueprint will include the following planning deliverables:

- Data Management Plan
- County-wide Deployment Plan
- Business & Financial Plan
- Workforce Development Plan
- Community Engagement Plan

The C-V2X intersection and vehicle prototype demonstration elements targeting safety and efficiency will be coupled with the technical, community engagement, and workforce development plans to inform this significant change management exercise. The Project is built on a foundation of collaboration and will use the planning phase to build a model for public-private partnerships which will foster further innovation and economic development. This economic sustainability aims to provide the means to reduce the growing number of casualties and injuries on our nation's transportation network while also helping to address the climate crisis.

Technologies, Goals and Outcomes:

The technologies being deployed in the project prototype demonstration include:

- Connected Vehicles
- Intelligent Sensor-based Infrastructure
- Smart Technology Traffic Signals

The goals and desired outcomes for the at-scale implementation include:

- **Safety and Reliability:** Develop a comprehensive plan for sustainably deploying lifesaving C-V2X technology for vulnerable road users, advanced safety warnings for connected vehicles, signal preemption for first responders.
- **Partnerships:** Establish a functioning public-private partnership model for C-V2X deployment that includes revenue-generation. Investigate the partnerships needed with learning institutions to prepare the future workforce to build and maintain C-V2X equipped infrastructure and vehicles.
- **Climate:** Demonstrate use cases advantageous to reduced congestion, and more efficient traffic flows.
- **Equity and Access:** Develop a plan to engage and educate key community and industry stakeholders and the public on benefits of C-V2X. Utilize smart intersections to provide benefits before the mass adoption of the technology.

Stage 1 Prototype Demonstration

System Architecture

The prototype demonstration will include the following elements:

- C-V2X infrastructure deployed at 5 intersections strategically selected for safety, vulnerable user traffic, equity, and availability of the required infrastructure to support the technology (e.g. advanced traffic controllers, network connectivity, etc.). In addition to the traffic signal controllers, the system at the intersections will include cameras, video analytics AI, the V2X Hub and Plug-ins, edge computing devices, and Wi-Fi enabled C-V2X roadside units (RSUs).
- C-V2X technology deployed in 10 county-owned vehicles. The system in the vehicles will include C-V2X on-board units (OBUs), Driver Displays, and antennae.
- The system in the Traffic Operations Center includes a cloud interface to the V2X authorization server, an interface to the SCMS provider, data visualization software and virtual monitoring software.

System Use Cases

Given the short duration of the Stage 1 project and the limited size of the prototype, targeted use cases are planned to establish a foundational C-V2X system that can demonstrate specific capabilities of C-V2X technology. Additional use cases may be introduced as part of the Stage 1 lessons learned. The use cases for the prototype demonstration are expected to be:

- C-V2X Signal Priority
- Vulnerable Road User (VRU) alerts via Cooperative Perception
- C-V2X Fleet Intelligence and data visualization
- Utilizing the unlicensed Wi-Fi spectrum for C-V2X communications that are not expected to fit in the newly reduced 5.9 GHz spectrum

Anticipated Scale of Stage 2 Deployment

The anticipated scale of a Stage 2 deployment is a multi-year plan for Oakland County to install and maintain this lifesaving V2X technology in a sustainable manner across the 900 square miles of roads and over 1500 traffic signals in the county in-line with the USDOT's national V2X deployment plan: "Saving Lives with Connectivity: A Plan to Accelerate V2X Deployment".

Project Evaluation Process

The evaluation of the project's prototype is broken down into three stages:

1. **Pre-Deployment:** The pre-deployment stage will define the system to meet base requirements. The evaluation starts at the test bench level and then expands to a full system layout test. For certain system elements (e.g. VRU detection) a secured and controlled test intersection is planned. Software testing and simulation will be used where appropriate. Data will be logged, and peer reviewed inside the project team before moving to the deployment stage.

2. **Intersection / Vehicle Deployment:** The deployment stage will include a validation process that ensures the system is acceptable for use and able to capture the data necessary to evaluate the performance measures. The validation process ensures the RSU, OBU and Edge device are communicating effectively and that the Traffic Management Center and /

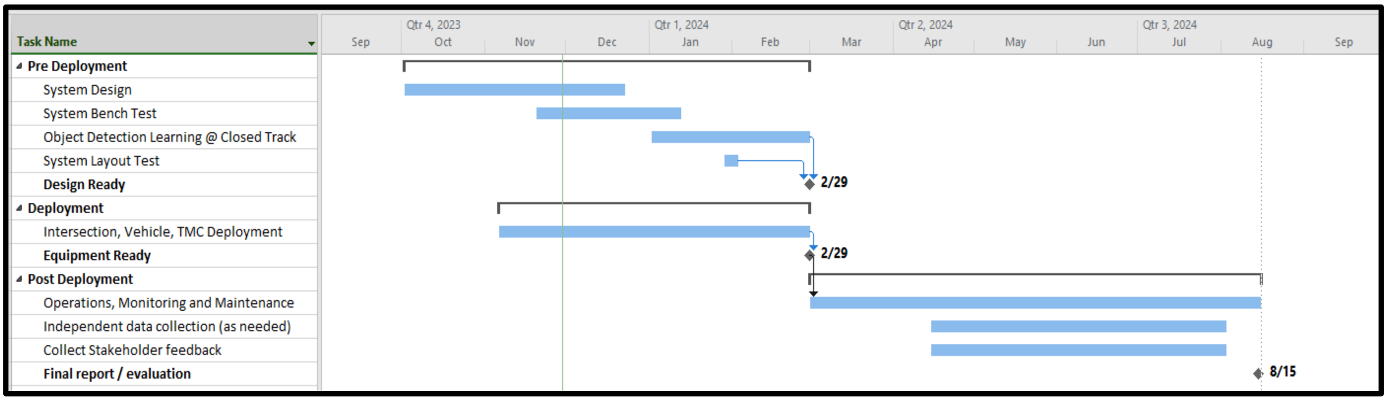
or Cloud servers receive the needed information. The team verifies the back-end servers are functioning, and the data analytics tools can access and retrieve the data.

3. **Post-Deployment Operations & Monitoring:** The system will operate for approximately 9 months during the post-deployment stage. Monitoring tools will be in place to demonstrate that the system is working as expected and capturing data on the system's performance. Data will be analyzed to determine if the system is meeting the performance measures laid out in this document. If the data required to evaluate a performance measure is not available from the monitoring tools, an independent data collection process will be identified to gather the data that is needed. For example, some performance measures will evaluate packet loss which is not expected to be available in the monitoring tools, so an independent data collection process will need to be taken to gather this data.

Table 1: Stakeholders Influence on Data Evaluation

Stakeholder	Evaluation Stage	Roles & Responsibility in Data Collection	Roles & Responsibility in Data Evaluation
RCOC	All Stages	Provide locations for system installation, provide network for data to be collected	Final review and approval of evaluation
P3Mobility	All Stages	Plan and deploy V2X platform that collects operational data	Make data available for evaluation, monitor system performance, perform evaluation
MSG	Pre-Deployment Post Deployment	Plan for and gather data related to traffic safety and efficiency	Make data available for evaluation, perform evaluation
Object Detection Vendor (TBD)	All Stages	Plan and deploy object detection software to collect data (non-PII) on objects	Make data available for evaluation
Brandmotion	Pre-Deployment, Deployment	Plan and deploy C-V2X OBUs to generate data	N/A
V2X Monitoring and Visualization Vendor (TBD)	Deployment Post Deployment	Provide monitoring and data analytics platform to collect data	Make data available for evaluation

Figure 1: Evaluation Schedule



2 Project Goals and Objectives for At-Scale Implementation

The table below identifies anticipated qualitative impacts of at-scale implementation related to the SMART program goal areas.

Table 2: Goals and Impact Analysis

Goal Area	Impact
Safety and Reliability	• Reduced number of VRU crashes and near-misses with C-V2X VRU driver alerts • Reduced number of crashes with authorized vehicles (e.g. emergency, snowplows, etc.) with C-V2X traffic signal priority and pre-emption • Improved safety with the C-V2X system that enables new use cases to be deployed as required • Improved response time for emergency vehicles with C-V2X emergency vehicle pre-emption • Reduced operating time for snowplows with C-V2X snowplow pre-emption • Reduced congestion with C-V2X traffic signal priority and pre-emption • Improved safety for AV’s that can include C-V2X information in their driving models
Resiliency	• Improved cybersecurity with the introduction of the SCMS into the C-V2X system
Equity and Access	• Improved safety for disadvantaged communities by including equity as a criterion for selecting C-V2X deployment locations. • Improved community engagement with the execution of a Community Engagement Plan that is developed specifically to educate and engage the public on the benefits of the C-V2X system • Improved knowledge for the workforce with the execution of a Workforce Development Plan to educate workers on C-V2X technology
Climate	• Reduced greenhouse gas emissions from reduced congestion with C-V2X traffic signal priority and pre-emption
Partnerships	• Improved financial sustainability of the C-V2X system by introducing a model that focuses on generating funds and attracting private investment to support the deployment, operations, and maintenance of the C-V2X system • Accelerated deployment of the C-V2X system with a model that attracts private investment • Accelerated deployment of C-V2X equipped vehicles by collaborating with OEMs and fleet providers during the planning stage
Integration	• Improved interoperability using C-V2X industry standards (e.g. IEEE, SAE, ITE) • Increased communication bandwidth by leveraging the U-NII Wi-Fi spectrum to complement 5.9 GHz C-V2X communications • Accelerated realization of benefits of the C-V2X system by leveraging infrastructure sensors to generate V2X cooperative perception messages

Costs of Implementation

The estimated cost of the prototype demonstration for Stage 1 of this grant is approximately $875,000. The anticipated costs of the at-scale implementation in Stage 2 are going to be evaluated as part of the Stage 1 planning process. The Stage 2 costs are expected to be reduced on a per-intersection basis as the deployment reaches economies of scale.

Historical Data Availability

Table 3: Goal Area Historical Data

Goal Area	Summary of Historical Data Available
Safety and Reliability	• County-wide crash data broken down by type of crash, vehicles involved, VRU involvement • County-wide traffic data on average daily traffic volumes and commute times
Resiliency	• No historical data available
Equity and Access	• Traffic safety and efficiency data for disadvantaged communities
Climate	• County-wide emissions data based on traffic congestion data
Partnerships	• Previous cost of C-V2X deployments prior to private investment being introduced
Integration	• No historical data available

3 Performance Measures for the Proof-of-Concept / Prototype

Table 4: Performance Measures

Evaluation Question	*Performance Measure*	*Performance Measure Target*
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 - ITE guidelines for driver human reaction times and deceleration
Signal Priority: How much time can be saved for a vehicle with signal priority?	Intersection traversal time	5% improvement from baseline
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 < 3 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
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
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

Evaluation Question	*Performance Measure*	*Performance Measure Target*
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
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
Overall System: Does the system provide value to the users?	Qualitative feedback from users	Net positive feedback

4 Evaluation Methodology for the Proof-of-Concept / Prototype

Proof of Concept Evaluation

The prototype will be evaluated by collecting data and comparing the collected data to various baselines. The table below indicates which baseline each performance measurement will be compared to:

Table 5: Evaluation Questionnaire

Evaluation Question	*Performance Measure*	*Performance Measure Target*	*Baseline Comparison*
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 - ITE guidelines for driver human reaction times and deceleration	Pre-deployment baseline of no advance VRU detection
Signal Priority: How much time can be saved for a vehicle with signal priority?	Intersection traversal time	5% improvement from baseline	Pre-deployment baseline of vehicle travel time without signal priority
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 < 3 cycles	Industry guidelines that are acceptable to RCOC

Evaluation Question	*Performance Measure*	*Performance Measure Target*	*Baseline Comparison*
Unlicensed Wi-Fi: Can a V2X message reliably be 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	Alternate technology baseline of 5.9 GHz C-V2X communication
Unlicensed Wi-Fi: How far can a message reliably be 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	Industry standard baseline for 5.9 GHz C-V2X communication range
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	Comparison of packet throughput before and during non-authorized users attempting to access
Financial Sustainability: How will vehicles be authorized for revenue generating V2X services in accordance with IOO policies?	Accurate authorization of V2X services for a vehicle	100% authorization accuracy	Pre-deployment baseline without authorization
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	Pre-deployment baseline of vehicle travel time without signal priority
Overall System: Does the system provide value to the users?	Qualitative feedback from users	Net positive feedback	Comparison to pre-deployment status

At-Scale Benefits vs Cost

In estimating the anticipated benefits associated with at-scale implementation of the C-V2X deployment, the methods will primarily involve extrapolating data from the 5-intersection prototype demonstration. This extrapolation will be based on the key performance measures identified above. These measures will be scaled proportionally to model the expected outcomes of a larger-scale deployment. Baseline data for this extrapolation will be drawn from existing traffic and safety data prior to the prototype implementation. Additionally, the extrapolation will consider variations in traffic patterns, intersection layouts, and local environmental factors to ensure a realistic and comprehensive estimation of benefits for the at-scale deployment. Simulation and analysis tools will be used to model the benefits for the at-scale deployment.

A similar approach will be taken to estimate the costs associated with at-scale implementation. Costs of parts and labor will be quantified during the prototype and extrapolated for the at-scale implementation. To understand the cost reductions associated with operating at-scale a separate exercise will be undertaken to ensure more accurate cost estimates are available. These cost estimates will be documented in an at-scale financial model that is part of the Business and Financial plan deliverable.

Capturing Project Learnings

Challenges, best practices, and recommendations for future deployers will be managed through the following activities:

- The project manager created an open issues list and risk log to document challenges faced throughout the project. These issues and risks will be reviewed at the end of the project and relevant items will be documented in the final report.
- At the project kickoff meeting project partners shared lessons learned from previous projects. These lessons were documented and then either addressed in our open issues list or the risk log allowing us to monitor and mitigate.
- To share learnings from the project, team members are actively participating in industry committees, councils and standards working groups. This is an opportunity for pilot projects to

share learnings and influence standards with real-life feedback. Team members currently participate in SAE, SCMS Manager, ITSA and ITE working groups.

- Additionally, the project team plans to participate in industry summits, webinars and meetings (e.g. ITSA Conference, USDOT V2X Summit) to distribute lessons learned and best practices.
- Additionally, the project lessons learned will be added to the ITS JPO Benefit, Cost, and Lessons Learned Database

5 Reference Sections

Table 6: Definitions

Term	Definition
Cooperative Perception	Leverages infrastructure-based sensors (e.g. camera) to detect Vulnerable Road Users. This information is then transmitted to nearby vehicles via C-V2X communication. This extends a vehicle's perception beyond its immediate line of sight, providing a more comprehensive understanding of its surroundings.
Edge Device	High-performance computer installed at an intersection
Extended Transportatio n Spectrum	Applies C-V2X communication principles to the U-NII, or unlicensed, Wi-Fi spectrum. This works to address the low-latency bandwidth limitations driven by the available and dedicated 5.9 GHz ITS spectrum. Targeted to accommodate the data necessary for cooperative perception and transmission of large MAP files. The Extended Transportation Spectrum could offer options to address general connectivity needs, such as infotainment services or operational data and services for autonomous vehicles.
Fleet Intelligence	Aggregates critical C-V2X data, including Basic Safety Messages (BSMs), MAP messages, Signal Phase and Timing (SPAT), and Sensor Data Sharing Messages (SDSMs). The data is stored and distributed for a variety of use cases.
Signal Preemption	Allows authorized vehicles like ambulances, fire trucks, police vehicles or snowplows to influence traffic signals, ensuring a quicker and safer route in critical situations.
Signal Priority	Signal priority is similar to signal preemption, but it is a less disruptive approach that can be used with public transit vehicles or commercial freight vehicles to help them move through traffic signals more efficiently and without creating congestion for surrounding vehicles.

Table 7: Acronyms and Abbreviations

Acronym	Description
AAA	Authentication, authorization, accounting
ATC	Advanced Traffic Controller
AV	Autonomous Vehicles
BSM	Basic Safety Message
CP	Cooperative Perception (detecting vulnerable road users VRU)
CV2X	Cellular Vehicle to Everything
EVP	Emergency vehicle Preemption
EVTA	Equipped Vehicle Trajectory Awareness
FSP	Fleet signal priority
IOO	Infrastructure Owners and Operators
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation System
ITSA	Intelligent Transportation Society of America
OBU	On Board Unit
P3	Public - Private - Partnership
PII	Personal identifiable information
RCOC	Road Commission Oakland County
RSU	Roadside Unit
SAE	Society of Automotive Engineers; safety messaging standards
SCMS	Security Credential Management System
SCP	Signal Control Prioritization
SDSM	Sensor Data Sharing Message
SEMCOG	Southeastern Michigan Council of Governments
SPaT	Signal Phase and Timing
TMC	Traffic Management Center
TSP	Transit Signal Priority
U-NII	Unified or Unlicensed National Information Infrastructure
V2X	Vehicle to Everything
VRU	Vulnerable Road User

Figure 4: System Block Diagram