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- Dist-Trans (an ODW Company)
- Central Ohio Transit Authority
- City of Columbus Division of Fire
- City of Columbus Division of Police
- City of Columbus Department of Public Service Traffic Operations
- City of Columbus Department of Public Service Design and Construction
- City of Columbus Department of Public Service Infrastructure Management
- City of Columbus Department of Development Code Enforcement
- City of Columbus Department of Technology
- Franklin County Engineer’s Office
- Ohio Department of Transportation / Drive Ohio
- Village of Obetz
- Siemens Industry, Inc. (Brandmotion, WNC)
- Kapsch (Danlaw, Path Master, Econolite)
Abstract

The purpose of this Operations and Maintenance Plan is to explain operational and maintenance activities for the Connected Vehicle Environment project—both during and after the demonstration—funded as part of the Smart Columbus program. This document provides a comprehensive view of the connected vehicle environment and its components, the roles and responsibilities that make it work, and the processes and procedures to maintain optimum functionality.
# Table of Contents

**Executive Summary** ................................................................................................................................. 1

**Chapter 1.  Introduction** ............................................................................................................................... 3  
  1.1. **Scope and Purpose** ................................................................................................................................. 3  
  1.2. **Document Organization** ......................................................................................................................... 3  
  1.3. **Project Description** ................................................................................................................................. 3  
    1.3.1. **Project Objectives** ............................................................................................................................... 4  
    1.3.2. **Connected Vehicle Applications** ......................................................................................................... 5  
    1.3.3. **System Geographic Scope** ................................................................................................................... 6  
    1.3.4. **Connected Vehicle Environment System Components** ......................................................................... 8  
    1.3.5. **Connected Vehicle Environment System Stakeholders** ....................................................................... 12  
  1.4. **References** ............................................................................................................................................ 16

**Chapter 2.  Materials and Resources** ......................................................................................................... 19  
  2.1. **Personnel** ............................................................................................................................................... 20  
  2.2. **Equipment, Software and Materials** ..................................................................................................... 22  
    2.2.1. **Equipment** .......................................................................................................................................... 22  
    2.2.2. **Costs** ................................................................................................................................................ 23  
  2.3. **Training** .................................................................................................................................................. 23  
    2.3.1. **Vehicle Operator Training** ................................................................................................................... 23  
    2.3.2. **Roadside Units Operations and Maintenance Training** ....................................................................... 25  
    2.3.3. **Onboard Unit Operations and Maintenance Training** ......................................................................... 26  
    2.3.4. **Traffic Controllers** .................................................................................................................................. 26  
    2.3.5. **CVCP** ................................................................................................................................................. 26  
    2.3.6. **Networking Equipment** ...................................................................................................................... 26

**Chapter 3.  Operations** .................................................................................................................................. 27  
  3.1. **Connected Vehicle Environment Operational Activities** ...................................................................... 27  
    3.1.1. **In-Vehicle Equipment** .......................................................................................................................... 27  
    3.1.2. **Infrastructure Components** .............................................................................................................. 28  
    3.1.3. **Operating System** .................................................................................................................................. 31  
  3.2. **Hours of Operation** ............................................................................................................................... 32  
    3.2.1. **Technical Support** ............................................................................................................................... 32  
  3.3. **Data Collection and Privacy** .................................................................................................................. 33  
    3.3.1. **Connected Vehicle Environment Project Data** ................................................................................... 33  
    3.3.2. **Data Privacy** ........................................................................................................................................ 34

**Chapter 4.  Maintenance** ............................................................................................................................. 37
4.1. Responsibilities.............................................................................................................. 37
4.2. Maintenance Activities.................................................................................................. 37
   4.2.1. In-Vehicle Equipment ............................................................................................ 38
   4.2.2. Infrastructure Components ................................................................................. 39
   4.2.3. Operating System ............................................................................................... 43

Appendix A. Acronyms and Definitions ........................................................................... 45
Appendix B. Glossary .......................................................................................................... 47
Appendix C. Connected Vehicle Co-Processor Configuration Instructions ...................... 49
Appendix D. Map Data Message Guidance ...................................................................... 57
Appendix E. Traveler Information Message Generation .................................................... 59

List of Tables
Table 1: Connected Vehicle Environment Project Scope .................................................... 4
Table 2. Connected Vehicle Applications and Vehicle Classes for Smart Columbus CVE ...... 5
Table 3. Reference Documents ............................................................................................ 16
Table 4. Connected Vehicle Environment System Stakeholder Responsibility Timeline ........ 19
Table 5. Connected Vehicle Environment Personnel Involved During Demonstration ........ 20
Table 6. Connected Vehicle Environment Personnel Post-Demonstration Support ............ 21
Table 7. Monthly/Yearly Recurring and Support Costs During Demonstration ................. 23
Table 8. Monthly/Yearly Recurring and Support Costs After Demonstration .................... 23
Table 9: Training Materials ............................................................................................... 25
Table 10. Data Dictionary for Connected Vehicle Environmental Messages .................... 32
Table 12. Maintenance of Data Ingestion to Operating System ........................................ 43
Table 13. Corrective Maintenance Activities ..................................................................... 44
Table 14. Acronym List ..................................................................................................... 45
Table 15. Glossary ............................................................................................................. 47

List of Figures
Figure 1: Connected Vehicle Environment Applications by Intersection .......................... 7
Figure 2: Connected Vehicle Environment System Diagram .......................................... 8
Figure 3: Connected Vehicle Environment High-Level Network Design ......................... 11
Figure 4: Transit Vehicle Interaction Event Recorder Network Data Flow ......................... 12
Figure 5: Centracs’ Roadside Unit Alerts ......................................................................... 29
Figure 6: Connected Mobility Control Center with Monitor Function .............................. 30
Figure 8: School Zone Pavement Markings and Signage ................................................... 59
Figure 9: Traveler Information Message Creator Typical Specification for School Zones in the CVE ... 60
Executive Summary

This Connected Vehicle Environment (CVE) Operations and Maintenance (O&M) Plan provides guidance of operations and maintenance of the CVE project. The Smart Columbus CVE project is one of the eight projects in the Smart Columbus program and is expected to enhance safety and mobility for vehicle operators and improve pedestrian safety in school zones by deploying connected vehicle (CV) infrastructure on the roadsides and CV equipment in vehicles. The CVE project also provides sources of high-quality data for traffic management and safety purposes.

This O&M plan describes an introduction to the CVE project and its system components (Chapter 1), necessary materials and resources (Chapter 2), and O&M activities (Chapter 3 and Chapter 4) for the success of the project.

The intended audience is the Smart Columbus CVE project team, the City of Columbus, U.S. Department of Transportation, transportation and Smart City researchers, and those engaged in the deployment of Smart Columbus program projects.
Chapter 1. Introduction

1.1. SCOPE AND PURPOSE

This document identifies the scope and purpose of the Connected Vehicle Environment (CVE) Operations and Maintenance (O&M) Plan (CVE O&M Plan). It explains how operational and maintenance activities are performed both during and after the demonstration period, funded as part of the Smart Columbus initiative. The following sections discuss the materials and resources, operational activities, maintenance tasks, and routines taking place to operate and maintain the CVE (defined in Section 1.3) and other associated systems used to service its users. This document also specifies the stakeholders—such as agencies, departments, and divisions within agencies—that rely on its successful operation. The purpose of this document is to provide a comprehensive view of the CVE project, the elements that make it work, and the processes and procedures for maintaining optimum functionality.

The primary goals and expectations of the CVE O&M Plan are as follows:

- Keep the CVE operational and provide optimal service to travelers.
- Provide access to troubleshooting tips and common system issues and how to resolve them.
- Facilitate communications between the support teams.

This CVE O&M Plan provides insight into the types of activities necessary to keep the CVE operational, and should serve as a guide for addressing and resolving issues that arise regarding the CVE operational, including the O&M of the installed roadside units (RSUs) and onboard units (OBU) and their integration with the Smart Columbus Operating System (Operating System).

1.2. DOCUMENT ORGANIZATION

The CVE O&M Plan is organized into the following chapters:

- **Chapter 1. Introduction** provides a high-level overview of the project, the CVE and its components, and the stakeholders involved.
- **Chapter 2. Materials and Resources** identifies the required personnel and equipment needed for O&M.
- **Chapter 3. Operations** provides insight into the types of activities that are necessary to keep the CVE operational.
- **Chapter 4. Maintenance** identifies the maintenance activities that are necessary to keep the CVE operational.

1.3. PROJECT DESCRIPTION

The CVE project is one of the eight projects in the Smart Columbus program that integrates smart traveler applications, automated vehicles, connected vehicles (CVs), and RSUs into its transportation network by focusing on deploying the following:

- **CV Infrastructure** – The project was responsible for building out the physical and logical CV infrastructure, which consisted of CV hardware and software (e.g., RSUs, onboard equipment, front and backhaul communications, equipment interfaces). The CVE generates the needed transportation-related data that are used by applications.
Chapter 1. Introduction

- **CV Applications and Data** – The project scope also consists of deploying CV-specific applications that leverage the data generated by the infrastructure to deliver real-time safety and mobility services. Data is collected, stored, and made available for use in other Smart Columbus project applications.

The foundation for the CVE is the Columbus traffic-signal system (CTSS), which is an open-architecture, computerized traffic-signal system and communications network that allows the City to monitor many of the region’s signalized intersections, traffic surveillance monitors, pavement weather sensors, and snow and ice crews using a high-speed network backbone. When complete, the CTSS will interconnect up to 1,250 traffic signals in the Columbus region and provide uniform signal coordination capability throughout the system.

The existing CTSS network was leveraged to connect to CV equipment at intersections along four select corridors and to equipment at intersections along the Alum Creek corridor managed by Franklin County, the Village of Obetz, and Ohio Department of Transportation (ODOT). Deployment of in-vehicle devices target populations near frequently used infrastructure deployment corridors. **Table 1** lists the improvements associated with the CVE project. The data created by the system has been anonymized, de-identified and aggregated, as necessary, by the CVE project team and stored by the Operating System for historical analysis and visualization.

**Table 1: Connected Vehicle Environment Project Scope**

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Applications and Data</th>
<th>Applications and Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>85 Roadside Units</td>
<td>Connected Vehicle Applications</td>
<td>Data Capture</td>
</tr>
<tr>
<td>The project installed roadside units and other connected vehicle compatible equipment at signalized intersections in the project areas.</td>
<td>The project deployed vehicle-to-vehicle safety, vehicle-to-infrastructure safety, and vehicle-to-infrastructure mobility applications.</td>
<td>The project captures, relates, stores, and responds to data generated by the infrastructure, used by the applications for traffic management.</td>
</tr>
<tr>
<td>1,000 to 1,050 Onboard Units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The project installed onboard units on participating private, public fleet, emergency, transit, and freight vehicles.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: City of Columbus*

1.3.1. **Project Objectives**

The Smart Columbus program has seven goals designed to achieve its vision of empowering residents to live their best lives through responsive, innovative, and safe mobility solutions with a supporting mission to demonstrate how Intelligent Transportation Systems and equitable access to transportation have positive impacts on every day challenges faced by cities. The CVE project plays a role in achieving the goal of better connecting Columbus residents to safe, reliable transportation that is accessible to all. Specific CVE project objectives have been developed based on the needs of the CVE stakeholders and are listed below.

- Improve motorists’ adherence to red lights.
- Improve adherence to speed limits in school zones.
- Improve emergency response times.
- Improve reliability of transit vehicle schedule adherence.
- Reduce truck wait (delay) time at signalized intersections.
- Increase number of truck turns per day.
- Improve traffic management capability.
The CVE met these objectives by deploying CV technology in vehicles and on the roadside. This technology allows data to be exchanged among multiple vehicles and between vehicles and infrastructure to improve transportation system safety, mobility, and data collection capability.

### 1.3.2. Connected Vehicle Applications

The intelligence of the CVE resides in the software (the CV applications) that run both on the RSU (primarily in the message handler) and on the OBU. These applications use the messages exchanged via Dedicated Short Range Communication (DSRC) to provide alerts and warnings to the drivers. On the vehicle side, the vehicle type is a variable that was considered as the City planned for installation. The vehicle type dictates the placement of antennas and need for a heads-up display (HUD).

For reference (and to the extent that the applications and vehicle type influence the configuration of the roadside and vehicle equipment), Table 2 is a matrix listing the CV applications—both Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I)—and vehicle types (light-duty vehicles [LDV], heavy-duty vehicle [HDV]), transit or emergency vehicles) planned for deployment in Columbus.

<table>
<thead>
<tr>
<th>Class</th>
<th>Application Name</th>
<th>Vehicle OBU Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Light-Duty Vehicles</td>
</tr>
<tr>
<td>Vehicle-to-Vehicle Safety</td>
<td>Emergency Electronic Brake Light Warning</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Forward Collision Warning</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Intersection Movement Assist</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Blind Spot Warning/Lane Change Warning</td>
<td>✓</td>
</tr>
<tr>
<td>Vehicle-to-Infrastructure Mobility</td>
<td>Transit Signal Priority**</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Freight Signal Priority**</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Emergency Vehicle Preemption*</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Vehicle Data for Traffic Operations</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Transit Vehicle Interaction Event Recording</td>
<td>-</td>
</tr>
<tr>
<td>Vehicle-to-Infrastructure Safety</td>
<td>Red Light Violation Warning</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Reduced Speed in School Zone Warning</td>
<td>✓</td>
</tr>
</tbody>
</table>

*The transit vehicle onboard unit does not issue warnings to the vehicle operators, but these warnings are logged by the Transit Vehicle Interaction Event Recorder application.

**The applications that reside on the individual roadside units varies, depending on the solution identified for the specific location.

Source: City of Columbus
1.3.3. **System Geographic Scope**

Figure 1 presents a complete overview of the CVE with respect to the individual intersections, the applications that are available at each intersection, and the presence of contributing elements (such as schools, police and fire stations, and freight corridors) that led to the selection of the intersection/application combination proposed.
Figure 1: Connected Vehicle Environment Applications by Intersection

*Source: City of Columbus*
1.3.4. Connected Vehicle Environment System Components

Figure 2 depicts the high-level relationships and dependencies of the CVE with existing external systems and the Operating System, entities, and agencies. In addition, third-party users can connect to the Operating System to access this information on system utilization.

![Figure 2: Connected Vehicle Environment System Diagram](source: City of Columbus)

1.3.4.1. ROADSIDE UNIT

RSUs are placed at a location at each intersection that maximizes DSRC range along the corridors of interest (Cleveland Avenue, High Street, Morse Road and Alum Creek Drive). RSUs are designed to be mounted on a vertical or horizontal pole or a mast arm or bracket arm (including those comprised of either round or square pipe). RSUs can also be tethered between a messenger wire and a tether wire.

- A DSRC unit is a roadside unit that includes two separate programmable DSRC radio, an integrated Global Positioning System (GPS), and all antenna connections.
- A mounted RSU power supply is a Power-over-Ethernet injector, which should also include grounding equipment. Specific details were coordinated with those parties responsible for installation.
- Mounting hardware may be required depending on how the RSU is installed at each intersection (i.e., whether it is on a mast arm or span wire).
• Cables, such as the Ethernet cables, may be required to connect an RSU as well as fiber-optic cables from a splice enclosure backhaul to the existing traffic signal cabinet. This includes equipment necessary to connect to a fiber-optic backhaul network (e.g., an Ethernet switch with transceivers, fiber-optic termination panel, and patch cables in the traffic signal cabinet).

1.3.4.2. **ONBOARD UNIT**

OBUs are intended to be installed in a discrete location inside of the vehicle, protected from the elements (such as under a seat, under the dash, or in the trunk). The OBU comprises several separate elements, which, when interconnected, allow the OBU to function as designed:

- DSRC radio: When located in vehicles, these radios are called OBUs. As with the RSU, the processing unit may be a separate device or within the radio itself depending on the specific unit.
- Antenna(s): A single integrated antenna consisting of both DSRC and GPS is required to connect to the DSRC radio. Magnetic type of antenna are used exclusively in Columbus.
- Human-Machine Interface (HMI): HMI are installed only in LDVs and select HDVs (as operated by the County) for the CVE demonstration. For the CVE project, the HMI used is a HUD.
- Wire harness: A pre-built wire harness is used to connect to vehicle power, accessory power, and, as necessary, turn signals, reverse, siren, doors or other.
- Mounting hardware: OBUs are installed on several types of vehicles including LDVs and HDVs. These include private vehicles, Central Ohio Transit Authority (COTA) transit buses, and fleet vehicles from the City police, fire, and emergency entities. Specific installation requirements for these individual vehicle types were developed and documented and the mounting hardware for each can differ by vehicle type.

1.3.4.3. **MESSAGE HANDLER**

Message handlers are micro-computers located between RSUs and traffic-signal controllers. They provide connectivity to external (internet-connected) systems and perform various roadside information-processing tasks. The message handler is hosted on the Connected Vehicle Co-Processor (CVCP). The CVCP is installed in the communications slot of an advanced transportation controller. A CVCP is used at every intersection.

More specifically, the message handler encodes and decodes J2735 messages for use with remote hosts such as the traffic-signal controller, Connected Mobility Control Center (CMCC), US-33 Smart Mobility Corridor Continuously Operating Reference Station, Security and Credentials Management System (SCMS), and the Operating System and provides data processing capabilities that support system functions that enable applications.

1.3.4.4. **TRAFFIC CONTROLLER**

A total of 85 signalized intersections were equipped with the necessary RSUs and support equipment to enable the CVE. The majority of these intersections are owned and operated by the City of Columbus. Franklin County owns and operates some intersections along Cleveland Avenue and Alum Creek Drive, while ODOT District 6 owns and operates three intersections on Alum Creek Drive, as does Franklin County with three and the Village of Obetz with one. All intersections are connected to the CTSS at the time of go-live for the CVE.

All City of Columbus owned intersections are equipped with Econolite Cobalt-C controllers, while other locations comprise both Econolite Cobalt and Siemens M60 controllers. This existing equipment and new equipment installed under contracts not pertaining to the CVE are outside the scope of the CVE O&M Plan.
In addition to the specified traffic-signal controller, each intersection is equipped with an Econolite CVCP card installed in the controller expansion slot. The CVCP is composed of an iMX6 Quad core processor with support for Linux 3.x. The CVCP is the preferred location for any local processing that may be necessary at the intersection.

1.3.4.5. TRAFFIC CV MANAGEMENT SYSTEM

The Traffic CV Management System is implemented using the Kapsch CMCC. The CMCC operates in the Microsoft Azure Environment and is composed of four components:

- Comm server – Central communication point between the roadside equipment, the CMCC database, and any external components.
- Display server – Drives the view and retrieval of data for the system operator.
- CMCC database – The central internal database stores the control parameters and messages generated in the CMCC and data received from the roadside equipment.
- Roadside control unit to RSU – Roadside control units (message handlers) manage the interface between the CMCC, traffic controller, and RSU. Roadside control units use Simple Network Management Protocol (SNMP) messaging to control RSUs.

1.3.4.6. NETWORK DESIGN

The Smart Columbus high-level network design is shown in Figure 3 and depicts the existing CTSS approach, in which a field-hardened Layer 2 switch is installed in each signal cabinet and interconnected via fiber to a communications node composed of a Layer 3 switch that can operate in an extended temperature and humidity range. Approximately 10 signal cabinets are interfaced via fiber to a communications node. The Layer 2 switch is also connected directly to the traffic-signal controller via the Ethernet. All the communications nodes are then connected to a Layer 3 switch that resides at the City’s Traffic Management Center (TMC), where Centracs, the signal system management software system used by the City, is also hosted. This network is then connected to the City’s existing internal City network, Metronet. All devices on CTSS are IPv4-based.

The CVE network essentially replicates the CTSS by installing Layer 2 switches in each signal cabinet and Layer 3 switches in the communications nodes. Also, as for the CTSS, these Layer 3 switches are all then interconnected by a Layer 3 switch housed at the TMC. The RSU management software is then interconnected to this same switch. Finally, a new firewall that isolates the CVE network from the public Internet was employed. Unlike the CTSS, the CVE network carries both IPv4 and IPv6 traffic.

The CVE connects with at least four external sources via the public Internet: the Operating System, the Integrity Security Service (ISS) certificate authority, a continuously operating reference station, and the OBU vendor over-the-air update service.
Figure 3: Connected Vehicle Environment High-Level Network Design

Source: City of Columbus
1.3.4.7. SECURITY CREDENTIALS MANAGEMENT SYSTEM

Both OBU and RSU use the SCMS to make sure they are working with data from trusted sources. Each RSU manufacturer (Kapsch, Danlaw, and Siemens) defined a secure process for configuring and equipping the units with the necessary security credentials. All RSU messages are signed using an application certificate, which provides information on which messages the RSU is allowed to broadcast. Each unit went through a secure enrollment process with the SCMS.

Siemens OBU requires a secure process to configure and equip the device with the necessary security credentials in the Smart Columbus system. Each unit went through a secure enrollment process with the SCMS.

Siemens configured each OBU using the appropriate setup processes including generating the enrollment keys, submitting the enrollment keys to the SCMS, retrieving the initial certificates, and loading the initial certifications on the unit. Once the OBU is enrolled in the SCMS, the OBU security modules will automatically connect to the SCMS to request one year of pseudonym certificates.

1.3.4.8. TRANSIT CV MANAGEMENT SYSTEM

The Transit CV Management System, located on the COTA network, is essentially a repository for event and message log data collected on transit vehicle OBUs as part of the Transit Vehicle Interaction Event Recorder (TVIER) application. The COTA network contains a Wi-Fi antenna that allows transit vehicle OBUs to offload event log data. The logs are forwarded to a backend server, known as the DataLog, for subsequent processing. The DataLog server periodically scans the upload folder for transferred log files, and the DataLog server decodes uploaded files and converts content into text file format. The DataLogs are used by the COTA fleet manager to monitor the operation of the device. Once logfiles are offloaded to COTA, they are deleted from the OBU. Figure 4 shows the TVIER network data flow.

![Figure 4: Transit Vehicle Interaction Event Recorder Network Data Flow](Source: City of Columbus)

1.3.4.9. OPERATING SYSTEM

The Operating System receives and stores CV data, which includes Basic Safety Messages (BSMs) generated by the participating vehicles when they pass through the intersections of the Smart Columbus CVE corridors. This data is used to evaluate the Smart Columbus performance measures and to also provide other useful metrics to the City. Event data captured from OBUs installed in the transit fleet will also be available. Known as the TVIER, all revenue service vehicles capture a 20-second window around an event (10 seconds before and 10 after) and offload this data when the bus returns to the garage on a daily basis. It is then processed and uploaded to the Operating System.

1.3.5. Connected Vehicle Environment System Stakeholders

Stakeholders include the City of Columbus and numerous departments within the City, vehicle operators, the Operating System, other local government agencies, DriveOhio and ODOT, COTA, RSU and OBU contractors and integrators, and third-party users that are involved in and rely on the operation and maintenance of the CVE.
1.3.5.1. CITY OF COLUMBUS

The City of Columbus, through the Smart Columbus program, is the owner of the CVE project. The City of Columbus is also an owner and operator of most of the intersections where CV equipment is deployed. The following departments within the City of Columbus participate in the CVE project:

- **Smart Columbus Program Management Office (PMO):** The Smart Columbus PMO developed and maintained the Operating System as part of the USDOT Smart City Challenge through a contract with Accenture. The Operating System is the data platform at the heart of the Smart Columbus data environment that integrates data and data services from multiple sources, including the planned Smart Columbus projects, traditional transportation data, and data from other community partners. As described in the previous section on system components (Section 1.3.4), the Operating System not only collects data relevant to the CVE, but it also houses the model to predict red-light running, over-speed indications and others associated with the CVE performance measures.

- **City of Columbus Department of Public Service (DPS):** The DPS will manage the CVE deployment, configuration, and O&M. The DPS Division of Traffic Management identified and allowed signal preempt and priority requests, maintained signal controller operations, and reported any malfunctioning components within Columbus city limits. DPS and contractors developed network plans and other installation specifications to provide guidance to RSU installers. The DPS also manages a fleet of OBU-equipped vehicles, which includes both maintenance and construction inspection vehicles. DPS has also provided facilities to serve as installation location for onboard equipment.

- **The City of Columbus Police and the City of Columbus Division of Fire** each manage a fleet of emergency vehicles that are equipped with OBUs. Public safety agencies will benefit from shorter response times along the High Street, Cleveland Avenue, and Morse Road corridors, because emergency vehicles will receive signal preemption at these intersections. Each agency provided space for installing OBU equipment in identified emergency vehicles.

- **The Columbus Department of Development** provided fleet vehicles that included the Division of Code Enforcement to serve as participants in the CVE. These vehicles are fully equipped with the OBU and HUD, and support all LDV CV applications as noted in Table 2.

- **City of Columbus Department of Technology (DoT)** is responsible for maintaining the fiber infrastructure (backhaul that provides connectivity to equipment on the roadside) and the underlying network management systems. The CVE involves establishing an IPv6 network in parallel with the existing network used to provide network connectivity to the traffic signal system. If backhaul connectivity is compromised, the DoT will assist DPS to diagnose and repair any connectivity issues. The CVE is not expected to affect DoT staffing or responsibilities. The DoT will have a role in implementing and maintaining the portion of the CVE that starts with the communications equipment in cabinets and extends to the TMC, as well as for implementing and maintaining the City-wide MetroNet and access to the public internet for the CVE. The DoT role in the CVE project is similar to its current role in the CTSS. DoT staff will help verify that the equipment procured can meet City standard configurations, and will also provide programming, security, maintenance, and installation support.

1.3.5.2. OTHER LOCAL GOVERNMENT ENTITIES

For signalized intersections along the Alum Creek Drive corridor, the DPS coordinated efforts with the Village of Obetz, the Franklin County Engineer’s Office (FCEO), and ODOT District 6. Collectively, these agencies will manage the deployment, configuration, operations, and maintenance of the CV roadside equipment along this corridor. They are responsible for identifying and allowing for priority requests,
maintaining signal controller operations, and reporting any malfunctioning components to Smart Columbus staff.

1.3.5.3. CENTRAL OHIO TRANSIT AUTHORITY

COTA had an active role in the CVE design, because the OBU’s integrate with the existing vehicle communications network and the OBU event logs are transferred to a COTA-maintained repository. An agreement between the City and COTA allows onboard equipment (OBE) devices and applications to be installed and information from them to be collected and used. COTA provided space in its maintenance facility for installing OBU equipment in transit vehicles and is responsible for managing data in the Transit CV Management System. COTA will use data archived in the Transit CV Management Center, as part of the TVIER application, to assess the potential for providing safety warnings to drivers and to evaluate the use of CV technology to enable signal priority.

1.3.5.4. HEAVY-DUTY VEHICLE OWNER

ODW Logistics, operating as Dist-Trans, manages a fleet of HDVs that are equipped with OBU’s. ODW will benefit from shorter travel times along the Alum Creek corridor and Morse Road corridor (east of I-270), because HDVs will receive signal priority at these intersections. An agreement between the City and ODW allows OBE devices and applications to be installed and information from them to be collected and used. ODW provided space for installing OBU equipment in identified HDVs.

1.3.5.5. DRIVEOHIO AND OHIO DEPARTMENT OF TRANSPORTATION

DriveOhio is a collaboration between government, research institutions, and private industry partners to build Ohio’s infrastructure for smart mobility and to facilitate smart mobility innovations. Supported by ODOT, DriveOhio also works to ensure Ohio’s regulatory environment and public policies are conducive to developing the infrastructure and technologies needed for smart mobility.

While DriveOhio efforts are outside the scope of the CVE project, the CVE project established a working CV system in which additional infrastructure and CV applications can be developed and easily deployed. The CVE project leveraged DriveOhio’s future CV investments in the state as part of the overall CVE, described in the following list:

- SCMS – The SCMS is provided through a statewide contract with ISS/Green Hills. DriveOhio has the contract with SCMS and has authorized the City to purchase SCMS services (digital certificates). This ultimately allows integrators to enroll and receive initial certificates for pre-loading on CV devices.

- ODOT CV guidance – In November 2019, ODOT released general guidance on CV DSRC deployments to ensure interoperability among all existing and future CV projects within the state and (for a time) with US DOT CV Pilot projects.

- DSRC channel utilization – Messages used in V2V safety applications (BSM) are assigned to Channel 172, and messages used in other applications (signal phase and timing [SPaT], Map Data Message [MAP], Signal Request Message, Signal Status Message, Radio Technical Commission for Maritimes Services Corrections Message, Traveler Information Message [TIM], and Wireless Access in a Vehicle Environment [WAVE] service advertisement) are assigned to Channel 180.

- Certificates types, provider service identifiers, and service-specific permissions – Certificate types (enrollment, pseudonym, application) to be used in deployments and provider service identifiers and service-specific permissions.
1.3.5.6. VEHICLE OPERATORS
During the deployment phase, vehicle operators are responsible for confirming that messages to them are clear and unambiguous. The CVE project identified four vehicle operator categories:

- **LDV operator** – LDV operators are the primary beneficiary of CV technology installed on vehicles, because they will receive warnings to improve their awareness of potential crash-imminent situations. They received training on what each warning indicates, so they can act to avoid a potential crash. LDV operators are integral to evaluating system messages and determining whether they are clear, concise, unambiguous, and actionable. Further, LDV operators will indicate whether conflicting or repeated incorrect indicators are given. A usage agreement between the City and each private-vehicle owner for the OBU (and accompanying CV applications) stipulates the usage terms and conditions for the OBU installed in the operator's vehicle. Usage agreements with owners of fleet vehicles equipped with OBUs are covered under understandings and agreements between each fleet-managing agency (FCEO, the City of Columbus, and COTA).

- **Transit vehicle operator** – A small portion of transit vehicles (CMAX route only) are TSP-enabled1; however, no specific role is indicated because the system does not provide any driver warnings or alerts. Transit vehicles equipped with OBUs are covered under a usage agreement between COTA and the City.

- **Emergency vehicle operator** – While emergency vehicle operators do not receive notifications or warnings, they will benefit from preemption at equipped intersections on High Street, Cleveland Avenue, and Morse Road.

- **HDV operator** – While HDV operators will not receive notifications or warnings, they will benefit from signal priority at Alum Creek intersections and Morse Road intersections east of I-270. Operators of freight-signal priority-equipped vehicles provided comments on perceived improvement in efficiency when traversing enabled corridors. HDVs equipped with OBUs are covered under a usage agreement between ODW and the City.

1.3.5.7. SECURITY AND CREDENTIALS MANAGEMENT SYSTEM VENDOR
ISS/Green Hills contracts with DriveOhio to provide SCMS services for CV deployments in Ohio. The City of Columbus has been authorized to purchase SCMS services (digital certificates) for all devices to be deployed as part of the CVE. These certificates are provided to the integrators for pre-loading certificates on devices. ISS/Green Hills will provide certificate updates on request.

1.3.5.8. ONBOARD UNIT SYSTEM INTEGRATOR
The OBU system integrator is a team composed of Siemens, Brandmotion, and WNC. Collectively, this team is responsible for supplying, configuring, installing, testing, maintaining, as well as possibly removing (from private vehicles) the in-vehicle components of the CVE. Siemens is responsible for managing the overall OBU integrator contract, leading the engineering activities and coordinating with WNC (the OBU manufacturer) and other support subcontractors to ensure the OBU meets all requirements. Brandmotion is responsible for installing OBUs. An agreement between Brandmotion and a local automotive repair shop (2 Brothers Automotive) provided space for and staff to support installation of OBUs.

During the demonstration period, the OBU system integrator is responsible for providing a reliable way to update OBU firmware.

---

1 For these operators, priority requests are enabled, but will be automatically denied to allow the existing system to operate in parallel.
1.3.5.9. **ROADSIDE UNIT SYSTEM INTEGRATOR**

The RSU system integrator is a team composed of Kapsch, Danlaw, Econolite, and Path Master. The team is responsible for supplying, configuring, operating, and maintaining the network of nearly 85 DSRC-based RSUs for the CVE. The scope of work for the RSU system integrator included development of any software components necessary to fulfill the RSU functions, integrating with the Operating System for real-time data exchange, developing software necessary to provide the safety and mobility applications, connecting to and implementing the statewide SCMS, enabling Over-The-Air (OTA) updates for OBUs, and connecting to additional outside resources such as a position correction service or network time source. The RSU system integrator also provided a back-office system to monitor the health and status of all deployed RSUs and provided updates to RSU firmware. The back-office system includes log inspection, configuration, and security profiles. In addition, the RSU system integrator supported the necessary test activities developed by a separate third party and demonstrated that the infrastructure components meet all requirements.

1.3.5.10. **RSU INSTALLATION CONTRACTOR**

Gudenkauf Corporation is the installation contractor responsible for completing the construction and preliminary configuration of the CVE network. This includes all fiber-optic cable installation, termination panels and network cables. Gudenkauf installed all roadside infrastructure components (e.g., DSRC RSUs, power-over-Ethernet modules, GPS antennas and CVCPs) provided by the RSU system integrator.

The RSU installation contractor adhered to network plans developed by the City and its contractor, and had oversight provided by the DPS Division of Design and Construction.

1.3.5.11. **THIRD-PARTY USERS**

Third-party users are members of the public—including community organizations, researchers and entrepreneurs—who will have limited access to data that is generated by the CVE project through the Operating System.

1.4. **REFERENCES**

Table 3 includes a list of documents that can be referenced for the CVE project as well as for the creation of this CVE O&M Plan. The System Architecture and Standards Plan, contains the physical, enterprise and communications views for CVE, including a table of all information flows.

<table>
<thead>
<tr>
<th>Title</th>
<th>Revision</th>
<th>Publication Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onboard Unit Installation Guide – Light Duty Vehicles (Confidential)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Onboard Unit Installation Guide – Transit Duty Vehicles (Confidential)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Onboard Unit Installation Guide – Heavy Duty Vehicles (Confidential)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Onboard Unit Installation Guide – Emergency Vehicles (Confidential)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Onboard Unit – DriveOhio Installation Guide (Confidential)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Connected Vehicle Co-Processor User Guide</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Title</td>
<td>Revision</td>
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<tr>
<td>----------------------------------------------------------------------</td>
<td>----------</td>
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<tr>
<td>Connected Vehicle Co-Processor Setup Guide</td>
<td>N/A</td>
<td>N/A</td>
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<td>Connected Vehicle Co-Processor Support Guide</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Connected Mobility Control Center User Guide</td>
<td>N/A</td>
<td>N/A</td>
</tr>
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<td>Roadside Unit – Kapsch Administrator Manual</td>
<td>N/A</td>
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</tr>
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<td>Roadside Unit – Kapsch Integrators Manual</td>
<td>N/A</td>
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<tr>
<td>Roadside Unit - Danlaw User Guide</td>
<td>N/A</td>
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<td>Connet Layer 2 Switches – Installation and Operation Manual</td>
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<td><a href="https://www.comnet.net/site/assets/files/14740/cnge11fx3tx8ms_poe_ho_im.pdf">https://www.comnet.net/site/assets/files/14740/cnge11fx3tx8ms_poe_ho_im.pdf</a></td>
<td>Updated Report</td>
<td>May 14, 2021</td>
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<td>Cisco Layer 3 Switches – Configuration Guide</td>
<td>N/A</td>
<td>September 15, 2020</td>
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<td>Connected Vehicle Environment (CVE) System Requirements:</td>
<td>Updated Report</td>
<td>May 10, 2021</td>
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<td><a href="https://d2rfd3nxvhfnf29.cloudfront.net/2021-05/SCC-B-CVE-SyRS-UPDATE%205.20.21.PDF">https://d2rfd3nxvhfnf29.cloudfront.net/2021-05/SCC-B-CVE-SyRS-UPDATE%205.20.21.PDF</a></td>
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<tr>
<td>Connected Vehicle Environment (CVE) Interface Control Document</td>
<td>Updated Report</td>
<td>May 4, 2021</td>
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<td><a href="https://d2rfd3nxvhfnf29.cloudfront.net/2021-05/SCC-B-CVE-ICD-UPDATE%204.4.21.pdf">https://d2rfd3nxvhfnf29.cloudfront.net/2021-05/SCC-B-CVE-ICD-UPDATE%204.4.21.pdf</a></td>
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<td>Data Privacy Plan:</td>
<td>Updated Report</td>
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<td><a href="https://d2rfd3nxvhfnf29.cloudfront.net/2021-01/SCC-B-SASP-UPDATED_V2.pdf">https://d2rfd3nxvhfnf29.cloudfront.net/2021-01/SCC-B-SASP-UPDATED_V2.pdf</a></td>
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<tr>
<td>Smart Columbus Operating System Operations &amp; Maintenance Plan:</td>
<td>Final Report</td>
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<td><a href="https://d2rfd3nxvhfnf29.cloudfront.net/2020-06/SCC-B-SCOS-O%26M-Final-v1.pdf">https://d2rfd3nxvhfnf29.cloudfront.net/2020-06/SCC-B-SCOS-O%26M-Final-v1.pdf</a></td>
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<td>Human Use Approval Summary:</td>
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<td>Data Management Plan:</td>
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</table>

*Source: City of Columbus*
Chapter 2. Materials and Resources

This section identifies the personnel responsible for operating and maintaining the CVE and equipment/materials used for the CVE O&M. Table 4 provides a list of various CVE components and the organization that is responsible for operation and maintenance during and after the pilot period. For purposes of the CVE, three periods of responsibility have been defined:

- **The Demonstration Period**, which includes deployment, testing and operations under the Smart City cooperative agreement thru May 31, 2021.
- **Extended Support Period**, which begins at the conclusion of the Demonstration Period, and runs approximately 15 months, depending on the contract the City has with each provider.
- **Post-Support Period**, beginning at the end of the Extended Support Period, approximately July 2022. Renewal contracts may be issued to provide additional support pending the outcome of ongoing Federal Communications Commission rulemaking related to DSRC licensing.

Table 4. Connected Vehicle Environment System Stakeholder Responsibility Timeline

<table>
<thead>
<tr>
<th>CVE Component</th>
<th>Organization</th>
<th>Responsibility period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadside Units</td>
<td>Kapsch</td>
<td>Demonstration Period</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extended Support Period</td>
</tr>
<tr>
<td>Roadside Units</td>
<td>City of Columbus</td>
<td>Post-Support Period</td>
</tr>
<tr>
<td>Connected Vehicle Traffic Management System (CMCC)</td>
<td>Kapsch</td>
<td>Demonstration Period</td>
</tr>
<tr>
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<td>Extended Support Period</td>
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<tr>
<td>Connected Vehicle Traffic Management System (CMCC)</td>
<td>City of Columbus</td>
<td>Post-Support Period</td>
</tr>
<tr>
<td>Connected Vehicle Co-Processor</td>
<td>Path Master</td>
<td>Demonstration Period</td>
</tr>
<tr>
<td>Connected Vehicle Co-Processor</td>
<td>City of Columbus</td>
<td>Extended Support Period</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post-Support Period</td>
</tr>
<tr>
<td>Traffic-Signal Controllers</td>
<td>City of Columbus, FCEO, Village of Obetz, Ohio Department of Transportation</td>
<td>Demonstration Period</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extended Support Period</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post-Support Period</td>
</tr>
<tr>
<td>Onboard Units (Fleet Only)</td>
<td>Siemens</td>
<td>Demonstration Period</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extended Support Period</td>
</tr>
<tr>
<td>Onboard Units (Fleet Only)</td>
<td>City of Columbus</td>
<td>Post-Support Period</td>
</tr>
<tr>
<td>Onboard Units (Private)</td>
<td>Siemens</td>
<td>Demonstration Period</td>
</tr>
<tr>
<td>Transit CV Mgmt. System</td>
<td>Siemens / COTA</td>
<td>Demonstration Period</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extended Support Period</td>
</tr>
<tr>
<td>Transit CV Mgmt. System</td>
<td>COTA</td>
<td>Post-Support Period</td>
</tr>
<tr>
<td>CVE Component</td>
<td>Organization</td>
<td>Responsibility period</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Operating System</td>
<td>Smart Columbus</td>
<td>Demonstration Period</td>
</tr>
<tr>
<td>Operating System</td>
<td>City of Columbus</td>
<td>Extended Support Period</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post-Support Period</td>
</tr>
</tbody>
</table>

Source: City of Columbus

2.1. PERSONNEL

Table 5 lists personnel, their positions, key functions, and the percentage of time dedicated to CVE O&M, if not full time, as defined during the Demonstration Period. Table 6 lists the same information but is focused on personnel who are involved during the planned post-demonstration support period. These tables will be reviewed for any needed revisions based on a known change in a named individual at the end of the demonstration.

Table 5. Connected Vehicle Environment Personnel Involved During Demonstration

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
<th>Key Functions</th>
<th>Commitment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Columbus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ryan Bollo</td>
<td>Project Manager</td>
<td>Project oversight and coordination with all stakeholders</td>
<td>75%</td>
</tr>
<tr>
<td>Mark Stephenoff</td>
<td>Traffic Operations</td>
<td>Traffic Management Center Manager, Traffic Signal System timing</td>
<td>15%</td>
</tr>
<tr>
<td>Alyssa Chenault</td>
<td>Communications Lead</td>
<td>Communications</td>
<td>20%</td>
</tr>
<tr>
<td>Kapsch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vivian Raines</td>
<td>Integrator Project Manager</td>
<td>Primary interface with City of Columbus Manage team assets</td>
<td>25%</td>
</tr>
<tr>
<td>Paul Hill</td>
<td>Network Engineer</td>
<td>Device configuration and troubleshooting</td>
<td>25%</td>
</tr>
<tr>
<td>Sara Khosravi</td>
<td>Developer</td>
<td>Testing, troubleshooting and firmware upgrade</td>
<td>20%</td>
</tr>
<tr>
<td>Siemens</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Venkateshawar Jadhav</td>
<td>Integrator Project Manager</td>
<td>Primary interface with City of Columbus Manage team assets</td>
<td>40%</td>
</tr>
<tr>
<td>Maulikbhai Patel</td>
<td>Support Engineer</td>
<td>Device configuration and troubleshooting</td>
<td>25%</td>
</tr>
<tr>
<td>Wolfgang Buckel</td>
<td>Support Engineer</td>
<td>Device configuration and troubleshooting</td>
<td>10%</td>
</tr>
<tr>
<td>Brand Motion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joel Hoffman</td>
<td>Installation Manager</td>
<td>Manage Onboard Unit installation</td>
<td>75%</td>
</tr>
</tbody>
</table>
### Chapter 2. Materials and Resources

#### Table 6. Connected Vehicle Environment Personnel Post-Demonstration Support

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
<th>Key Functions</th>
<th>Commitment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>City of Columbus</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ryan Bollo</td>
<td>Project Manager</td>
<td>Project oversight and coordination with all stakeholders</td>
<td>25%</td>
</tr>
<tr>
<td>Mark Stephenoff</td>
<td>Traffic Operations</td>
<td>Traffic Management Center Manager, Traffic Signal System timing</td>
<td>10%</td>
</tr>
<tr>
<td><strong>Kapsch</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Name | Role | Key Functions | Commitment (%)
---|---|---|---
Vivian Raines | Integrator PM | Primary interface with City of Columbus, manage team assets | On-Call
Paul Hill | Network Engineer | Device configuration and troubleshooting | On-Call
Sara Khosravi | Developer | Testing, troubleshooting and firmware upgrade | On-Call

**Siemens**

Venkateshawar Jadhav | Integrator PM | Primary interface with City of Columbus, manage team assets | On-Call
Maulikbhai Patel | Support Engineer | Device configuration and troubleshooting | On-Call

**Brand Motion**

John Sandlin | Lead Installer | Trainer, installer | On-Call

**Accenture**

Timothy Regan | Developer | Develop algorithms and visualization to support performance measures and other dashboard elements | 25%

*Source: City of Columbus*

## 2.2. EQUIPMENT, SOFTWARE AND MATERIALS

This section discusses the operating equipment, software, and other computing facilities used for operating the CVE.

### 2.2.1. Equipment

The CVE comprises roadside, in-vehicle and back-office components as documented in Section 1.3.4. Several of the items are physical assets, owned by the City, partners or stakeholders. Other equipment resides on hosted services (i.e., cloud-based). The City does not have any direct responsibility for the equipment providing the hosted services, as they are part of contracted services with the respective vendor.

Physical devices that fail will be replaced following the guidance offered in this plan and corresponding vendor documentation. If the device remains under warranty, it will subsequently be replaced. Devices for which the City maintains spare equipment for immediate replacement will be used as available. This includes RSUs from all three vendors, OBUs, and Econolite CVCPs. Any failed device would be replaced under warranty.

The Econolite Cobalt signal controllers are part of normal inventory, and as such, needed replacements will be sourced from general inventory and not Smart Columbus specific resources. Likewise, the County maintains both Siemens and Econolite controllers as required for replacement at intersections they maintain.
The City maintains the computer equipment which hosts Centracs under a coordinated effort between the DPS and the DoT. Repair or replacement of that system is outside of the scope of the CVE project.

Cloud services used by the CVE—such as the SCMS, the CMCC, and the Operating System—are the responsibility of a third party not directly affiliated with the CVE.

2.2.2. **Costs**

Table 7 and Table 8 provide recurring costs and the party responsible for each cost related to the project’s O&M during and after the demonstration.

**Table 7. Recurring and Support Costs During Demonstration**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
<th>Responsible Party</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT&amp;T IPv6 Internet Service</td>
<td>$150 / month</td>
<td>City of Columbus</td>
<td>Required to access external resources, such as the SCMS</td>
</tr>
<tr>
<td>SCMS Certificates (IEEE 1609.2)</td>
<td>$10 / OBU annually</td>
<td>DriveOhio</td>
<td>Annual fee covered by DriveOhio for first two years</td>
</tr>
<tr>
<td></td>
<td>$60 / RSU annually</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrator Support</td>
<td>Part of integrator contract</td>
<td>Kapsch, Siemens</td>
<td></td>
</tr>
</tbody>
</table>

*Source: City of Columbus*

**Table 8. Recurring and Support Costs After Demonstration**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
<th>Responsible Party</th>
<th>Comments</th>
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<tr>
<td>AT&amp;T IPv6 Internet Service</td>
<td>$150 / month</td>
<td>City of Columbus</td>
<td>Required to access external resources, such as the SCMS</td>
</tr>
<tr>
<td>SCMS Certificates (IEEE 1609.2)</td>
<td>$10 / OBU annually</td>
<td>City of Columbus</td>
<td>Columbus assume cost beginning in 2021</td>
</tr>
<tr>
<td></td>
<td>$60 / RSU annually</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSU Support</td>
<td>$150,000</td>
<td>Kapsch</td>
<td>15 month period starting May 2021 thru July 31, 2022</td>
</tr>
<tr>
<td>OBU Support</td>
<td>$160,000 / year</td>
<td>Siemens</td>
<td>Starting June 2021 thru August 30, 2022</td>
</tr>
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</table>

*Source: City of Columbus*

2.3. **TRAINING**

2.3.1. **Vehicle Operator Training**

2.3.1.1. **PRIVATE DRIVERS**

The participants watched a video providing training on the equipment being installed. The registrar/trainer was available to answer questions from the participant in the use of the OBU while the OBU was installed in
the vehicle. The participant training was conducted primarily by video for consistency followed by trainer Q&A during the installation process. The training covered was:

- CV 101 – CV User-Oriented Fundamentals
- USDOT CV program background
- Smart Columbus Demonstration Deployment background
- Functions of the OBU and apps
- Participant communication
- Safety – Once again, driver responsibility to control the vehicle at all times
- Questions

The participant training included two videos; reviewing the Institutional Review Board (IRB)-approved Informed Consent document and use of the equipment, an informational packet, user manual and wallet card. Participants were also provided with additional information via the columbusconnectedcars.com website including how to contact the principal investigator for support. CVE project staff conducting the training received human subjects research training.

2.3.1.2. CITY OF COLUMBUS

Training was provided to DPS and Columbus Department of Development drivers for familiarization with the equipment and safety reporting procedures. This training was provided through the City of Columbus’ existing training gateway, an online portal, by which the participants will have access to a training module specific for the CVE project. In this module, participants were shown two recorded videos. The first video covers the Informed Consent document. At the conclusion of this video, participants were then presented with the written Informed Consent document to review, and the training concluded with a prompt for participants to contact the Principal Investigator with questions before virtually providing consent. Following the participant providing virtual consent, the training module then provided a second video, which provided equipment training. At the conclusion of the second video, participants were provided with a link to download the user manual. The City’s training gateway tracks who completes the training.

2.3.1.3. PRIVATE FREIGHT OPERATOR (DIST-TRANS CO., LLC [ODW LOGISTICS])

Training was provided to Private Freight Operators via two training videos distributed through their manager(s). The Principal Investigator provided a step-by-step instruction sheet for distributing the videos, getting any questions answered, and obtaining verbal consent. At the conclusion of the training, these participants were also provided with a user manual.

2.3.1.4. FRANKLIN COUNTY

Training was provided to Franklin County drivers via two training videos distributed through their manager(s). The Principal Investigator provided a step-by-step instruction sheet for distributing the videos, getting any questions answered, and obtaining verbal consent. At the conclusion of the training, these participants were also provided with a user manual.

2.3.1.5. CENTRAL OHIO TRANSIT AUTHORITY BUS AND PARATRANSIT OPERATORS AND MANAGERS

As a stakeholder and the owner and operator of the regional transit system and fleet vehicles, COTA is a key CVE participant. COTA employees who will operate equipped vehicles are outlined below:
• Bus drivers (OBU only, no HUD)
• Paratransit drivers (OBU only, no HUD)
• Managers (OBU and HUD)

Training was provided to COTA drivers via two training videos distributed through their manager(s). The Principal Investigator provided a step-by-step instruction sheet for distributing the videos, getting any questions answered, and obtaining verbal consent. At the conclusion of the training, these participants were also provided with a user manual.

2.3.2. Roadside Units Operations and Maintenance Training

Kapsch has provided a series of training presentations related to their overall CV ecosystem and product offerings, found in Table 9. These materials were not customized specific to Smart Columbus, and as such, they do contain information related to a few products and services that are not used by Smart Columbus. They do however cover items deployed by the City. Specifically, Columbus implements the RIS-8160 RSU, CMCC and the Connected Vehicle Validator absent the Omnisight feature. Any reference to a Kapsch OBU other than as part of the Connected Vehicle Validator, or the Omnisight Cloud Services, are not part of the Smart Columbus toolkit.

Table 9: Training Materials

<table>
<thead>
<tr>
<th>Module</th>
<th>Description</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connected Vehicle (CV) Introduction</td>
<td>The basics on what makes up connected vehicle systems and solutions including an overview of the CV products</td>
<td>45 minutes</td>
</tr>
<tr>
<td>CV Messaging</td>
<td>An overview of the messages used for connected vehicles</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Connected Mobility Control Center (CMCC) Introduction</td>
<td>An overview on using the CMCC</td>
<td>30 minutes</td>
</tr>
<tr>
<td>CMCC Locations, Devices and Messages</td>
<td>Setting up the network using CMCC</td>
<td>60 minutes</td>
</tr>
<tr>
<td>CMCC Administration</td>
<td>How to be a CMCC Administrator</td>
<td>20 minutes</td>
</tr>
<tr>
<td>CMCC Operations</td>
<td>Monitoring and troubleshooting the system using CMCC</td>
<td>30 minutes</td>
</tr>
<tr>
<td>CV Validator Operations</td>
<td>Setting up and Using the CV Validator</td>
<td>45 minutes</td>
</tr>
<tr>
<td>Roadside Unit (RSU) Introduction &amp; Setup</td>
<td>Preparing the RSU for installation</td>
<td>45 minutes</td>
</tr>
<tr>
<td>RSU Installation</td>
<td>Mounting the RSU at the roadside</td>
<td>30 minutes</td>
</tr>
<tr>
<td>RSU Verification</td>
<td>How to verify the RSU Installation</td>
<td>30 minutes</td>
</tr>
</tbody>
</table>

Source: City of Columbus

Siemens and Danlaw did not provide any specific training materials as the integration elements were performed by Siemens and Kapsch directly; however, both did provide User Guides, as indicated in the list of references.
2.3.3. Onboard Unit Operations and Maintenance Training

The Smart Columbus contract with the OBU Systems Integrator required three distinct deliverables to support OBU installation. These deliverables included an OBU Unit Preparation Guide—which describes the bench configuration process—Installation Guides (per vehicle class) and Installation Checklists (again per vehicle class). Collectively, these items comprise the major steps necessary to configure, install, and confirm proper installation and operation of the onboard equipment. This includes the physical OBU, the antenna, and the wiring harness—with all vehicle connections, and as applicable, the HUD. These guides and checklist, available in final form, are maintained in the Smart Columbus archives. These guides assume a general understanding of automotive electronics and use of both tools and a computer. The original OBU installation team was staffed by experienced installers, who subsequently trained other installers. No City staff were trained to install onboard equipment as part of Smart Columbus.

The list of guides and corresponding checklists include:

- OBU Installation Guide – Emergency Vehicle (covers both Fire and Police)
- OBU Installation Guide – Heavy Duty Vehicles
- OBU Installation Guide – Light Duty Vehicles
- OBU Installation Guide – Transit Duty Vehicle
- OBU Installation Checklist – Emergency Vehicle
- OBU Installation Checklist – Heavy Duty Vehicle
- OBU Installation Checklist – Light Duty Vehicle (Paratransit Only)
- OBU Installation Checklist – Light Duty Vehicle
- OBU Installation Checklist – Transit Vehicle (CMAX Only)
- OBU Installation Checklist – Transit Vehicle
- OBU Unit Preparation Procedures

DriveOhio under a separate contract with Brandmotion, the firm which installed OBUs for Smart Columbus, funded a general OBU installation and training guide intended to train and serve as reference for ODOT maintenance staff. As a partner with Smart Columbus, DriveOhio will make the final version of this guide available to the City.

2.3.4. Traffic Controllers

No specific training for traffic controller integration was provided outside of what was needed to install the CVCP, which is discussed in the subsequent section.

2.3.5. CVCP

Econolite provided a training module in the form of a detailed presentation. Further, the CVCP also included a User Guide (with Errata), a Support Guide, a Setup Diagram, and procedures for installing / configuring the Operating System.

2.3.6. Networking Equipment

No training was performed in relationship to the networking equipment.
Chapter 3. Operations

This section provides an overview of the policies and high-level procedures governing the operation of the CVE. It is intended to govern all operations as described in the Concept of Operations and the activities necessary to achieve the project objectives. It also serves as a guide for addressing and resolving issues that may arise regarding the roadside and in-vehicle equipment deployed by the City of Columbus and data collection by the Operating System.

### 3.1. CONNECTED VEHICLE ENVIRONMENT OPERATIONAL ACTIVITIES

During normal operations of the CVE, all devices—both roadside and onboard—are fully enabled, communicating between vehicles and between vehicles and infrastructure with all indicated applications enabled. Further, all messages sent or received by the RSUs, including signal phase and timing (SPaT), MAP, Signal Status Message, Signal Request Message, and any BSMs received by an RSU are forwarded to the Operating System. There are no time-of-day restrictions or scheduled downtime periods for the system. RSUs are expected to renew certificates on a weekly basis and OBUs to renew weekly or annually, depending on the type of certificate loaded. Once deployed and active, there are no associations between an OBU and a participant (public or private) and as such, all subsequent OBU firmware updates are conducted strictly via DSRC-enabled over-the-air updates.

Unlike other CV Pilots, no OBU event logs or similar data are collected from OBUs, either over-the-air or in any other manner, the exception being event logs captured by the equipped transit fleet operated by COTA.

The following describes the typical system performance monitoring / operational activities and troubleshooting activities related to the CVE. It is organized by the three major elements of the CVE: In-Vehicle Systems, Infrastructure Components (including the network and RSU), and the Operating System.

#### 3.1.1. In-Vehicle Equipment

Smart Columbus OBUs either include an HMI (in the form of a HUD), or do not include an HMI. All private LDVs include a HUD. The mix of public and private-fleet vehicles consists of both HUD-equipped and those without. COTA fixed-route transit buses, which are not HUD-equipped, capture and download OBU-based events—the only vehicle class configured as such. Performance monitoring and troubleshooting vary for each of these three configurations, as detailed below.

##### 3.1.1.1. HEADS-UP DISPLAY EQUIPPED

Over 311 CV-equipped LDVs are owned and operated by private individuals participating in the Smart Columbus program per the Informed Consent Agreement. As indicated in Section 2.3, each participant is trained regarding the operation of the connected vehicle equipment, specifically the HUD and its alerts and warnings. Each participant understands and has signed a participant agreement. Similarly, an additional 250 public-sector fleet vehicles are equipped with a HUD and receive the same warnings and indicators as the private participants. All participants are trained to identify correct HUD operation and how to report defective or malfunctioning HUD. The HUD display shows a startup screen with current firmware, along with an audible tone, which indicates that the device is operational. Occasionally, the HUD may display indications that the device is in the firmware update process. Once this process has completed and the OBU has been restarted via the normal ignition off / ignition on cycle, the device should again display the Smart Columbus startup screen. If at any time the vehicle operator observes that the startup screen and tone are not
occurring, they should contact Smart Columbus. It should be noted that certain update functions may take several minutes and that repeatedly and quickly cycling power to the device may not result in the indicated startup screen. In this case, the operator should wait at least 5 minutes before cycling power. After startup, once the device is operational, there are no immediate indicators on the screen that the device is functioning. This was intentional to avoid any unnecessary distraction to the driver. Only driver warning messages generated by the CV applications display, and only when appropriate. No other performance monitoring or troubleshooting steps are necessary or warranted for HUD-equipped vehicles.

3.1.1.2. CV-EQUIPPED VEHICLES WITHOUT A HUD
The remainder of CV-equipped vehicles—including fire, police, and COTA fixed-route transit and paratransit vehicles—are equipped with the CV onboard unit and antenna, but they do not have a HUD. Operators of these vehicles do not receive any indication of proper device operations and as such, performance monitoring and troubleshooting are not prescribed for the operators.

The approximately 330 COTA revenue service vehicles that implement the TVIER application are configured to capture events and messages in onboard logs and to upload those logs to a COTA-hosted server when the vehicle returns to the maintenance facility (garage) at night. The output of the TVIER download indicates specific vehicle information and can be used to determine if a vehicle is generating and reacting to CV messages. COTA operations staff determine if any OBU is not reporting (uploading) on a regular basis (or if the events/messages logged are atypical), and in turn, contact Smart Columbus for possible remedy.

3.1.2. Infrastructure Components
The items that were installed to support the build out Smart Columbus include the RSU and related power supply, the CVCP, Layer 2 network switches installed in each signal cabinet, fiber patch-panels and necessary Cat5e Ethernet, and 24-strand fiber-optic drop cables. Layer 3 switches were installed at strategically placed communications cabinets. Smart Columbus also leverages the existing traffic-signal controller and unused fiber to complete the CVE. Performance monitoring and troubleshooting vary for each of these components, as detailed below.

3.1.2.1. ROADSIDE UNIT
RSUs are designed to continuously broadcast and receive CV messages around the clock, with no planned downtime. They also interact with other infrastructure components to fulfill the complete Operational Design Domain (ODD) of the CVE. Details of the RSU’s role can be found in other Smart Columbus documents.

RSUs are programmable, fully automated devices, requiring no normal human intervention to perform their intended functions. They have features to maintain the accuracy of their system clock, to refresh the security certificates they utilize, to maintain system memory by purging older logs, and other features required to fulfill their ODD. However, as indicated below, it is highly recommended that the RSUs be monitored for any potential issues.

The City of Columbus DPS, Division of Traffic Management is responsible for operating RSUs and associated equipment. This function is performed specifically by Traffic Operations staff and is monitored primarily using an enhanced version of the Econolite’s Centracs Advanced Traffic Management System. Centracs is typically used to monitor and manage the City’s inventory of traffic-signal controllers, but as part of the Smart Columbus program, a version of Centracs was created that adds alert monitoring for RSUs. RSUs that are experiencing operational issues will be reported in the warning panels available in Centracs (see example in Figure 5). Operations staff have been trained to identify and respond to these alerts, details of which are described in the maintenance section.
In the case where an alert is indicated, Operations staff should then use CMCC to investigate the operational state of the overall CVE, which includes the RSU, CVCP and the Traffic-Signal Controller (TSC).

Performance monitoring is performed by accessing the CMCC software and ensuring that all systems show as green. To further check operations, it is recommended that the operator select random locations from the list of equipped locations and invoke the “Monitor” feature, which if functioning correctly, will show the intersection geometry and signal status. Figure 6 shows the screen view with all RSUs operating. The monitor button is also indicated. City staff have been trained on the major features of CMCC, and detailed training is available as noted in Section 2.3. Detailed steps for the use of CMCC are included in the Maintenance portion of this plan.
3.1.2.2. CONNECTED VEHICLE CO-PROCESSOR

Similar to the RSU, the CVCP is designed to continuously operate with no user intervention, providing the interface between the TSC and the RSU (aka message handler), as well as providing the location for hosting the CMCC client software, which is the interface that allows for SNMP management of the RSU. CVCP communication status is available thru the CMCC interface, while any other communication requires a direct connection via PuTTY or similar terminal emulator. Troubleshooting is limited to rebooting the device remotely, else it may require a manual reset, which requires physical access to the device in the cabinet.

3.1.2.3. TRAFFIC-SIGNAL CONTROLLER (TSC)

TSCs are the source of the SPaT information broadcast by RSUs at equipped locations. TSCs are designed to be fully automated, executing the pre-set timing patterns based on the time of day and other parameters. These functions are monitored by traffic operations staff using Centracs. Operations staff also have the ability to override current timing plans in instances where a plan change is necessary. This is also done remotely via Centracs. The CVE will automatically react to the change in signal timing and broadcast the revised SPaT. No additional requirements on the part of the Traffic Operations staff are necessary to enable the Layer 2 network switch.

Layer 2 network switches are installed in each controller cabinet and are connected to both the dedicated CVE fiber, as well as the CVCP and the RSU. No recurring user intervention is required for the Layer 2 switch. Traffic Operations staff are familiar with accessing these switch devices when a remote reboot is possible. Issues requiring further action are deferred to the DoT.

3.1.2.4. LAYER 3 NETWORK SWITCH

Layer 3 network switches are installed in strategically placed communications cabinets, interfacing typically between 12 signal-controller cabinets. These Layer 3 switches serve to connect each group of controller cabinets to the primary fiber network and ultimately to the TMC. No recurring user intervention is required for the Layer 2 switch. Traffic Operations staff are familiar with accessing these switch devices when a remote reboot is possible. Issues requiring further action are deferred to the DoT.
3.1.2.5. **INTERNET SERVICES**

The CVE is connected to dual-band IPv4/IPv6 internet service provided by AT&T. This is a dedicated service specific to the CVE. It is used to connect to the CMCC cloud services, the SCMS, and the OBU over-the-air update server. Outages are reported directly to AT&T by DPS staff.

3.1.2.6. **CONNECTED VEHICLE TRAFFIC MANAGEMENT SYSTEM (CMCC)**

The Connected Vehicle Traffic Management System is fulfilled by the Kapsch CMCC cloud-based system. CMCC allows for health and status monitoring of the CVE, device configuration, message assignment (MAP and TIM) and various reporting. As indicted for the RSU, operations personnel should regularly check the status of the CVE by reviewing CMCC and monitoring various devices.

3.1.2.7. **SECURITY CREDENTIAL MANAGEMENT SYSTEM**

Electronic security certificates are being provided by ISS/Greenhills under an agreement with DriveOhio and their statewide SCMS contract. No recurring-user intervention is required for this service. Once a device (RSU or OBU) is enrolled, it will automatically connect to the SCMS, via the IPv6 internet service to renew the certificate on the indicated frequency. No documented troubleshooting steps are related to the SCMS other than to work with the OBU and RSU integrator, along with ISS.

3.1.2.8. **OVER-THE-AIR UPDATE SERVICE**

OBUs have a built-in feature to check if applicable device firmware updates are available on the vendor hosted update service. No recurring user intervention is required for this service. New, tested versions of any firmware are placed on the service (after approval by the City), and OBUs receive these updates via a DSRC connection. Siemens has the ability to report the number and OBU serial numbers that have received the update. There is no process to match serial numbers with vehicles, and as such, no process is in place to notify vehicle operators of the updates. No future process is expected.

3.1.3. **Operating System**

The Operating System is the cloud-based, dynamic, governed, data-delivery platform. It is designed to ingest and disseminate data from external systems for processing via a microservices architecture. The Operating System also serves as the source for real-time operational data and archived historical data from a combination of data storage sources for use by the City and third-party applications/developers.

3.1.3.1. **DATA ON THE OPERATING SYSTEM**

For the purposes of the CVE project, the following datasets are captured by the Operating System:

- CVE Operational Data
- TVIER Data

The first dataset presents information about the messages generated by the participating vehicles when they pass through the intersections of the Smart Columbus CVE corridors as well as messages generated by the infrastructure and broadcast by RSUs. This includes SPaT, MAP, TIMs, Signal Request Messages, and SSMs.

*Table 10* lists the data dictionaries for the CVE message datasets.
Table 10. Data Dictionary for Connected Vehicle Environmental Messages

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>messageBody</td>
<td>json</td>
<td>This field presents information about the contents of Basic Safety Messages (BSMs) received by Roadside Units (RSUs) from participating vehicle Onboard Units (OBUs). Contents include speed, heading, traction, yaw, braking, location coordinates, and message size.</td>
</tr>
<tr>
<td>messageType</td>
<td>string</td>
<td>Type of message received by the RSUs. Only BSMs were collected as part of this project.</td>
</tr>
<tr>
<td>sourceDevice</td>
<td>string</td>
<td>Name of the OBU that transmitted the BSM.</td>
</tr>
<tr>
<td>Timestamp</td>
<td>string</td>
<td>Timestamp at which the BSM was received by the OBU. The maximum expected latency for message transmission is 100 milliseconds.</td>
</tr>
</tbody>
</table>

Source: City of Columbus

The second dataset includes CV application event data recorded on and downloaded from the OBUs installed in COTA revenue-service vehicles. This dataset includes both information about the actual CV application event (Forward Collision Warning Application, Emergency Electronic Brake Light Application, Red Light Violation Warning Application) as well as messages sent/received by the OBU for a configurable time period before and after the events.

Table 11 lists the data dictionaries for the CVE message datasets.

Table 11. Data Dictionary for Transit Vehicle Interaction Event Recorder Event Logs

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>messageBody</td>
<td>json</td>
<td>This field presents information about the contents of Basic Safety Messages (BSMs) received by Roadside Units (RSUs) from participating vehicle Onboard Units (OBUs). Contents include speed, heading, traction, yaw, braking, location coordinates, and message size.</td>
</tr>
<tr>
<td>messageType</td>
<td>string</td>
<td>Type of message received by the RSUs. Only BSMs were collected as part of this project.</td>
</tr>
<tr>
<td>sourceDevice</td>
<td>string</td>
<td>Name of the OBU that transmitted the BSM.</td>
</tr>
<tr>
<td>Timestamp</td>
<td>string</td>
<td>Timestamp at which the BSM was received by the OBU. The maximum expected latency for message transmission is 100 milliseconds.</td>
</tr>
</tbody>
</table>

Source: City of Columbus

3.2. HOURS OF OPERATION

3.2.1. Technical Support

3.2.1.1. PARTICIPANT SUPPORT

Participants will have contact with the Smart Columbus PMO and the CVE project team through a website, which will offer an online support form, and email and phone contact information to schedule appointments,
and report equipment or application problems or any traffic mishaps that may occur. The link to this site is www.columbusconnectedcars.com.

### 3.2.1.2. OPERATING SYSTEM TECHNICAL SUPPORT

Technical support pertaining to accessing the publicly available data on the Operating System (https://www.smartcolumbusos.com/) can be reached through the web via the link at https://www.smartcolumbusos.com/contact-us.

The following information is required in the correspondence:

- Contact name and organization
- Email
- Subject (Tech Help/Request)
- Message
- Verification (reCAPTCHA)

### 3.3. DATA COLLECTION AND PRIVACY

This section covers the data collected as part of the CVE project as well as by the Operating System, outlining how data is collected, stored, and protected. This section is broken out into subsections for each of these entities.

Data security refers to the tools, policies, practices, and procedures used to protect data from being accessed, manipulated, or destroyed, or being leveraged by those with a malicious intent or those who are unauthorized to do so. Data privacy is the reasonable expectation that data of a sensitive nature will be kept confidential, sanitized and/or encrypted, and respectfully and responsibly maintained by all users, managers, and collectors of the data, while adhering to applicable laws, regulations, policies, and procedures.

With regards to data privacy, while the Data Privacy Plan provides overarching guidance for every project on privacy and security controls for data within the overall Smart Columbus program, detailed information on privacy and security controls for the CVE project will be implemented as necessary.

#### 3.3.1. Connected Vehicle Environment Project Data

The CVE project will collect and generate a variety of data, falling into two categories:

- Application data (such as the warnings and alerts generated by the devices)
- Device data (from both the vehicle and RSUs)

##### 3.3.1.1. APPLICATION DATA

Personal information collected in the CVE project will be kept to the minimum necessary for the system to function effectively. Data collected by the V2X communication system as described in the CVE project Concept of Operations will not contain Personally Identifiable Information (PII) or PII-related data. All V2V and V2I communications are designed using the Institute for Electrical and Electronics Engineers (IEEE) 1609.2 standard to provide communications security and protect user privacy. CV application data consists of Society of Automotive Engineers J2735 messages that are produced but not stored by the CVE.

Vehicle OBUs send out a BSM every tenth of a second over DSRC, which are one-way or two-way short-range to medium-range (about 1 kilometer) wireless communication channels specifically designed for
automotive use and with its own protocols and standards. Briefly, the BSM safety V2V core data elements consist of time, position, speed, heading, acceleration, braking system status, and vehicle size. The data within the BSM does not include information on the vehicle owner/operator, make/model, license plate, or vehicle identification number.

3.3.1.1 Data Storage

There is no PII or PII-related data that is connected through the vehicle OBUs and RSUs. First, no device in the field, either OBU or RSU, stores any data; rather, the data is used/consumed and then forwarded. The OBU does not log or archive the messages that are sent. Likewise, if an OBU sees another OBU and receives a BSM, it processes the message, reacts, and then discards. Again, the OBU neither logs nor stores any information. In the case of the Columbus CVE Project, TVIER creates a log of all transit vehicle interactions. These event logs are stored temporarily on the OBU and will be downloaded later for use by the agency. For these transit vehicles, data scrubbing/obfuscation routines will be implemented as necessary pending recurring data privacy audits.

3.3.1.2.1 DEVICE DATA

Aside from the messages and alerts/warnings generated by the CV applications, the CV devices (OBU and RSU) that produce and forward this information are also protected by a hardware security module. This module is a physical computing device that safeguards and manages digital keys for authentication. The CVE project design also indicates tamper indications in the form of a warranty seal. This is not an active disabling circuit. The current CVE design also includes preliminary plans for cabinet opening and network monitoring as well, and these details can also be provided with a future protocol submission.

3.3.1.2 Data Storage

As mentioned in Section 3.3.1.1.1, there is no PII or PII-related data that is collected or stored from the devices.

3.3.2 Data Privacy

The Smart Columbus Data Privacy Plan provides an overarching framework for the ways in which Smart Columbus will protect the security of personal information that it collects and uses, and the privacy of the individuals to whom this information pertains. Smart Columbus is committed to being a responsible steward of this personal information. The Data Privacy Plan applies to all individuals who use or share data with Smart Columbus, including all Smart Columbus employees, partners, independent evaluators and consultants. Where applicable, contract and other acquisition-related documents include terms providing for compliance with the requirements of the Data Privacy Plan.

Title 49, Code of Federal Regulations (CFR), Part 11 codifies the USDOT-adopted Common Rule, which provides guidance on defining when a project falls under the rule, and associated requirements, for approvals, oversight, and IRB involvement. Because Smart Columbus is federally funded and involves the use of participants, approval of human use by an IRB is required.

Documents for submission to the IRB were developed for the CVE project and include the participant recruitment plan, Informed Consent document, training plans and materials, and ongoing amendments as needed, in addition to this research protocol. A Human Use Approval Summary report was delivered to USDOT covering the entirety of the ongoing IRB process. The Smart Columbus PMO and the CVE project team understands that IRB approval is subject to continuing and periodic review as progress advances past concept development and into the details of recruitment, screening, registration, PII and sensitive PII (SPII) data storage, training, and message sharing with participants. Treatment of Smart Columbus participant
data, especially of vulnerable populations, will depend on project provisions revealed through the IRB process and review of this protocol and future submissions. The CVE project team will submit periodic updates to the IRB to revise the project-specific research protocol documents and informed consent documents as the Smart Columbus demonstration progresses. In the context of data privacy, participant PII and SPII data integrity and storage are of interest.

3.3.2.1. PROTECTING PII

The protection of PII is crucial for capturing the trust of system users who wish to maintain their privacy. The use of the SCMS ensures that messages are valid, however does not necessarily protect them from being read. While a single message is not considered PII, it could be possible to reconstruct a trip from a group of messages that could lead to identification of an individual and their whereabouts. Such circumstances exist when there are few vehicles on the roadway, or certain patterns exist in messages, allowing specialized pattern recognition software to distinguish between individuals in a group. However, some degree of effort or knowledge would also be required to acquire and process this data. Data that is collected as part of the CVE must not be able to be used for or against an individual.

A data strategy (detailed in the Data Management Plan) was implemented to specify how message data should be treated to preserve anonymity while supporting safety and mobility applications. This could be as simple as removing any identifying features, increasing or decreasing the frequency with which data from a particular area is stored, or aggregating the data spatially and temporally to obfuscate individual users. If it is found that processing of this nature is required to preserve PII, it is expected to be performed outside of the Operating System by a vendor/supplier or member of the core CVE project team.

3.3.2.2. PRIVACY AND DATA SECURITY

The CVE project data is collected and stored in the Operating System for system operation purposes; participant registration data will NOT be provided to or stored in the Operating System. It is against the policy of such agencies to retain information that could be used to identify individuals, although there are no regulations precluding the collection of such information for internal (system) use only. Further, stakeholders identified privacy as a concern during outreach. Data collected from the CVE is expected to be used for research, which, as a general matter, could result in publication. IRB approval may be necessary for the use of data that could compromise an individual’s ability to remain anonymous in these research projects. Policy regarding the use of human subject data for research is specified in the CFR Title 49, Part 11.²

One concern that users of the CVE may have is the potential use of data gathered from onboard equipment systems as evidence in a legal matter. This concern was raised during the Linden outreach activities. Specifically, there were concerns that warnings from the CV system could be used for enforcement purposes. To alleviate this concern, participants and the City may need to acknowledge a “terms of agreement” for vehicle data that is captured and stored on the Operating System. The terms of use would not allow that data to be used for purposes other than for transportation management and transportation studies. In addition, a user may argue that the non-issuance of warnings provides deniability when a crash occurs. Outreach and education will need to be provided to alleviate these issues.

Chapter 4. Maintenance

As noted in Chapter 2, there are three different periods during which operations (Chapter 3) and maintenance (this chapter) must be performed: the Demonstration period, the Extended Support period, and finally the Post-Support period. The operations chapter discussed performance monitoring and basic troubleshooting. This chapter focuses on three different modes of maintenance: preventive maintenance, service/repair/replacement, and system decommissioning. Consistent with Chapter 3, this chapter is organized first by system component and then by the modes. Many of the activities and steps associated with maintenance are already captured in vendor-supplied manuals and guides. That information is not duplicated here, but instead, the reader is directed to the appropriate companion references.

4.1. RESPONSIBILITIES

The responsibility for maintenance falls to different parties during the different phases of the project. Further, Table 4 outlines the specific responsibilities for the major system components during each of these operational periods. In general however, responsibility can be characterized as follows for each of the following period.

- Demonstration Period
  - Vendors / integrators responsible for their work / products as defined in their respective scope of work
  - City responsible for managing the CVE network
- Extended Support Period
  - Vendors / integrators responsible for their work / products as defined in their respective scope of work
  - City responsible for managing the CVE network
- Post-Support Period
  - City responsible for all components, including hardware and CVE network

Exception to these responsibilities and Table 4 are captured below.

4.2. MAINTENANCE ACTIVITIES

In general, the CVE was designed to operate continuously with no planned maintenance or downtime. Once deployed OBUs are effectively “on their own” with no central monitoring or scheduled maintenance. Only issues identified by the vehicle operator will be addressed, and only when reported by the operator. On the other hand, most of the infrastructure components are monitored, and as such, are candidates for more rigorous maintenance protocols, including both preventive maintenance, and processes for repair/replacement. Decommissioning is not presently planned, but information related to that O&M need is also included.

As with Chapter 3, maintenance is organized by in-vehicle equipment, infrastructure components, and lastly the Operating System.
4.2.1. In-Vehicle Equipment

Installation and configuration of in-vehicle equipment is guided by documentation produced by the vendors and referenced in earlier sections of this plan.

4.2.1.1. HEADS-UP DISPLAY EQUIPPED VEHICLE

Preventive Maintenance

- No preventive maintenance is prescribed for the OBU or HUD. A soft cloth similar to that used to clean eyeglasses may be used to clean the screen of the HUD as necessary.

Servicing / Repair / Replacement

- There are no field serviceable parts associated with the OBU. Failed items will be replaced with a similar item. Factory enrollment in SCMS will be provided for OBUs using standard pseudo certificates appropriate for all HUD-enabled vehicles.
- Installation, configuration, and system checkout will be completed using the appropriate OBU Installation Guide and OBU Installation Checklist as identified in Section 2.3.3.

System Decommissioning

- Equipment removal will be performed using the reverse of procedures as documented in the appropriate OBU Installation Guide and OBU Installation Checklist as identified in Section 2.3.3.

4.2.1.2. CONNECTED VEHICLE EQUIPPED VEHICLES WITHOUT A HUD

Preventive Maintenance

- No preventive maintenance is prescribed for the OBU.

Servicing / Repair / Replacement

- No field serviceable parts are associated with the OBU. Failed items will be replaced with a similar item. Factory enrollment in SCMS will be provided for OBUs using standard pseudo certs for those not implementing signal preempt or priority, and device with custom certificates appropriate for freight, fire, police and transit vehicles.
- Installation, configuration, and system checkout will be completed using the appropriate OBU Installation Guide and OBU Installation Checklist as identified in Section 2.3.3.

System Decommissioning

- Equipment removal will be performed using the reverse of procedures as documented in the appropriate OBU Installation Guide and OBU Installation Checklist as identified in Section 2.3.3.
4.2.2. Infrastructure Components

Maintenance activity for infrastructure are organized by each subsystem/component, and by maintenance activity as documented previously.

4.2.2.1. ROADSIDE UNIT

Preventive Maintenance

- No preventive maintenance is prescribed for the RSU.
- If an RSU is not showing as Green in the CMCC, the responsible party should first perform a software (warm) reboot of the RSU.
- If that does not resolve the problem, a cold reboot (physical power cycle) of the RSU itself should be performed.
- If the above actions do not resolve the problem, power cycling of both the CVCP and the RSU (in that order), performed at roadside, should be performed.

Servicing / Repair / Replacement

- No field serviceable parts are associated with the RSU. Failed items will be replaced with a similar item.
- Installation, configuration, and system checkout will be completed using the documentation for the appropriate RSU as listed in the references in Table 3.
- Steps will include:
  - Set IP addresses per City network configuration to match that of the device being replaced. (Note: IP addresses are maintained in a separate, secured file by the DPS.)
  - Reset default password.
  - Complete configuration per manufacturers steps.
  - Enroll device in SCMS.
  - Install device.

System Decommissioning

- Equipment removal will be performed by an approved contractor of City staff.
- When removed, the RSU should also be removed from the configuration of CMCC and Centracs.

4.2.2.2. CONNECTED VEHICLE CO-PROCESSOR / MESSAGE HANDLER

Preventive Maintenance

- No preventive maintenance is prescribed for the CVCP.
- If a CVCP is not showing as Green in CMCC, the responsible party should first perform a warm reboot of the message handler (CVCP).
- If that does not resolve the problem, a cold reboot (physical power cycle) of the RSU itself should be performed.
Servicing / Repair / Replacement

- No field serviceable parts are associated with the CVCP. Failed items will be replaced with a similar item.
- Installation, configuration, and system checkout will be completed using the vendor-supplied guides as identified in Table 3.
- Appendix C of this plan includes detailed configuration instructions for the CVCP as developed during the deployment period.

System Decommissioning

- Equipment removal will be performed by approved personnel and will consist simply of removing the CVCP from the TSC.
- Once removed, the CVCP should also be removed from the configuration of CMCC.

4.2.2.3. TRAFFIC-SIGNAL CONTROLLER

Preventive Maintenance

- No preventive maintenance is prescribed for the TSC.
- If a TSC is not showing as Green in CMCC, the responsible party should first confirm that SPaT is activated in the controller and the S90 software is enabled.
- If that does not resolve the problem, a cold reboot of the CVCP itself should be performed.

Servicing / Repair / Replacement

- No field serviceable parts are associated with the TSC. Failed items will be replaced with similar item.
- Installation, configuration, and system checkout will be completed using the vendor-supplied guides.

System Decommissioning

- TSC removal is outside of the scope of this CVE O&M Plan.

4.2.2.4. LAYER 2 NETWORK SWITCHES

Preventive Maintenance

- No preventive maintenance is prescribed for the Layer 2 switches.

Servicing / Repair / Replacement

- No field serviceable parts are associated with the Layer 2 switch. Failed items will be replaced with similar item.
- Installation, configuration, and system checkout will be completed using the vendor-supplied guides as identified in Table 3.

System Decommissioning

- Equipment removal will be performed by approved personnel.
- Removal comprises removing the Layer 2 switch from the signal cabinet.
- Once removed, the switch should also be removed from any SNMP management tables and configuration maintained by DPS.
4.2.2.5. LAYER 3 NETWORK SWITCHES

**Preventive Maintenance**
- No preventive maintenance is prescribed for the Layer 3 switches.

**Servicing / Repair / Replacement**
- Initial diagnostic will include reviewing of the logs, with a soft warm reboot possibly required to facilitate this.
- No field serviceable parts are associated with the Layer 3 switch. Failed items will be replaced with similar item.
- Installation, configuration, and system checkout will be completed using the vendor-supplied guides as identified in Table 3.

**System Decommissioning**
- Equipment removal will be performed by approved personnel.
- Removal comprises removing the Layer 3 switch from the communications cabinet.
- Once removed, the switch should also be removed from any SNMP management tables and configuration maintained by the DoT.

4.2.2.6. INTERNET SERVICES

**Preventive Maintenance**
- No preventive maintenance is prescribed for the internet services supplied by AT&T.

**Servicing / Repair / Replacement**
- No field serviceable components are associated with internet services.
- City staff should verify that power and other equipment at the TMC have not been compromised before reporting an outage to AT&T.
- Any outages will be reported to AT&T customer services.

**System Decommissioning**
- Termination of the service must follow the guidance of the contract with AT&T and is outside of the scope of this plan.
- DPS staff will be responsible for ensuring any requirements to terminate service are met.

4.2.2.7. CONNECTED MOBILITY CONTROL CENTER

**Preventive Maintenance**
- Preventive Maintenance of the CMCC is the responsibility of Kapsch and their host provider, Microsoft Azure. All necessary operating systems patches, including security, will be performed regularly by Kapsch and Microsoft.

**Servicing / Repair / Replacement**
- No field serviceable parts are associated with CMCC.
- CMCC outages will be reported to Kapsch.
- Kapsch will generate a trouble ticket and respond to the City within 4 hours.
Chapter 4. Maintenance

- An estimate of the resolution of the outage will be provided to the City.
  Note: A failure of CMCC does not necessarily constitute a failure of the CVE overall, but data collection and health and status monitoring could be affected.

System Decommissioning
- Decommissioning of the CMCC likely reflects a decommissioning of CVE overall or a switch to a different provider, both of which are outside of the scope of this plan.

4.2.2.8. SECURITY AND CREDENTIALS MANAGEMENT SYSTEM

Preventive Maintenance
- No preventive maintenance is prescribed for the SCMS.

Servicing / Repair / Replacement
- No field serviceable parts are associated with SCMS.
- SCMS access is via the IPv6 network. Troubleshooting should begin by examining the network, network permissions, and firewall rules.
- New or replacement OBU's or RSU's will need to be enrolled in the SCMS before being deployed.

System Decommissioning
- Transitioning to a different certificate provider is outside of the scope of this plan.
- If SCMS is discontinued, applicable firewall rules will be updated to reflect removal of service.

4.2.2.9. OVER-THE-AIR UPDATES

Preventive Maintenance
- No preventive maintenance is prescribed for the OTA server. Siemens will maintain access to this service for the life of their support agreement with the City.

Servicing / Repair / Replacement
- No field serviceable parts are associated with the OTA server.
- OTA server access is via the IPv6 network. Troubleshooting should begin by examining the network, network permissions, and firewall rules.
- New OBU's may need to be permitted in the OTA server.

System Decommissioning
- Transitioning to a different certificate provider is outside of the scope of this plan.
- If OTA updates are discontinued, applicable firewall rules will be updated to reflect removal of service.
4.2.2.10. SYSTEM MESSAGE UPDATES

Upon occasion, it may be necessary to change the contents of a MAP or TIM associated with a change in pavement markings, work zones, etc. Detailed procedures have been created for both and are included in Appendix D and Appendix E, respectively.

4.2.2.11. SPECTRUM REALLOCATION

On May 3, 2021, the Federal Communications Commission (FCC) issued the final report and order related to the re-allocation of the 5.9GHz spectrum in which DSRC operates. This ruling requires all licensed RSUs to cease operations on the lower 45 MHz of the spectrum by July 2022. As is documented in the companion design documentation for the CVE, the decision was made in November 2019 to transition to operation of licensed devices to channel 180, fully compliant with this initial ruling, per 47 CFR part 90. Therefore, no change to RSU operations are required as a result of this ruling. A future ruling is however expected, likely in the 2024 timeframe, which will require DSRC to cease operations completely. If the further ruling does indeed move forward, the City will need to proceed with decommissioning devices per Section 4.2.2.1 above.

47 CFR part 95, which address OBU, has also been revised to limit their operation to the 5.895 – 5.925 GHz band, but there is no timeframe indicated in the ruling as to when devices must be compliant with this ruling. OBUs deployed in Smart Columbus currently operate on channels 172 and 180. Per the ruling, channel 172 would no longer be permissible. Depending on the FCC’s clarification of the ruling, OBUs may either need to be upgraded to support channel 180 operations or decommissioned per the guidance in Section 4.2.1.1 above.

4.2.3. Operating System

4.2.3.1. PREVENTIVE MAINTENANCE ACTIVITIES

The Operating System team will schedule ingestion jobs for various data feeds based on their update frequency. In case of any changes or updates to the data feed schema or endpoint, the Operating System team will update the data pipeline to reflect the changes. These data pipeline updates can take up to 6 hours. Table 12 provides activities associated with updating data collected in the Operating System.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Frequency</th>
<th>Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Update data structure/schema in Operating System</td>
<td>Data ingested into the Operating System has changed and requires updates to the existing data structure/schema.</td>
<td>As needed</td>
<td>6 hours</td>
</tr>
</tbody>
</table>

Source: City of Columbus

4.2.3.2. CORRECTIVE MAINTENANCE ACTIVITIES

Table 13 lists the corrective maintenance activities associated with addressing issues related to the Operating System. Effort noted as “TBD” indicates that the effort (which may vary) would be estimated based on identified fault and the required fix.
Table 13. Corrective Maintenance Activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Frequency</th>
<th>Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nightly extract, transform and load (ETL) and re-training process fails</td>
<td>Errors might occur in the nightly ETL and during re-training process. The Operating System team will monitor these activities to ensure they are operating properly.</td>
<td>As needed</td>
<td>TBD</td>
</tr>
</tbody>
</table>

Source: City of Columbus

The Operating System team will regularly perform preventive maintenance tasks in order to keep the system operating optimally. Preventive and corrective maintenance for the CVE datasets is the same as all other datasets in the Operating System and is covered in the separate Operating System O&M Plan³.

³ [https://d2rfd3nxvhnf29.cloudfront.net/2020-06/SCC-B-SCOS-O%26M-Final-v1.pdf](https://d2rfd3nxvhnf29.cloudfront.net/2020-06/SCC-B-SCOS-O%26M-Final-v1.pdf)
Appendix A. Acronyms and Definitions

Table 14 provides project-specific acronyms used throughout this document.

Table 14. Acronym List

<table>
<thead>
<tr>
<th>Abbreviation/Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>APPS</td>
<td>CV Applications</td>
</tr>
<tr>
<td>BSM</td>
<td>Basic Safety Message</td>
</tr>
<tr>
<td>CFR</td>
<td>Code of Federal Regulations</td>
</tr>
<tr>
<td>CMCC</td>
<td>Connected Mobility Control Center</td>
</tr>
<tr>
<td>COTA</td>
<td>Central Ohio Transit Authority</td>
</tr>
<tr>
<td>CTSS</td>
<td>Columbus Traffic Signal System</td>
</tr>
<tr>
<td>CV</td>
<td>Connected Vehicle</td>
</tr>
<tr>
<td>CVCP</td>
<td>Connected Vehicle Co-Processor</td>
</tr>
<tr>
<td>CVE</td>
<td>Connected Vehicle Environment (Smart Columbus Project #2)</td>
</tr>
<tr>
<td>CVRIA</td>
<td>Connected Vehicle Reference Implementation Architecture</td>
</tr>
<tr>
<td>DoT</td>
<td>(City of Columbus) Department of Technology</td>
</tr>
<tr>
<td>DPS</td>
<td>Columbus Department of Public Service</td>
</tr>
<tr>
<td>DSRC</td>
<td>Dedicated Short Range Communications</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
</tr>
<tr>
<td>HDV</td>
<td>Heavy-Duty Vehicle</td>
</tr>
<tr>
<td>HMI</td>
<td>Human-Machine Interface</td>
</tr>
<tr>
<td>HUD</td>
<td>Heads-Up Display</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol [address]</td>
</tr>
<tr>
<td>IRB</td>
<td>Institutional Review Board</td>
</tr>
<tr>
<td>ISS</td>
<td>Integrity Security Service</td>
</tr>
<tr>
<td>LDV</td>
<td>Light-Duty Vehicle</td>
</tr>
<tr>
<td>MAP</td>
<td>Map Data Message</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>Operations and Maintenance</td>
</tr>
<tr>
<td>OBE</td>
<td>Onboard Equipment (many or all onboard devices)</td>
</tr>
<tr>
<td>OBU</td>
<td>Onboard Unit (one onboard device)</td>
</tr>
</tbody>
</table>
## Appendix A. Acronyms and Definitions

<table>
<thead>
<tr>
<th>Abbreviation/Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODD</td>
<td>Operational Design Domain</td>
</tr>
<tr>
<td>ODOT</td>
<td>Ohio Department of Transportation</td>
</tr>
<tr>
<td>Operating System</td>
<td>Operating System (Smart Columbus Project #1)</td>
</tr>
<tr>
<td>OTA</td>
<td>Over-the-Air</td>
</tr>
<tr>
<td>PII</td>
<td>Personally Identifiable Information</td>
</tr>
<tr>
<td>RSU</td>
<td>Roadside Unit</td>
</tr>
<tr>
<td>SCMS</td>
<td>Security Credential Management System</td>
</tr>
<tr>
<td>SNMP</td>
<td>Simple Network Management Protocol</td>
</tr>
<tr>
<td>SPaT</td>
<td>Signal Phase and Timing</td>
</tr>
<tr>
<td>SyRS</td>
<td>System Requirements Specification</td>
</tr>
<tr>
<td>TIM</td>
<td>Traveler Information Message</td>
</tr>
<tr>
<td>TMC</td>
<td>Traffic Management Center</td>
</tr>
<tr>
<td>TSC</td>
<td>Traffic-Signal Controller</td>
</tr>
<tr>
<td>TSP</td>
<td>Traffic Signal Priority Applications</td>
</tr>
<tr>
<td>TVIER</td>
<td>Transit Vehicle Interaction Event Recording</td>
</tr>
<tr>
<td>USDOT</td>
<td>United States Department of Transportation</td>
</tr>
<tr>
<td>V2I</td>
<td>Vehicle-to-Infrastructure</td>
</tr>
<tr>
<td>V2V</td>
<td>Vehicle-to-Vehicle</td>
</tr>
<tr>
<td>WAVE</td>
<td>Wireless Access in a Vehicle Environment</td>
</tr>
<tr>
<td>WRA</td>
<td>WAVE Route Advertisement</td>
</tr>
</tbody>
</table>

*Source: City of Columbus*
### Table 15. Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>APPS</td>
<td>Represents the functional group of CV Apps to be deployed</td>
</tr>
<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System used for OBU positioning. GPS is an example of a GNSS.</td>
</tr>
<tr>
<td>BSW/LCW</td>
<td>Blind Spot Warning/Lane Change Warning CV App</td>
</tr>
<tr>
<td>CORS</td>
<td>Continuously Operating Reference System serves as a source of GNSS positioning correction information</td>
</tr>
<tr>
<td>CV Pilot</td>
<td>USDOT-sponsored CV deployments in Wyoming, Tampa, and New York City</td>
</tr>
<tr>
<td>EVP</td>
<td>Emergency Vehicle Preempt CV App</td>
</tr>
<tr>
<td>EEBL</td>
<td>Emergency Electronic Brake Light CV App</td>
</tr>
<tr>
<td>FCW</td>
<td>Forward Collision Warning CV App</td>
</tr>
<tr>
<td>FSP</td>
<td>Freight Signal Priority CV App</td>
</tr>
<tr>
<td>IMA</td>
<td>Intersection Movement Assist CV App</td>
</tr>
<tr>
<td>ITP</td>
<td>Intent to Platoon Signal Priority CV App</td>
</tr>
<tr>
<td>MAP</td>
<td>J2735 Message used to convey roadway geometry and movements to OBU</td>
</tr>
<tr>
<td>MHP</td>
<td>Message Handler/Processor serves to route messages between RSU and other infrastructure devices. Optional.</td>
</tr>
<tr>
<td>MSG</td>
<td>Represents the J2735 and J2945 messages that used as part of the CVE</td>
</tr>
<tr>
<td>RLVW</td>
<td>Red Light Violation Warning CV App</td>
</tr>
<tr>
<td>RSM</td>
<td>Roadside Safety Message – CAMP–driven message expected to be part of J2945</td>
</tr>
<tr>
<td>RSSZ</td>
<td>Reduced Speed School Zone CV App</td>
</tr>
<tr>
<td>TMC</td>
<td>Traffic Management Center – the location that will house the system to monitor operations of network of signal controllers and will include RSUs</td>
</tr>
<tr>
<td>TrCVMC</td>
<td>Transit Management Center – location where transit fleet is managed, including data capture from onboard systems, to include the CVE data</td>
</tr>
<tr>
<td>TSC</td>
<td>Traffic Signal Controller (source of SPaT data)</td>
</tr>
<tr>
<td>TSP</td>
<td>Transit Signal Priority CV App</td>
</tr>
<tr>
<td>TVIER</td>
<td>Monitors Transit Vehicle Interactions CV App</td>
</tr>
<tr>
<td>VDTO</td>
<td>Vehicle Data for Traffic Operations CV App</td>
</tr>
</tbody>
</table>

*Source: City of Columbus*
Appendix C. Connected Vehicle Co-Processor Configuration Instructions

This brief set of instructions covers the steps taken to configure a CVCP for use in a Connected Vehicle System. This configuration process will allow an IP address to be assigned to the CVCP, as well as designate the IP addresses for the bridge so that both the traffic signal controller and the bridge can communicate with the CVCP.

This guide is written in a step-by-step fashion so that persons who are unfamiliar with the process or any of the programs used in the process are able to perform it.

Pre-Requisites

1. Download PuTTY
   https://www.chiark.greenend.org.uk/~sgtatham/putty/latest.html
2. Download WinSCP
   https://winscp.net/eng/download.php
3. Save the configuration file to your computer. Make sure you are using the latest version. Latest version as of 1/8/21: rcu_install-rsu-snmp-arm-ecp-1.2.3
4. Obtain a copy of the list of IP addresses and default gateways assigned to all devices (e.g. Comnet L2 switch, CVCP bridge, CVCP module, DSRC radio) to be deployed.
5. Manually set IP addresses for your computer
   a. Navigate to Network Connections
   b. Right click on Ethernet and select Properties
   c. From the list, select Internet Protocol Version 4 (TCP/IPv4), and click on Properties
   d. Click Advanced…
   e. In the IP addresses box, add the following IP addresses and subnet masks.
      i. IP: 10.70.10.247 Subnet Mask: 255.255.255.0
      ii. IP: 10.91.XX.247 Subnet Mask: 255.255.255.0
         The third octet XX corresponds to the subnet(s) of the CVCP(s) you will be setting up.
   f. Click OK, OK, Close.
6. Obtain list of CVCP cloud login credentials.
   Note: These IP addresses are specific for configuring CVCP for the Columbus CVE.
   Connecting to various networks via Ethernet between CVCP configuration sessions may require these IP addresses to be automatically removed or reset, depending on your agency’s/company’s IT policy and computer settings.
   Always check to ensure these IP addresses are set before starting configuration.

Configuration Steps

1. Check that the controller you are using for configuration is set up to emulate the network settings of the controller in the field that the CVCP will be paired with.
2. With the controller unplugged, connect the CVCP into the CVCP slot on the left side of the controller. This may require a blank side panel to be removed from the controller.
3. Power on the controller
4. Connect your computer to the CVCP using an Ethernet Cable. Any port on the CVCP can be used.
5. Open WinSCP
6. Use WinSCP to connect to the CVCP.
If you have not previously saved a login profile (or if this is your first time configuring a CVCP), enter the following information to log into the CVCP:

a. File protocol: SCP
b. Host name: 10.70.10.52 (this is the default assigned IP address for the CVCP)
c. Port Number: 22
d. User name: econolite
e. Password: ecpi2ecpi
f. Click Login
g. When prompted, save the Login profile.

Note: The profile name will default to: econolite@10.70.10.52

If you have previously saved a login profile, then simply select the saved Login profile from the list on the left and click Login.

7. On the left half of the WinSCP screen, navigate to the location where the configuration file is saved (Prerequisite step #3).
8. Click and drag the configuration file to the blank space on the right half of the screen.

The file will appear on the right side of the screen.
9. Close WinSCP
10. Open PuTTY
11. Use PuTTY to connect to the CVCP. Enter the following information to log into the CVCP:
   a. Host name (or IP address): 10.70.10.52 (this is the default assigned IP address for the CVCP)
   b. Port: 22
   c. Connection type: SSH
   d. Click Open. If information is correct, the PuTTY terminal will pop up.

12. Log in and run the eTrans OBU Self Extracting Installer. Enter the following into the PuTTY terminal:

<table>
<thead>
<tr>
<th>PuTTY terminal prompt...</th>
<th>Type _____ and hit Enter</th>
</tr>
</thead>
<tbody>
<tr>
<td>login as:</td>
<td>econolite</td>
</tr>
<tr>
<td>econolite@10.70.10.52's password:</td>
<td>ecpi2ecpi</td>
</tr>
<tr>
<td></td>
<td>password will not appear on the screen as you are typing.</td>
</tr>
<tr>
<td>$</td>
<td>su –</td>
</tr>
<tr>
<td></td>
<td>command for Super User</td>
</tr>
<tr>
<td>#</td>
<td>sh /home/econolite/rsu_install-rsu-snmp-arm-ecp-1.1.3A.ssx</td>
</tr>
<tr>
<td></td>
<td>This is the location of the configuration file loaded onto the CVCP from Step 7.</td>
</tr>
</tbody>
</table>

13. Configure the CVCP IP address. Enter the following into the PuTTY terminal:

<table>
<thead>
<tr>
<th>PuTTY terminal prompt...</th>
<th>Type _____ and hit Enter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Would you like to change the default ethernet address 10.70.10.52?</td>
<td>y</td>
</tr>
<tr>
<td>Enter the IP address to use:</td>
<td>&lt;IP address assigned to CVCP module&gt;</td>
</tr>
<tr>
<td>Enter the network mask to use: [255.255.255.0]</td>
<td>255.255.255.0</td>
</tr>
<tr>
<td>Enter the default gateway to use:</td>
<td>&lt;Default gateway assigned to intersection on CVE network&gt;</td>
</tr>
<tr>
<td></td>
<td>Typically same as CVCP IP address with .1 for final octet</td>
</tr>
</tbody>
</table>
### Appendix C. Connected Vehicle Co-Processor Configuration Instructions

<table>
<thead>
<tr>
<th>PuTTY terminal prompt...</th>
<th>Type _____ and hit Enter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Would you like to change the default ethernet address 10.70.10.52? [Y/n]</td>
<td>y</td>
</tr>
<tr>
<td>Enter the IP address to use:</td>
<td>10.91.87.31</td>
</tr>
<tr>
<td>Enter the network mask to use: [255.255.255.0]</td>
<td>255.255.255.0</td>
</tr>
<tr>
<td>Enter the default gateway to use:</td>
<td>10.91.87.1</td>
</tr>
</tbody>
</table>

Note: CVCP IP address and default gateway in this example are for the intersection of Morse Road at Westerville Road

14. Synchronize Time

<table>
<thead>
<tr>
<th>PuTTY terminal prompt...</th>
<th>Type _____ and hit Enter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please enter the IP address of the controller for time synchronization:</td>
<td>&lt;IP address assigned to controller&gt;</td>
</tr>
<tr>
<td>Typically same as CVCP IP address with .90 for second octet</td>
<td></td>
</tr>
</tbody>
</table>

Note: CVCP IP address and default gateway in this example are for the intersection of Morse Road at Westerville Road

15. Configure the Bridge IP address. Enter the following into the PuTTY terminal:

<table>
<thead>
<tr>
<th>PuTTY terminal prompt...</th>
<th>Type _____ and hit Enter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Would you like to set up a second network for communication to the controller? [Y/n]</td>
<td>y</td>
</tr>
<tr>
<td>Enter the IP address to use (note that this should be in the same network as 10.90.87.31):</td>
<td>&lt;IP address assigned for Bridge&gt;</td>
</tr>
<tr>
<td>Enter the network mask to use: [255.255.255.0]</td>
<td>255.255.255.0</td>
</tr>
</tbody>
</table>

Note: Bridge IP address in this example is for the intersection of Morse Road at Westerville Road

16. When prompted, hit Enter.

17. Configure cloud processing. Use CVCP cloud login credentials (Pre-Requisite Step 6). Enter the following into the PuTTY terminal:

<table>
<thead>
<tr>
<th>PuTTY terminal prompt...</th>
<th>Type _____ and hit Enter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Would you like to continue with cloud processing? [Y/n]</td>
<td>y</td>
</tr>
<tr>
<td>Enter the server to use for cloud processing: [ qa.etranssystems.com]</td>
<td>columbus-comm.cv.kapschtraffic.com</td>
</tr>
<tr>
<td>Enter port to use for cloud processing [255]</td>
<td>255</td>
</tr>
</tbody>
</table>
PuTTY terminal prompt...

| Please enter the credentials for connecting to: production.etranssystems.com | morse_westerville_cvcp
| User name: | (will be different for each device) |
| Password: | SMRTCol3291
| (will be different for each device) |

Would you like to continue with cloud processing? [Y/n] y

Enter the server to use for cloud processing: [ qa.etranssystems.com] columbus-comm.cv.kapschtraffic.com

Enter port to use for cloud processing [255] 255

PuTTY terminal prompt...

| Please enter the credentials for connecting to: production.etranssystems.com |
| User name: columbus_ccu_ecp |
| Password: password |

Note: User name and password in this example are for the intersection of Morse Road at Westerville Road. Credentials will be different for each device.

18. Type `reboot` and hit Enter. This will cause the CVCP to reboot. Close PuTTY
19. After about 30 seconds. Open PuTTY again, and connect to the CVCP, see Step 11
20. Check Connectivity. Enter the following into the PuTTY terminal, and perform the following checks:

PuTTY terminal prompt...

| $ | su - |
| # | ping `<IP address assigned to Controller>`
| | The CVCP should ping the controller at 1Hz (output indicating success is shown in green).
| | To stop pinging the controller, hit Ctrl+C |
| # | ping `<IP address assigned to Bridge>`
| | The CVCP should ping the bridge at 1Hz (output indicating success is shown in green).
| | To stop pinging the bridge, hit Ctrl+C |
PuTTY terminal prompt... | Type _____ and hit Enter
---|---
# | Date
The terminal will display the date and time *(output shown in green)*. Check the date and time on the controller to ensure they match.

```
$ su -
# ping 10.90.87.39
PING 10.90.87.39 (10.90.87.39) 56(84) bytes of data.
64 bytes from 10.90.87.39: icmp_seq=1 ttl=64 time=0.159 ms
64 bytes from 10.90.87.39: icmp_seq=2 ttl=64 time=0.085 ms
...
64 bytes from 10.90.87.39: icmp_seq=18 ttl=64 time=0.114 ms
^C
--- 10.90.87.39 ping statistics ---
18 packets transmitted, 18 received, 0% packet loss, time 16993ms
rtt min/avg/max/mdev = 0.071/0.090/0.159/0.023 ms
# ping 10.90.87.31
PING 10.90.87.31 (10.90.87.31) 56(84) bytes of data.
64 bytes from 10.90.87.31: icmp_seq=1 ttl=64 time=0.560 ms
64 bytes from 10.90.87.31: icmp_seq=2 ttl=64 time=0.510 ms
64 bytes from 10.90.87.31: icmp_seq=3 ttl=64 time=0.464 ms
^C
--- 10.90.87.31 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2000ms
rtt min/avg/max/mdev = 0.464/0.511/0.560/0.043 ms
# date
Sat Nov  2 13:25:33 UTC 2019
```

Note: CVCP and Bridge IP addresses in this example are for the intersection of Morse Road at Westerville Road.
Appendix C. Connected Vehicle Co-Processor Configuration Instructions

Setup CVCP on Kapsch CMCC (must have proper permissions)

1. Navigate to https://columbus.cv.kapschtraffic.com/rsu-location-page/
2. From the top bar, Click System Setup – Devices
3. Click on the small + icon in the lower left corner
4. Change the Device type to CCU
5. The Device Name should match the name in the Columbus Installation Planner
6. Enter the CVCP IP Address as in Step 13
7. Enter same username and password as in Step 17
8. Leave Host Type blank

Manually Editing Configuration Files

*Once defaults values have been changed, the installer will not prompt the user as indicated in the steps above. There are times where a value may have been entered incorrectly or a CVCP needs to be configured for another intersection. The steps below indicate how to manually change the configuration files

- Open File
  - Controller IP Address: Type “vi /home/econolite/controller_ip” and hit enter
  - CVCP IP address and Bridge IP address: Type “vi /etc/network/interfaces” and hit enter
    - “iface eth0 inet static is the CVCP IP address
    - “iface eth0:0 inet static” is the Bridge IP address
  - Cloud server url: Type “vi /home/econolite/etrans/etrans.conf” and hit enter
  - Cloud Login Credentials: Type “vi /home/econolite/etrans/comm-credentials” and hit enter
- Modify File
  - Delete a whole line: Type “dd”. Type Shift + ”o” to enter a new line. Type the updated information in the line. Hit escape.
  - Change a single word/value: Move the cursor to the value you want to change. Type ”cw”. Enter the new value. Hit escape.
- Close File
  - Save and close: Type “:x” and hit enter.
  - Close without saving: Type “:q!” and hit enter.

Troubleshooting

- If you are having issues logging into the CVCP, make sure your computer is set to the correct IP address (see Prerequisite step 5).
- If the CVCP is not completely tightened in the controller, it will be powered but will not be able to communicate with the controller.
- Attempting to log into the CVCP before it has fully started may result in not being able to log into the CVCP. The Ethernet cable may need to be unplugged and plugged back in.
Appendix D. Map Data Message Guidance
SMART CITY INTERSECTION DIGITIZATION UPDATE

August 2019

Greg Antonini
Franklin County Engineer’s Office - Tax Map Division
Table of Contents

Introduction 3
Methodology Part I: Data Validation 3
Methodology Part II: Digitization of Intersections 4
Methodology Part III: Intersection Export 13
Challenges 16
List of Completed Intersections 19
List of Incomplete Intersections 21
Conclusion 22
Appendix A: List of Tables and Figures 23
Appendix B: Python Code for GIS to Excel Export 24
Introduction

Throughout the last several months, intersections along three major corridors including Morse Road, Cleveland Avenue, and High Street, have been digitized to provide data for the generation of MAP messages for the Smart Columbus Connected Vehicle Environment. Contained in this report is the methodology for the intersection digitization and export as well as an overview of the problems encountered throughout this project along with their solutions. This report also identifies the work that is complete and what still remains to be done.

Methodology

Part I: Data Validation

Due to the large time commitment and amount of labor involved with surveying an intersection, it was not feasible to survey every intersection to capture points and lines. Therefore, the Franklin County Engineer’s Office - Survey Department captured GPS data on three intersections (Cleveland Ave. & Ferris Rd., Cleveland Ave. & Hudson St., and Cleveland Ave. & 2nd Ave.) so the GPS points could be compared with FCEO’s 2017 orthographic image. It was determined that the orthographic image was not georeferenced correctly and thus could not be used to visually plot the points and lines of the remaining intersections. As an alternative, FCEO downloaded another set of aerial imagery from the Ohio Statewide Imagery Program (OSIP). When the GPS points were overlaid on top of the OSIP images, it was clear that these images were georeferenced well enough to visually digitize the points and lines. The comparison below shows the difference in how the different aerials were georeferenced:

Figure 1: Imagery Comparison – FCEO Left, OSIP Right
Methodology

Part II: Digitization of Intersections

To begin work on an intersection, first a point was placed in the approximate center of the intersection. The attributes that were populated for the point at the center of the intersection include: latitude, longitude, intersection name, intersection number, and type (center of intersection). A circle having a radius of 1200 feet was drawn around the center of the circle. The attributes for the circle include: type, center, stop bar, crosswalks, lanes, intersection name, intersection number, revision number, and master lane width. The attributes were completed as follows:

- **Type:**
  Initially, all circles were given a type value of 0 because no work had yet been done with the intersection. As work progressed, this type value was changed to reflect the status of the intersection according to the following table:

<table>
<thead>
<tr>
<th>VALUE</th>
<th>SIGNIFICANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Intersection is incomplete</td>
</tr>
<tr>
<td>1</td>
<td>Unable to complete intersection due to an obstruction in the imagery</td>
</tr>
<tr>
<td>2</td>
<td>FCEO Survey has provided GPS data for this intersection, but the attributes and lane line data have not been completed</td>
</tr>
<tr>
<td>3</td>
<td>Intersection has all points and lines drawn in</td>
</tr>
<tr>
<td>5</td>
<td>Intersection could not be completed due to ongoing construction</td>
</tr>
<tr>
<td>7</td>
<td>Intersection is complete</td>
</tr>
</tbody>
</table>

- **Center:** 1 if the point at the center of the intersection is present, 0 otherwise
- **Stop bar:** 1 if the stop bars have been digitized, 0 otherwise
- **Crosswalks:** 1 if the crosswalk end points have been digitized, 0 otherwise
- **Lanes:** 1 if the lane lines have been drawn in, 0 otherwise
- **Intersection Name:** Name of the Intersection
- **Intersection Number:** Value specified by City of Columbus DPS
- **Revision Number:** Set to 0 initially, then incremented if the geometry of the intersection changes requiring the MAP message to be modified after deployment
- **Master Lane Width:** The default lane width, set to 366 for every intersection, which is 12 feet converted to centimeters
These attributes were updated as work on the particular intersection progressed. An example of the circle attributes of a completed intersection is shown below:

**Figure 2: Completed Circle Attributes**

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJECTID</td>
<td>62</td>
</tr>
<tr>
<td>Type</td>
<td>7</td>
</tr>
<tr>
<td>Center</td>
<td>1</td>
</tr>
<tr>
<td>Stop Bar</td>
<td>1</td>
</tr>
<tr>
<td>Crosswalks</td>
<td>1</td>
</tr>
<tr>
<td>Lanes</td>
<td>1</td>
</tr>
<tr>
<td>SHAPE_Length</td>
<td>7539.142044</td>
</tr>
<tr>
<td>SHAPE_Area</td>
<td>4522260.559605</td>
</tr>
<tr>
<td>Intersection Number</td>
<td>3415</td>
</tr>
<tr>
<td>Intersection Name</td>
<td>HEATON RD. AT MORSE RD.</td>
</tr>
<tr>
<td>Revision Number</td>
<td>0</td>
</tr>
<tr>
<td>Master Lane Width</td>
<td>366</td>
</tr>
</tbody>
</table>

After the center of the intersections and circles were created, the stop bar end points were digitized next. Points given type “Stopbar Endpoint” were placed on the two corners of the stopbar farthest from the center of the intersection. Refer to the image shown below for a visual representation of stopbar endpoint placement (points shown in blue):

**Figure 3: Stopbar Endpoint Placement**
Next, all of the lane points for a given intersection were drawn in. A lane point was placed against the stopbar in the center of the lane and often enough thereafter so that there was less than one meter of variance from the actual center of the lane when drawing a line between any two points. This resulted in more lane points being placed in locations where there are curves or where one lane merged into another lane. The final lane points of the ingress lanes were placed either 1200 feet from the center of the intersection, or approximately 10 meters from the crosswalk of the next intersection, whichever came first. The final lane points of the egress lanes were placed approximately 10 meters away from the crosswalk, which in many cases was a point that overlapped with the last ingress lane point of the adjacent intersection. In situations like this where a point overlapped, two points were placed. One of the points is associated with the egress lane of one intersection, and the other point is associated with the ingress lane of the other intersection. For a visual representation of general lane point placement, refer to the diagram below:

There exists one other case of overlapping points. This occurs where a through lane splits into a through lane and a turn lane. Two points were placed in this instance: one point which is the endpoint of the turn lane, and one point designed to be a midpoint of the through lane so that the through lane perfectly aligns with the end of the turn lane. For a visual representation of this case, refer to the image below:
Next, all of the crosswalk points for a given intersection were drawn in. A crosswalk point was placed at each end of the crosswalk aligned with the center of the crosswalk as shown in the figure below (crosswalk points in light green):
Once all points were drawn in, the lane lines were drawn in. Each lane line was drawn from the beginning lane point to the end lane point with a vertex at every lane point in between. A lane line was also drawn in between the crosswalk endpoints. Refer to the image below for an intersection after all points and lines have been drawn:

*Figure 7: Completed Points and Lines*
Subsequent to the drawing of all points and lines was the completion of the remaining attributes. The attributes for the points were completed as follows:

- **Lane Number:**
  Each lane was assigned a lane number, with lane numbers increasing in the clockwise direction according to the following table:

<table>
<thead>
<tr>
<th>Range (decimal)</th>
<th>Approach Group Description (Typical 4-way intersection)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>not available or not known</td>
<td>SAE J2735</td>
</tr>
<tr>
<td>1 - 15</td>
<td>special case (typically not used)</td>
<td>Local Principles for Lane ID Assignment</td>
</tr>
<tr>
<td>16 - 47</td>
<td>north-most approach</td>
<td></td>
</tr>
<tr>
<td>48 - 79</td>
<td>east approach (or next clockwise approach)</td>
<td></td>
</tr>
<tr>
<td>80 - 111</td>
<td>south approach (or next clockwise approach)</td>
<td></td>
</tr>
<tr>
<td>112 - 143</td>
<td>west approach (or next clockwise approach)</td>
<td></td>
</tr>
<tr>
<td>144 - 175</td>
<td>other approach (or next clockwise approach)</td>
<td></td>
</tr>
<tr>
<td>176 - 207</td>
<td>other approach (or next clockwise approach)</td>
<td></td>
</tr>
<tr>
<td>208 - 239</td>
<td>other approach (or next clockwise approach)</td>
<td></td>
</tr>
<tr>
<td>240 - 254</td>
<td>flyover approaches</td>
<td></td>
</tr>
<tr>
<td>255</td>
<td>reserved for future use</td>
<td>SAE J2735</td>
</tr>
</tbody>
</table>

Lane numbers were skipped for sidewalks and medians where present so that they can be optionally digitized in the future. Each crosswalk was given the lane number after the final lane or sidewalk for that approach. Refer to the figure below to see how the south approach of Morse Crossing at Morse Rd. was numbered:
- Order: Points in each lane were ordered, starting with 0 and increasing away from the center of the intersection.
- Latitude: Generated by GIS
- Longitude: Generated by GIS
- Elevation: FCEO has not obtained elevation data so this has been populated with 0.
- Width: The width of the lane at the location of the lane point, reported as an offset in centimeters from the last lane point. In the case of the beginning lane point, the width is reported as an offset from the master lane width of 366.
- Intersection Name: Only populated for the point at the center of the intersection as described on page 3.
- Intersection Number: 4-digit intersection number
- Type: Lane Point, Stopbar Endpoint, or Crosswalk Endpoint
- Direction: Approach (Ingress) or Egress
Refer to the figure below to see an example of attributes for a completed lane point:

*Figure 9: Lane Point Attributes*

In this case, the lane point is the beginning of lane 114 (4th clockwise approach) of intersection 4029 having a width that is 61 cm. less than the master lane width of 366 cm.

Next, the attributes for the lane lines were completed as follows:

- Lane Number: see above for lane numbering schema
- Lane Type: Vehicle, Bike, Crosswalk, Parking (see “Challenges” section), Sidewalk (not used)
- Descriptive Name: Explains lane heading as well as any actions that may be taken from that lane at the intersection
- Revision: Set to 0.
- Intersection Number: 4-digit intersection number
Refer to the figure below to see an example of attributes for a completed lane line:

*Figure 10: Lane Line Attributes*

![Lane Line Attributes Table]

Finishing this step marks the completion of the digitization of the intersection. This process was repeated until all intersections were completed.
Methodology

Part III: Intersection Export

Since it is necessary for all digitized data to be in a spreadsheet tool containing tabs for intersection information, lane properties, and lane points to be able to generate MAP messages, a method was needed to extract the data from the geodatabase to this specific spreadsheet layout.

First, a Python 2.7 program was written which prompts for the number of the intersection that the user wishes to export (Figure 10). The program then generates 3 files: the center of intersection information, the lane line information, and the lane point information. These three files are then merged into one excel file (Figure 11) after which the data is easily copied and pasted into the MAP message generation spreadsheet tool (Figure 12). Note that the MAP message generation spreadsheet tool does not account for flyover lanes not tied to a particular intersection (see “Challenges” section) or stopbar endpoints, so these elements have not been exported.

Figure 11: Python Export Tool

The code and implementation details for the program can be found in Appendix B.
Figure 12: Output of Python Export Tool
Figure 13: MAP Message Generation Spreadsheet Tool

![Excel Spreadsheet with data for Center Latitude, Lane Number, Lat, Lon, Elevation, Width, and other properties.](image)

Franklin County Engineer's Office - Tax Map Division
Challenges

One issue encountered during this project was how to account for any lanes that go over or under an approach. For example, cars traversing a freeway should not be receiving MAP messages corresponding to a street below. It was decided to also draw lane points and lines on the freeways in these places. These highway lane points will then be specified at a different elevation than the lane points of the street below. FCEO does not have the elevation data. The data has not been exported because the elevation data is missing, the freeway lanes are not currently tied to a particular intersection, and the MAP message spreadsheet tool was not suited for this data. The data is currently stored in a separate highway layer, numbered with the flyover lane range (240-254). It is still being determined how to split the highway lanes (shown in cyan) and lane points (shown in magenta) between the two MAP messages belonging to the intersections east and west of the freeway. I-71 at Morse Rd. is shown in the image below for reference:

Figure 14: I-71 at Morse Rd.
As there is no stopbar with continuous right turn lanes, another decision had to be made in these situations as it is unclear where the ingress and egress begin and end. Two attributes for each continuous right turn lane needed to be considered when drawing the ingress and egress lanes and points: (1) whether or not a crosswalk exists, and (2) if the right turn adds a lane or immediately merges with the traffic stream. The following methodology was decided upon as shown:

**Figure 15: Continuous Right Turns**

Another issue discussed was how to deal with parts of roadway marked “Do Not Block Driveway,” such as in front of a fire station on Cleveland Avenue. Unfortunately, this type of message cannot be communicated in a MAP message so this area was simply drawn as if the “Do Not Block Driveway” did not exist.

It was initially unclear how to account for Two Way Left Turn Lanes (TWLTL) as these lanes do not have a set beginning and end, do not merge with another lane, and are not only for turns at a signaled intersection. Since there is not a specific well-defined way to represent a TWLTL in a MAP message, it was decided that a TWLTL would be represented as a regular turn lane with the beginning of the lane at the stopbar and the end of the lane 60 feet from the stopbar.

Determining what qualifies as a “Parking Lane” was also difficult. It was decided that a parking lane would only be digitized if it is always for parking at all times and has a defined lane line. This means that if a lane was a through lane at some times of the day and parking others, it was digitized as a through lane only. Digitizing these lanes as parking lanes would require drawing “overlay lanes” on top of the travel lane so that various MAP messages could be generated and available for every possible scenario depending whether or not parking is allowed at a given time. A system to output the appropriate MAP message for the given time or
situation would have to be put in place. Furthermore, smaller streets that allow parking but have no lane lines whatsoever (many examples of this along High St. in the OSU campus area) also did not have parking lanes digitized. Additionally, the through lanes in these “smaller street” circumstances were digitized according to the path where cars are most likely to drive as there were no lane lines to follow.
List of Completed Intersections

The following intersections were completed:

<table>
<thead>
<tr>
<th>Intersection #</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>3010</td>
<td>CLEVELAND AVE. AT SECOND AVE.</td>
</tr>
<tr>
<td>3012</td>
<td>CLEVELAND AVE. AT FIFTH AVE.</td>
</tr>
<tr>
<td>3014</td>
<td>CLEVELAND AVE. AT WINDSOR AVE.</td>
</tr>
<tr>
<td>3015</td>
<td>CLEVELAND AVE. AT SEVENTEENTH AVE.</td>
</tr>
<tr>
<td>3017</td>
<td>CLEVELAND AVE. AT TWENTIETH AVE.</td>
</tr>
<tr>
<td>3018</td>
<td>CLEVELAND AVE. AT TWENTY-FOURTH AVE.</td>
</tr>
<tr>
<td>3019</td>
<td>CLEVELAND AVE. AT DUXBERRY AVE.</td>
</tr>
<tr>
<td>3020</td>
<td>CLEVELAND AVE. AT HUDSON AVE.</td>
</tr>
<tr>
<td>3021</td>
<td>CLEVELAND AVE. AT MYRTLE AVE.</td>
</tr>
<tr>
<td>3022</td>
<td>CLEVELAND AVE. AT GENESSEE AVE.</td>
</tr>
<tr>
<td>3023</td>
<td>ABERDEEN AVE. AT CLEVELAND AVE.</td>
</tr>
<tr>
<td>3024</td>
<td>CLEVELAND AVE. AT WEBER RD.</td>
</tr>
<tr>
<td>3092</td>
<td>MORSE RD. AT STYGLER RD.</td>
</tr>
<tr>
<td></td>
<td>L BRANDS DRIVEWAY/ HAP CREMEAN AT MORSE RD.</td>
</tr>
<tr>
<td>3093</td>
<td>CLEVELAND AVE. AT OAKLAND PARK AVE.</td>
</tr>
<tr>
<td>3154</td>
<td>CLEVELAND AVE. AT FERRIS RD.</td>
</tr>
<tr>
<td>3161</td>
<td>I-270 SB RAMPS AT MORSE RD.</td>
</tr>
<tr>
<td>3162</td>
<td>I-270 NB RAMPS AT MORSE RD.</td>
</tr>
<tr>
<td>3163</td>
<td>APPIAN WAY AT MORSE RD.</td>
</tr>
<tr>
<td>3209</td>
<td>MORSE RD. AT SUNBURY RD.</td>
</tr>
<tr>
<td>3228</td>
<td>MORSE RD. AT STELZER RD.</td>
</tr>
<tr>
<td>3231</td>
<td>EASTON LOOP &amp; EASTON SQUARE AT MORSE RD.</td>
</tr>
<tr>
<td>3237</td>
<td>MORSE CROSSING AT MORSE RD.</td>
</tr>
<tr>
<td>3290</td>
<td>CHESFORD RD. AT MORSE RD.</td>
</tr>
<tr>
<td>3291</td>
<td>MORSE RD. AT WESTERVILLE RD.</td>
</tr>
<tr>
<td>3405</td>
<td>INDIANOLA AVE. AT MORSE RD.</td>
</tr>
<tr>
<td>3407</td>
<td>MORSE RD. AT SINCLAIR RD. /I-71 SB</td>
</tr>
<tr>
<td>3408</td>
<td>I-71 NB RAMPS AT MORSE RD.</td>
</tr>
<tr>
<td>3409</td>
<td>MORSE RD. AT SANDY LANE RD.</td>
</tr>
<tr>
<td>3410</td>
<td>MAIZE RD. AT MORSE RD.</td>
</tr>
<tr>
<td>3411</td>
<td>McFADDEN RD. AT MORSE RD.</td>
</tr>
<tr>
<td>3412</td>
<td>KARL RD. AT MORSE RD.</td>
</tr>
<tr>
<td>3413</td>
<td>MORSE RD. AT NORTHLAND RIDGE BLVD.</td>
</tr>
<tr>
<td>3414</td>
<td>MORSE RD. AT TAMARACK BLVD.</td>
</tr>
<tr>
<td>3415</td>
<td>HEATON RD. AT MORSE RD.</td>
</tr>
<tr>
<td>3416</td>
<td>MORSE RD. AT WALFORD ST./ NORTHTOWNE BLVD.</td>
</tr>
<tr>
<td>3417</td>
<td>MALIN ST. AT MORSE RD.</td>
</tr>
<tr>
<td>3440</td>
<td>CLEVELAND AVE. AT MORSE RD.</td>
</tr>
<tr>
<td>3446</td>
<td>EVANSWOOD DR. AT MORSE RD.</td>
</tr>
<tr>
<td>Number</td>
<td>Intersection</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------------------------------</td>
</tr>
<tr>
<td>4006</td>
<td>ARCADIA AVE. AT HIGH ST.</td>
</tr>
<tr>
<td>4007</td>
<td>DODRIDGE ST. AT HIGH ST.</td>
</tr>
<tr>
<td>4009</td>
<td>HIGH ST. AT OLENTANGY ST.</td>
</tr>
<tr>
<td>4017</td>
<td>FIFTH AVE. AT HIGH ST.</td>
</tr>
<tr>
<td>4019</td>
<td>TENTH AVE. AT HIGH ST.</td>
</tr>
<tr>
<td>4020</td>
<td>HIGH ST. AT CHITTENDEN AVE.</td>
</tr>
<tr>
<td>4021</td>
<td>HIGH ST. AT TWELTH AVE.</td>
</tr>
<tr>
<td>4025</td>
<td>HIGH ST. AT WOODRUFF AVE.</td>
</tr>
<tr>
<td>4026</td>
<td>HIGH ST. AT LANE AVE.</td>
</tr>
<tr>
<td>4028</td>
<td>HIGH ST. AT PATTERSON AVE.</td>
</tr>
<tr>
<td>4029</td>
<td>HIGH ST. AT HUDSON AVE.</td>
</tr>
<tr>
<td>4032</td>
<td>HIGH ST. AT KELSO RD.</td>
</tr>
<tr>
<td>4033</td>
<td>HIGH ST. AT WEBER RD.</td>
</tr>
<tr>
<td>4034</td>
<td>HIGH ST. AT PACEMONT RD.</td>
</tr>
<tr>
<td>4035</td>
<td>COMO AVE. AT HIGH ST.</td>
</tr>
<tr>
<td>4036</td>
<td>HIGH ST. AT NORTH BROADWAY</td>
</tr>
<tr>
<td>4037</td>
<td>HIGH ST. AT OAKLAND PARK AVE.</td>
</tr>
<tr>
<td>4038</td>
<td>HIGH ST. AT TORRENCE RD.</td>
</tr>
<tr>
<td>4039</td>
<td>ERIE RD. AT HIGH ST.</td>
</tr>
<tr>
<td>4040</td>
<td>ACTION RD./ HOLLENBACK RD. AT HIGH ST.</td>
</tr>
<tr>
<td>4041</td>
<td>HIGH ST. AT GLENMONT AVE.</td>
</tr>
<tr>
<td>4042</td>
<td>COOKE RD. AT HIGH ST.</td>
</tr>
<tr>
<td>4043</td>
<td>HENDERSON RD. AT HIGH ST.</td>
</tr>
<tr>
<td>4044</td>
<td>DOMINION BLVD. AT HIGH ST.</td>
</tr>
<tr>
<td>4045</td>
<td>HIGH ST. AT WEISHEIMER RD.</td>
</tr>
<tr>
<td>4046</td>
<td>HIGH ST. AT GARDEN RD.</td>
</tr>
<tr>
<td>4047</td>
<td>HIGH ST. AT MORSE RD.</td>
</tr>
<tr>
<td>4107</td>
<td>ELEVENTH AVE. AT HIGH ST.</td>
</tr>
<tr>
<td>6909</td>
<td>CLEVELAND AVE. AT HUY RD.</td>
</tr>
<tr>
<td>6910</td>
<td>CLEVELAND AVE. AT INNIS RD.</td>
</tr>
<tr>
<td>6911</td>
<td>CLEVELAND AVE. AT ELMORE AVE.</td>
</tr>
<tr>
<td>6912</td>
<td>CLEVELAND AVE. AT COOKE RD.</td>
</tr>
<tr>
<td>6914</td>
<td>CLEVELAND AVE. AT NORTHERN LIGHTS</td>
</tr>
</tbody>
</table>
List of Incomplete Intersections

Some intersections were not completed due to ongoing construction or other issues. The intersections impeded by construction may be digitized by placing the approved plans for the intersection as a layer in the GIS, then drawing the points and lines on top of the plans. This would be a close enough estimation to the striping on the intersection after construction is completed. It is not feasible to wait for the satellite imagery to be updated for some intersections. The intersections not completed are listed below:

<table>
<thead>
<tr>
<th>Intersection #</th>
<th>Name</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>3013</td>
<td>CLEVELAND AVE. AT ELEVENTH AVE.</td>
<td>Approach cannot be digitized visually due to tunnel on south side</td>
</tr>
<tr>
<td>4018</td>
<td>HIGH ST. AT SEVENTH AVE. / KING AVE.</td>
<td>Construction</td>
</tr>
<tr>
<td>4022</td>
<td>FIFTEENTH AVE. AT HIGH ST.</td>
<td>Construction</td>
</tr>
<tr>
<td>4023</td>
<td>HIGH ST. AT SEVENTEENTH AVE.</td>
<td>Construction</td>
</tr>
<tr>
<td>4024</td>
<td>EIGHTEENTH AVE. / MCDONALD'S AT HIGH ST.</td>
<td>Construction</td>
</tr>
<tr>
<td>4027</td>
<td>HIGH ST. AT NORTHWOOD AVE.</td>
<td>Construction</td>
</tr>
<tr>
<td>4072</td>
<td>HIGH ST. AT THIRTEENTH AVE.</td>
<td>Construction</td>
</tr>
<tr>
<td>4103</td>
<td>HIGH ST. AT NINTH AVE.</td>
<td>Construction</td>
</tr>
</tbody>
</table>
Conclusion

In conclusion, 72 out of 80 identified intersections along three of Columbus’s high traffic corridors were digitized and exported to enable MAP message creation. Intersections were digitized by first placing a point at the center and drawing a circle having a radius of 1200 feet from the center point. Then, stopbar endpoints and crosswalk endpoints were drawn along with lane points. Next, the lane lines were drawn between the points and the attributes of the points and lines were populated. A number of challenges were encountered throughout the digitization process, but the majority of issues have been solved. Moving forward, the appropriate data will be sent to the vendor responsible for the connected vehicle hardware and software and the remaining intersections will need to be digitized once construction has been completed.
Appendix A
List of Tables and Figures

Tables
Table 1: Lane Point Diagram 4
Table 2: Lane Assignments 9

Figures
Figure 1: Imagery Comparison 3
Figure 2: Completed Circle Attributes 5
Figure 3: Stopbar Endpoint Placement 5
Figure 4: Lane Point Diagram 6
Figure 5: Through Lane Splits into Turn Lane & Through Lane 7
Figure 6: Crosswalk Points 7
Figure 7: Completed Points and Lines 8
Figure 8: Lane Numbering 10
Figure 9: Lane Point Attributes 11
Figure 10: Lane Line Attributes 12
Figure 11: Python Export Tool 13
Figure 12: Output of Python Export Tool 14
Figure 13: MAP Message Generation Spreadsheet Tool 15
Figure 14: I-71 at Morse Rd. 16
Figure 15: Continuous Right Turns 17
Appendix B
Python Code for GIS to Excel Export

```
print('Loading. Please wait...')
import arcpy
import pandas as pd
import os

# Creates an excel file containing the geometry and attributes of all lane points and crosswalk points
def outputPoints(intersection):
    points = "C:\Users\gantonini\Desktop\Smart City.gdb\Points"
    output = "R:\JWIGGINS\Smart City\Intersection Outputs\Points_" + intersection + ".xls"
    if os.path.exists(output):
        while True:
            overwrite = raw_input("File already Exists. Do you want to overwrite? (Enter y or n): ")
            if (overwrite == "y" or overwrite == "Y"):
                expression = "Intersect_Num = " + intersection + " And (PT_Type = 'LN' Or PT_Type = 'CW')"
                arcpy.env.workspace = "C:\Users\gantonini\Desktop\Smart City.gdb"
                arcpy.env.overwriteOutput = True
                my_shp_layer = "C:\Users\gantonini\Desktop\Smart City.gdb\Points"
                arcpy.MakeFeatureLayer_management(my_shp_layer, "my_shp_layer_temp")
                arcpy.SelectLayerByAttribute_management("my_shp_layer_temp", "NEW_SELECTION", expression)
                arcpy.CopyFeatures_management("my_shp_layer_temp", "correctPoints")
                arcpy.conversion.TableToExcel("correctPoints", output, "ALIAS", "DESCRIPTION")
                break
            elif overwrite != "n" and overwrite != "N":
                print("Please enter y or n.")
            else:
                arcpy.Delete_management("C:\Users\gantonini\Desktop\Smart City.gdb\correctPoints")
                arcpy.Delete_management("my_shp_layer_temp")
                break
    else:
        expression = "Intersect_Num = " + intersection + " And (PT_Type = 'LN' Or PT_Type = 'CW')"
        arcpy.env.workspace = "C:\Users\gantonini\Desktop\Smart City.gdb"
        my_shp_layer = "C:\Users\gantonini\Desktop\Smart City.gdb\Points"
        arcpy.MakeFeatureLayer_management(my_shp_layer, "my_shp_layer_temp")
        arcpy.SelectLayerByAttribute_management("my_shp_layer_temp", "NEW_SELECTION", expression)
        arcpy.CopyFeatures_management("my_shp_layer_temp", "correctPoints")
        arcpy.conversion.TableToExcel("correctPoints", output, "ALIAS", "DESCRIPTION")
```
```python
arcpy.Delete_management("C:\Users\gantonini\Desktop\Smart City.gdb\correctPoints")
arcpy.Delete_management("my_shp_layer_temp")

#Creates an excel file containing the attributes of all lane lines
def outputLanes(intersection):
    lanes = "C:\Users\gantonini\Desktop\Smart City.gdb\Lanes"
    output = "R:\JWIGGINS\Smart City\Intersection Outputs\Lanes_" + intersection + ".xls"
    if os.path.exists(output):
        while True:
            overwrite = raw_input("File already Exists. Do you want to overwrite? (Enter y or n): ")
            if (overwrite == "y" or overwrite == "Y"):
                expression = "Intersection_Num =" + intersection
                arcpy.env.workspace = "C:\Users\gantonini\Desktop\Smart City.gdb"
                arcpy.env.overwriteOutput = True
                my_shp_layer = "C:\Users\gantonini\Desktop\Smart City.gdb\Lanes"
                arcpy.MakeFeatureLayer_management(my_shp_layer, "my_shp_layer_temp")
                arcpy.SelectLayerByAttribute_management("my_shp_layer_temp", "NEW_SELECTION", expression)
                arcpy.CopyFeatures_management("my_shp_layer_temp", "correctPoints")
                arcpy.conversion.TableToExcel("correctPoints", output, "ALIAS", "DESCRIPTION")
                break
            elif overwrite != "n" and overwrite != "N":
                print("Please enter y or n.")
            else:
                arcpy.Delete_management("C:\Users\gantonini\Desktop\Smart City.gdb\correctPoints")
                arcpy.Delete_management("my_shp_layer_temp")
                break
    else:
        expression = "Intersection_Num =" + intersection
        arcpy.env.workspace = "C:\Users\gantonini\Desktop\Smart City.gdb"
        my_shp_layer = "C:\Users\gantonini\Desktop\Smart City.gdb\Lanes"
        arcpy.MakeFeatureLayer_management(my_shp_layer, "my_shp_layer_temp")
        arcpy.SelectLayerByAttribute_management("my_shp_layer_temp", "NEW_SELECTION", expression)
        arcpy.CopyFeatures_management("my_shp_layer_temp", "correctPoints")
        arcpy.conversion.TableToExcel("correctPoints", output, "ALIAS", "DESCRIPTION")
        arcpy.Delete_management("C:\Users\gantonini\Desktop\Smart City.gdb\correctPoints")
        arcpy.Delete_management("my_shp_layer_temp")
```

#Creates an excel file containing the attributes of the point at the center of the intersection
```python
def outputIntersection(intersection):
    points = "C:\Users\gantonini\Desktop\Smart City.gdb\Points"
```
output = "R:\JWIGGINS\Smart City\Intersection Outputs\Intersection_" + intersection + ".xls"
if os.path.exists(output):
    while True:
        overwrite = raw_input("File already Exists. Do you want to overwrite? (Enter y or n): ")
        if (overwrite == "y" or overwrite == "Y"):
            expression = "Intersect_Num = " + intersection + " And PT_Type = 'C'
            arcpy.env.workspace = "C:\Users\gantonini\Desktop\Smart City.gdb"
            arcpy.env.overwriteOutput = True
            my_shp_layer = "C:\Users\gantonini\Desktop\Smart City.gdb\Points"
            arcpy.MakeFeatureLayer_management(my_shp_layer, "my_shp_layer_temp")
            arcpy.SelectLayerByAttribute_management("my_shp_layer_temp", "NEW_SELECTION", expression)
            arcpy.CopyFeatures_management("my_shp_layer_temp", "correctPoints")
            arcpy.conversion.TableToExcel("correctPoints", output, "ALIAS", "DESCRIPTION")
            break
        elif overwrite != "n" and overwrite != "N":
            print("Please enter y or n.")
        else:
            arcpy.Delete_management("C:\Users\gantonini\Desktop\Smart City.gdb\correctPoints")
            arcpy.Delete_management("my_shp_layer_temp")
            break
else:
    expression = "Intersect_Num = " + intersection + " And PT_Type = 'C'
    arcpy.env.workspace = "C:\Users\gantonini\Desktop\Smart City.gdb"
    my_shp_layer = "C:\Users\gantonini\Desktop\Smart City.gdb\Points"
    arcpy.MakeFeatureLayer_management(my_shp_layer, "my_shp_layer_temp")
    arcpy.SelectLayerByAttribute_management("my_shp_layer_temp", "NEW_SELECTION", expression)
    arcpy.CopyFeatures_management("my_shp_layer_temp", "correctPoints")
    arcpy.conversion.TableToExcel("correctPoints", output, "ALIAS", "DESCRIPTION")
    arcpy.Delete_management("C:\Users\gantonini\Desktop\Smart City.gdb\correctPoints")
    arcpy.Delete_management("my_shp_layer_temp")

#Combines all three excel files into one excel file with three separate tabs

def combineExcel(intersection):
    df1 = pd.read_excel("R:\JWIGGINS\Smart City\Intersection Outputs\Intersection_" + intersection + ".xls", parse_cols=[0,3,4,5,7,8], index_col=0)
    df2 = pd.read_excel("R:\JWIGGINS\Smart City\Intersection Outputs\Lanes_" + intersection + ".xls", parse_cols=[0,1,2,3,4], index_col=0)
    df3 = pd.read_excel("R:\JWIGGINS\Smart City\Intersection Outputs\Points_" + intersection + ".xls", parse_cols=[0,1,2,3,4,5,6], index_col=0)
writer = pd.ExcelWriter("R:\JWIGGIS\Smart City\Intersection Outputs\\" + intersection + ".xls")
df1.to_excel(writer, index= False, sheet_name='Basic Info')
df2.to_excel(writer, index= False, sheet_name='Lane Properties')
df3.to_excel(writer, index= False, sheet_name='Lane Points')
writer.save()

print('Cleaning up...')
o.s.remove("R:\JWIGGIS\Smart City\Intersection Outputs\Intersection_" + intersection + ".xls")
o.s.remove("R:\JWIGGIS\Smart City\Intersection Outputs\Lanes_" + intersection + ".xls")
o.s.remove("R:\JWIGGIS\Smart City\Intersection Outputs\Points_" + intersection + ".xls")

#This function calls each of the above functions using a specific intersection as the input parameter
def default():
    print('Extracting point data...')
    outputPoints(intersection)
    print('Extracting lane data...')
    outputLanes(intersection)
    print('Extracting intersection data...')
    outputIntersection(intersection)
    print('Creating output file...')
    combineExcel(intersection)
    print("Success!")

#Prompts the user to input the number of the intersection to output and exports
#intersection data by calling the default function until the user enters 'end'
count_run = 1
while True:
    if count_run == 1:
        intersection = raw_input('Enter the intersection number: ') 
        if intersection.isdigit():
            default()
        else:
            print('
' + "***Please enter a valid intersection number.***" + '
')
        count_run = count_run + 1
    else:
        intersection = raw_input('Enter the intersection number or type \'end\' to exit: ') 
        if intersection == 'end':
            break
        else:
            if intersection.isdigit():
                default()
            else:
                print('
' + "***Please enter a valid intersection number.***" + '
')
            count_run = count_run + 1
Appendix E. Traveler Information Message Generation

The TIMs messages for the Smart Columbus Connected Vehicle Environment were generated using the USDOT TIM Message Creator https://webapp.connectedvcs.com/tim/. This document describes the process that was used to generated TIM messages using this tool.

First a polygon region was defined. The polygon region represents the physical boundaries of the school zone. The school zone for each direction of travel is defined as the location of the “SCHOOL” pavement marking until signage that indicates “End School Zone Speed Limit”. The end of the school zone for one direction of travel does not necessarily correspond to the beginning of the zone for the opposite direction of travel.

![Beginning of School Zone Pavement Marking](image1)

![End of School Zone Signage](image2)

Figure 7: School Zone Pavement Markings and Signage

*Source: City of Columbus*

Once the polygon is defined, a “Verified Point Marker” is dragged and dropped onto the map, roughly near the center of the school zone. A “Speed Limit” feature is also dragged and dropped onto the map, roughly near the center of the school zone. The following “speed limit” feature attributes were specified:

- **Marker Info**
  - Start Time: Current time specified
  - End Time: 5 minutes later than current time specified
    - Note that the start time and end time are used to populate the startTime and duration data elements in the TIM message – these values are overwritten by the message handler based on data from the school zone management system.
  - Latitude: automatically populated based on location of marker – value is not edited.
  - Longitude: automatically populated based on location of marker – value is not edited.
  - Elevation: automatically populated based on location of marker – value is not edited.
  - Master Lane Width: automatically populated – value is not edited.

- **Content**
  - MUTCD: (1) Regulatory Sign
  - Info Type: (2) Road Signage

- **Directionality**
  - Direction: (3) Both
  - Headings: *all heading slices selected*
Appendix E. Traveler Information Message Generation

- ITIS Codes (in order)
  - Code 4124: School Zone
  - Code 12564: number 20
  - Code 8720: MPH units

---

**Our Lady of Peace School Zone (High Street at Dominion Blvd)**

Start Time: 11/21/2019 12:03 PM
End Time: 11/22/2019 12:03 PM
Latitude: 40.05356887
Longitude: -83.0198645231357
Elevation: 213
Master Lane Width: 366
SSP TIM Rights: 0 to 31
SSP Location Rights: 0 to 31
Packet ID: 310656750
SSP Content Rights: 0 to 31
SSP Type Rights: 0 to 31
MUTCD: (1) Regulatory Sign (Red) -
Info Type: (2) Road Signage -
Priority: (3) Both -
Direction: (3) Both -

Select the heading slices:

- Text: Type Text (Limit: 16 chars)
- Codes: 4124, 12564, 8720

---

Figure 8: Traveler Information Message Creator Typical Specification for School Zones in the CVE

Source: City of Columbus