Smart Columbus

Concept of Operations for the Connected Vehicle Environment for the Smart Columbus Demonstration Program

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Final – June 8, 2018

FHWA-JPO-17-521

Source: City of Columbus – November 2015

U.S. Department of Transportation

Produced by City of Columbus, Ohio
U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology

Notice

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-17-521		

4. Title and Subtitle	5. Report Date
Concept of Operations for the Connected Vehicle Environment for the Smart Columbus Demonstration Program	08-June-2018
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
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9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
City of Columbus 90 West Broad Street Columbus, OH 43215-9004	11. Contract or Grant No. DTFH6116H00013
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation (USDOT) Federal Highway Administration (FHWA) Office of Acquisition and Grants Management 1200 New Jersey Avenue, SE Mail Drop: E62-204 Washington, DC 20590	Concept of Operations 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This document describes the Concept of Operations (ConOps) for the Smart Columbus program Connected Vehicle Environment project. This ConOps provides an approach that ensures that the Connected Vehicle Environment is built to address safety and mobility needs of system users in the City of Columbus, Ohio through a planned deployment of connected vehicle equipment on 1,800 vehicles and at 113 roadside locations. This document will describe the current system, the needs of the users of this system, how the proposed system will address these needs, constraints on the system, and potential operational characteristics of the system, but it will not impose requirements on the system or recommend a specific technology solution. Ultimately, this document provides a connection between program-level visions and goals and project-level concepts. Technical specifications and design details will be developed in subsequent documents.

17. Key Words	18. Distribution Statement
Smart Columbus, Connected Vehicle Environment, Concept of Operations	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	213	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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Chapter 1. Introduction

This Concept of Operations (ConOps) serves as the first in a series of engineering documents for the Connected Vehicle Environment (CVE) for the Smart Columbus program. The purpose of this ConOps is to clearly convey a high-level view of the system to be implemented from the viewpoint of each stakeholder. This document frames the overall system, sets the technical course for the project, and serves as a bridge between early project motivations and the technical requirements. The ConOps is technology-independent, focuses on the functionality of the proposed system, and forms the basis of the project. The ConOps also serves to communicate the users' needs and expectations for the proposed system. Finally, this document gives stakeholders the opportunity to give input as to how the proposed system should function, which will help build consensus and create a single vision for the system moving forward.

The structure of this document is tailored from the Institute of Electrical and Electronics Engineers (IEEE) Standard 1362-1998 containing the following sections:

- **Chapter 1, Introduction** provides a high-level overview of the general concepts and nature of the CVE project.
- **Chapter 2, References** identifies all documents referenced and interviews conducted in developing this document.
- **Chapter 3, Current System** describes the current and supporting systems and problem(s) to be addressed.
- **Chapter 4, Justification and Nature of Changes** describes the features that motivate the project's development.
- **Chapter 5, Concept for the New System** provides a high-level description of the proposed system resulting from the features described in **Chapter 4**.
- **Chapter 6, Operational Scenarios** presents how the project is envisioned to operate from various perspectives.
- **Chapter 7, Summary of Impacts** describes the impacts the project will have on the stakeholders, users, and system owners/operators.
- **Chapter 8, Analysis of the Connected Vehicle Environment** provides an analysis of the impacts presented in **Chapter 7**.
- **Chapter 9, Notes** Includes additional information to aid in the understanding of this ConOps.

Project Scope

In 2016, the U.S. Department of Transportation (USDOT) awarded $40 million to the City of Columbus, Ohio, as the winner of the Smart City Challenge. With this funding, Columbus intends to address the most pressing community-centric transportation problems by integrating an ecosystem of advanced and innovative technologies, applications, and services to bridge the sociotechnical gap and meet the needs of residents of all ages and abilities. In conjunction with the Smart City Challenge, Columbus was also awarded a $10 million grant from Paul G. Allen Philanthropies to accelerate the transition to an electrified, low-emissions transportation system.

With the award, the city established a strategic Smart Columbus program with the following vision and mission:

- Smart Columbus Vision: Empower residents to live their best lives through responsive, innovative, and safe mobility solutions
- Smart Columbus Mission: Demonstrate how and ITS and equitable access to transportation can have positive impacts of every day challenges faced by cities.

To enable these new capabilities, the Smart Columbus program his organized into three focus areas addressing unique user needs: enabling technologies, emerging technologies, and enhanced human services. The CVE primarily addresses needs in the enabling technologies program focus area.

The CVE project is one of the nine projects in the Smart Columbus program and is a significant enabler to other technologies delivered through the other eight projects. The CVE project will integrate smart traveler applications, automated vehicles, connected vehicles, and smart sensors into its transportation network by focusing on deploying CV infrastructure and CV applications.

- **CV Infrastructure** – The project will focus on building out the physical and logical CV infrastructure, which will consist of CV hardware and software (e.g. roadside units (RSUs), on-board equipment, front and backhaul communications, equipment interfaces, etc.). The CVE will generate the needed transportation-related data that are used by applications.
- **CV Applications and Data** – The project scope also consists of deploying CV-specific applications that will leverage the data generated by the infrastructure to deliver real-time safety and mobility services. Data will be collected, stored, and made available for use in other Smart Columbus project applications.

The CVE is expected to enhance safety and mobility for vehicle operators and improve pedestrian safety in school zones by deploying CV infrastructure on the roadside and CV Equipment in vehicles. The CVE will also provide sources of high-quality data for traffic management and safety purposes. The foundation for the CVE is the Columbus Traffic Signal System (CTSS), which is a high-speed network backbone. When complete, the CTSS will interconnect the region’s 1,250 traffic signals and provide uniform signal coordination capability throughout the system. CTSS Phase E, which will connect all CVE corridors (detailed later in this ConOps) with the exception of Alum Creek Drive, is expected to be complete in December 2018. An expansion of the CTSS to connect Alum Creek Drive will be included in the next phase of the CTSS and is expected to be complete in 2020. The CV infrastructure deployment will occur along seven major corridors/areas. The deployment of in-vehicle devices will target populations that are located near or frequently use the infrastructure deployment corridors. Improvements associated with the CVE include:

Table 1: Connected Vehicle Environment Project Scope

Infrastructure		Applications and Data	
113 RSUs The project will install RSUs and other CV-compatible equipment at signalized intersections in the project areas.	**1,800 OBUs** The project will install onboard units (OBUs) on participating private, emergency, transit, and freight vehicles.	**CV Applications** The project will deploy vehicle-to-vehicle (V2V) safety, vehicle-to-infrastructure (V2I) safety, and V2I mobility applications.	**Data Capture** The project will capture, relate, store, and respond to data generated by the infrastructure, used by the applications for traffic management.

Source: City of Columbus

The intent of the CVE project is to improve safety and mobility of travelers by deploying CV technology. Because the CVE primarily intends to deploy CV technology (not the development of new applications or functionality), it is important for the reader to understand that the ability of the CVE to address the user needs captured in this ConOps depends on the availability of deployment-ready hardware and software solutions. Thus, the design and implementation of the CVE will draw on these previous development efforts. The Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT)[1] and its predecessor, the Connected Vehicle Reference Implementation Architecture (CVRIA)[2], are resources that provide descriptions of CV applications that have been researched in the context of the National ITS architecture. Furthermore, the Open Source Application Development Portal (OSADP) contains software for applications that have been developed[3]. When possible, applications on the CVRIA and OSADP will be used as-is or will have minimal modifications made to address user needs documented in this ConOps.

Given that the primary scope of the CVE is to realize the benefits of deploying CV technology into an operational environment, only applications that have demonstrated sufficient levels of development and testing are being considered for implementation. However, the CVE will be designed in such a way that added functionality concepts (that need further development) can be integrated with the CVE once development and testing have matured to a point where they are deployment-ready. Additionally, due to the networked nature of devices in the CVE, several policies and constraints related to information technology and data security are expected to be developed as part of the deployment.

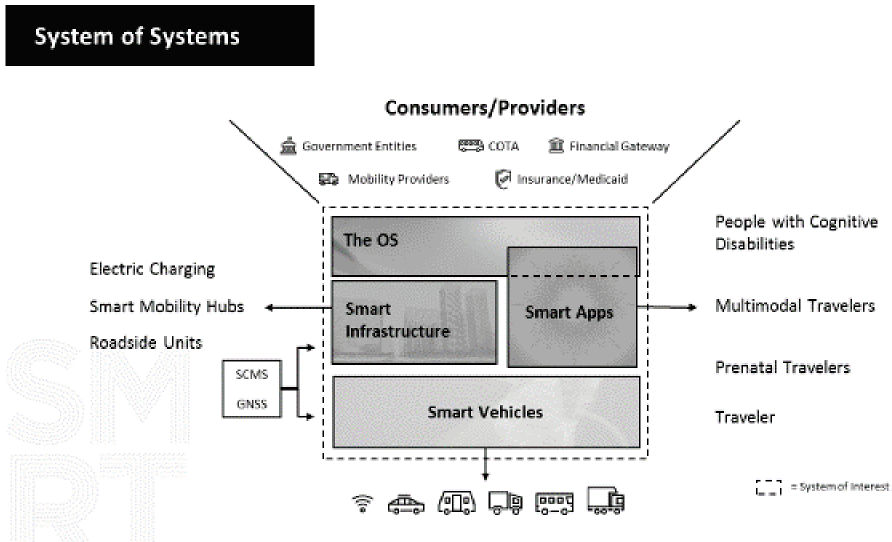
Project Relation to the System of Systems

The Smart Columbus program has many interrelated systems that work together to provide a System of Systems (SoS). Information from these systems are shared in the Smart Columbus Operating System (Operating System). Both real-time and archived data is maintained in the Operating System for use by other Smart Columbus projects and future applications. The SoS provides Smart Applications (Apps), Smart Vehicles, and Smart infrastructure to travelers in the Columbus area. The Operating System enables the SoS to share data with many other internal and external systems to provide the framework for the services provided. **Figure 1: System of Systems Context Diagram** shows the relationship of the SoS to the external travelers and systems, and highlights those systems or elements that are affected by the CVE, as noted by the star icon. Specifically, the Smart Infrastructure element contains the RSUs and corresponding network that enable interactions between RSUs and the Operating System. Smart Vehicles include the OBUs that will be installed in vehicles and, as shown, include all five vehicle types. Smart Applications include the software-oriented solutions that will deliver other Smart Columbus project capabilities such as multimodal trip planning, common payment, prenatal trip assistance, etc. The Operating System is the repository for all performance data from the Smart Infrastructure and Smart Vehicles, as well as the microservices platform that allow the Smart Applications to be directly integrated. Finally, the CVE has a dependency on the Security Credential Management System (SCMS) and Global Network Satellite System (GNSS) services.

[1] *https://local.iteris.com/arc-it/*

[2] *https://local.iteris.com/cvria/*

[3] *Open Source Application Development Portal. https://www.itsforge.net/*



Source: City of Columbus

Figure 1: System of Systems Context Diagram

The CVE works with several other Smart Columbus projects and external systems to provide Smart Vehicles and Smart Infrastructure. CVE will receive inputs from the GNSS and SCMS. CVE will provide OBUs for trucks to allow truck platooning and freight signal priority. It will provide OBUs to Connected Electric Automated Vehicles (CEAV) to allow for transit signal priority (TSP) and other infrastructure communications. It will provide OBUs to light-duty vehicles to provide a wide range of safety warning applications. The RSUs, co-located with traffic signals, will provide approaching drivers with signal phase and timing information which can be used to generate in-vehicle warnings (e.g. Red Light Violation Warning). The traffic signal and CV data will be provided to the Traffic Management Center (TMC) for monitoring and analysis.

Chapter 2. References

Table 2: Connected Vehicle Environment Resources lists resources (documents, online information, and standards) relevant to the Smart Columbus CVE.

Table 2: Connected Vehicle Environment Resources

Document Number	Title	Rev	Pub. Date
FHWA-JPO-17-518	Smart Columbus Systems Engineering Management Plan (SEMP) for Smart Columbus Demonstration Program https://rosap.ntl.bts.gov/view/dot/34764	-	January 16, 2018
-	Beyond Traffic: The Smart City Challenge – Phase 2 – Volume 1: Technical Application https://www.columbus.gov/WorkArea/DownloadAsset.aspx?id=2147487896	-	May 24, 2016
-	Connected Vehicle Environment Technical Working Group Meeting #1	-	December 19, 2016
-	Connected Vehicle Environment Technical Working Group Meeting #2	-	February 7, 2017
-	Connected Vehicle Environment Technical Working Group Meeting #3	-	April 19, 2017
-	CEAV Technical Working Group Meeting #1	-	December 19, 2016
-	CEAV Technical Working Group Meeting #2	-	February 27, 2017
-	CEAV Technical Working Group Meeting #3	-	April 19, 2017
-	COTA Outreach Meeting #1	-	September 26, 2016
-	COTA Outreach Meeting #2	-	January 26, 2017
-	COTA Outreach Meeting #3	-	March 9, 2017
-	COTA Outreach Meeting #4	-	March 20, 2018
-	Department of Public Safety Outreach Meeting #1	-	March 28, 2017
-	Department of Public Safety Outreach Meeting #2	-	August 21, 2017

Document Number	Title	Rev	Pub. Date
-	Open Source Application Development Portal https://www.itsforge.net/	-	-
-	Security Credential Management System Proof–of–Concept Implementation – EE Requirements and Specifications Supporting SCMS Software Release 1.0 http://www.its.dot.gov/pilots/pdf/SCMS_POC_EE_Requirements20160111_1655.pdf	-	January 11, 2016
-	End Entity Requirements and Specifications Supporting SCMS Software Release https://wiki.campllc.org/display/SCP	-	*Cont. updated*
-	Mid-Ohio Regional Planning Commission – 2016-2040 Columbus Area Metropolitan Transportation Plan http://www.morpc.org/wp-content/uploads/2017/12/060216FINAL-MTP-REPORT-merged.pdf	-	May 2016
-	The City of Columbus – Multi-Modal Thoroughfare Plan https://www.columbus.gov/publicservice/Connect-Columbus/	-	-
-	Central Ohio Transit Authority (COTA) – Long Range Transit Plan https://www.cota.com/wp-content/uploads/2016/04/LRTP.pdf	-	April 2016
-	Columbus, Ohio – Code of Ordinances (Columbus City Code) https://www.municode.com/library/oh/columbus/codes/code_of_ordinances	-	-
-	Ohio Revised Code http://codes.ohio.gov/orc/	-	-
-	Ohio Department of Transportation – Access Ohio 2040 http://www.dot.state.oh.us/Divisions/Planning/SPR/StatewidePlanning/access.ohio/AO40_library/ODOTAccessOhio2014.pdf	-	-

Document Number	Title	Rev	Pub. Date
-	Ohio Manual of Uniform Traffic Control Devices. Ohio Department of Transportation http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/OhioMUTCD/Pages/OMUTCD2012_current_default.aspx	-	January 13, 2012
-	Traffic Signal Design Manual. City of Columbus Department of Public Service https://www.columbus.gov/WorkArea/DownloadAsset.aspx?id=2147498299	-	August 10, 2017
-	MORPC – Previous High-Crash Intersections http://www.morpc.org/wp-content/uploads/2017/12/001.Previous_HCL.pdf	-	-
-	*MORPC – Top 100 Regional High-Crash Intersections (2017)* http://www.morpc.org/wp-content/uploads/2017/12/001.HCL_2014_2016_Top100.pdf	-	-
-	Multi-Modal Intelligent Traffic Signal System (MMITSS) ConOps http://www.cts.virginia.edu/wp-content/uploads/2014/05/Task2.3._CONOPS_6_Final_Revised.pdf	-	December 4, 2012
FHWA-JPO-14-117	Transit Safety Retrofit Package Development TRP Concept of Operations https://rosap.ntl.bts.gov/view/dot/3453	-	May 28, 2014
DOT HS 811 492A	Vehicle Safety Communications Applications (VSC-A) Final Report, https://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2011/811492A.pdf	-	September 2011
FHWA-JPO-13-060	Vehicle-to-Infrastructure (V2I) Safety Applications Concept of Operation Document https://rosap.ntl.bts.gov/view/dot/26500	-	March 8, 2013
-	Enhanced Transit Safety Retrofit Package (E-TRP) Concept of Operations *Link to document not available at the time of publication of this ConOps.*	-	-

Document Number	Title	Rev	Pub. Date
-	Transit Bus Stop Pedestrian Warning Application Concept of Operations Document *Link to document not available at the time of publication of this ConOps.*	-	-
-	Fiber Infrastructure – City of Columbus City/College http://columbus.maps.arcgis.com/apps/OnePane/basicviewer/index.html?appid=2275ec668d2d4fad969ba30e8a241d5e	-	-
-	Ohio Department of Transportation – Qualified Products List (QPL) http://www.dot.state.oh.us/Divisions/ConstructionMgt/Materials/Pages/QPL.aspx	-	-
-	Iteris – Connected Vehicle Reference Implementation Architecture. http://local.iteris.com/cvria/	-	-
-	CVRIA – Motorcycle Approaching Indication http://local.iteris.com/cvria/html/applications/app116.html#tab-3	-	-
-	CVRIA – Emergency Electronic Brake Light http://local.iteris.com/cvria/html/applications/app23.html#tab-3	-	-
-	CVRIA – Forward Collision Warning http://local.iteris.com/cvria/html/applications/app31.html#tab-3	-	-
-	CVRIA – Intersection Movement Assist http://local.iteris.com/cvria/html/applications/app36.html#tab-3	-	-
-	CVRIA – Blind Spot Warning + Lane Change Warning http://local.iteris.com/cvria/html/applications/app7.html#tab-3	-	-
-	CVRIA – Emergency Vehicle Preemption http://local.iteris.com/cvria/html/applications/app24.html#tab-3	-	-
-	CVRIA – Freight Signal Priority http://local.iteris.com/cvria/html/applications/app33.html#tab-3	-	-

Document Number	Title	Rev	Pub. Date
-	CVRIA – Transit Signal Priority http://local.iteris.com/cvria/html/applications/app79.html#tab-3	-	-
-	CVRIA – Vehicle Data for Traffic Operations http://local.iteris.com/cvria/html/applications/app87.html#tab-3	-	-
-	CVRIA – Red Light Violation Warning http://local.iteris.com/cvria/html/applications/app57.html#tab-3	-	-
-	CVRIA – Reduced Speed Zone Warning / Lane Closure http://local.iteris.com/cvria/html/applications/app60.html#tab-3	-	-
-	MORPC – Central Ohio Regional ITS Architecture http://www.morpc.org/itsArchitecture/	-	October 4, 2017
-	Columbus Dispatch – When are Speed Restrictions in School Zones in Effect? 11/11/13 http://www.dispatch.com/content/stories/local/2013/11/11/school-zones-not-uniform.html	-	November 11, 2013
-	USDOT – Intelligent Transportation Systems – DSRC the Future of Safer Driving Fact Sheet https://www.its.dot.gov/factsheets/dsrc_factsheet.htm	-	-
-	USDOT – Connected Vehicles and Cybersecurity https://www.its.dot.gov/cv_basics/cv_basics_cybersecurity.htm	-	-
-	Transportation Research Board – Technology Readiness Level Assessments for Research Program Managers and Customers Webinar. 4/28/2016 http://onlinepubs.trb.org/Onlinepubs/webinars/160428.pdf	-	April 28, 2016
-	Code of Federal Regulations (CFR) Title 49 Part 11 – Protection of Human Subjects. Government Publishing Office https://www.gpo.gov/fdsys/pkg/CFR-2003-title49-vol1/xml/CFR-2003-title49-vol1-part11.xml	-	October 1, 2003

Document Number	Title	Rev	Pub. Date
SAE J2735 _201603	Dedicated Short Range Communications (DSRC) Message Set Dictionary	-	March 2016
SAE J2945/1 _201603	On-Board System Requirements for V2V Safety Communications	-	March 2016
SAE J2945/9 (draft)	Performance Requirements for Safety Communications to Vulnerable Road Users	-	-
SAE J3067 _201408	Candidate Improvements to Dedicated Short Range Communications (DSRC) Message Set Dictionary (SAE J2735) Using Systems Engineering Methods	-	August 2014
IEEE 802.3	IEEE Standard for Ethernet	-	2015
IEEE 1362	Guide for Information Technology – System Definition – Concept of Operations (ConOps) Document	-	1998
IEEE 1609.2	IEEE Standard for Wireless Access in Vehicular Environments -- Security Services for Applications and Management Messages	-	2016
IEEE 1609.3	IEEE Standard for Wireless Access in Vehicular Environments (WAVE) -- Networking Services	-	2016
IEEE 1609.4	IEEE Standard for Wireless Access in Vehicular Environments (WAVE) -- Multi-Channel Operation	-	2016
NTCIP 1202	NTCIP Object Definitions for Actuated Traffic Controllers	3	January 2005
NTCIP 1211	NTCIP Objects for Signal Control and Prioritization (SCP)	-	October 2014
-	City of Columbus Traffic Signal System (CTSS) Phase E 23 CFR 940 System Engineering Analysis Document	-	April 2018

323 *Source: City of Columbus*

Chapter 3. Current System

Presently, no CV infrastructure is on the roadside, in vehicles, or on mobile devices in the immediate Columbus area. The City does, however, operate a robust network of traffic signals, along with other Intelligent Transportation System (ITS) devices used to manage the transportation network in the region. This section provides an overview of the goals and scope of the current transportation system, supporting policies and procedures, areas targeted for CV deployment, current modes of operation, and user classes impacted by the current system.

Background and Objectives

Available transportation plans, most of which do not include a CV element, will help direct the development of user needs and scenarios for the CVE. The Mid-Ohio Regional Planning Commission (MORPC), the Central Ohio Transit Authority (COTA), the City of Columbus, and the Ohio Department of Transportation (ODOT) all have existing plans that contain regional transportation goals and objectives. The sections below summarize the portions of these plans that are related to the CVE.

MORPC's 2016-2040 Columbus Area Metropolitan Transportation Plan[4] documents the ongoing transportation planning process by MORPC and its partners. It identifies strategies and projects to maintain and improve the transportation system between 2016 and 2040. Long-term targets for the region that are relevant to the CVE include:

- Increase the average number of jobs reachable within 20 minutes via automobile and within 40 minutes via transit.
- Minimize the percentage of total vehicle miles traveled under congested conditions.
- Minimize the amount of extra, or buffer, travel time necessary when planning expected trip travel time.
- Increase the percentage of facilities functionally classified as a Principal Arterial (or above) employing coordinated ITS technologies.
- Minimize the difference in trip travel time for disadvantaged populations relative to the regional trip travel time.
- Reduce the number of fatalities and serious injuries from crashes.

CV supports these targets by improving the safety and mobility on roadways. With fewer incidents, there is less congestion. In turn, reduced congestion would be expected to result in reduced travel time. CV technology also can improve efficiency, such as signal priority, which may also reduce travel times and congestion.

Connect Columbus[5] is a multimodal thoroughfare plan prepared by the City of Columbus Department of Public Service. The CVE aligns with certain aspects of the Connect Columbus plan – particularly the

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[4] *Mid-Ohio Regional Planning Commission – 2016-2040 Columbus Area Metropolitan Transportation Plan. http://www.morpc.org/wp-content/uploads/2017/12/060216FINAL-MTP-REPORT-merged.pdf*

[5] *The City of Columbus – Multi-Modal Thoroughfare Plan. https://www.columbus.gov/publicservice/Connect-Columbus/*

focus on improving safety and reducing congestion. The plan shapes the future of transportation in Columbus by creating a framework for enhancing alternative modes of transportation (such as transit), which are represented in the CVE.

COTA's 2016-2040 Long-Range Transit Plan[6] is a comprehensive strategy for enhancing public transit in Central Ohio. The CVE, including the use of traffic signal priority and onboard safety features, is expected to align with the following aspects of the long-range plan:

- **Ridership**: Achieve ridership of 25 million passenger trips by 2025.
- **Expansion**: Plan and invest in a multimodal, high-capacity, mass transit system connecting Central Ohio residents to opportunity, economic prosperity and to each other.
- **Perception**: Be recognized in our communities, our region, and nationally, as an essential partner in economic development and mobility solutions and as a leader in technological innovation and sustainability.

Access Ohio 2040[7] is ODOT's long-range transportation plan to guide, inform, and support transportation policies and investment strategies for the coming years. Aspects of the plan that align with the CVE include reducing congestion, increasing travel reliability, and continuing to improve transportation system safety.

Operational Policies and Constraints

Regulations governing the operation of motor vehicles as well as that of pedestrian travel in Columbus are listed in Title 21 of Columbus City Code and Title 45 of Ohio Revised Code. Chapters of Title 21 (Columbus) and Title 45 (Ohio) that best describe operational policies and constraints of use of the roadway network are listed in **Table 3: City of Columbus and State of Ohio Traffic Code Relevant to Connected Vehicle Environment**.

[6] *Central Ohio Transit Authority (COTA) – Long Range Transit Plan. https://www.cota.com/wp-content/uploads/2016/04/LRTP.pdf*

[7] *ODOT – Access Ohio 2040. http://www.dot.state.oh.us/Divisions/Planning/SPR/StatewidePlanning/access.ohio/AO40_library/ODOTAccessOhio2014.pdf*

Table 3: City of Columbus and State of Ohio Traffic Code Relevant to Connected Vehicle Environment

Columbus City Code – TITLE 21 – TRAFFIC CODE[8] https://www.municode.com/library/oh/columbus/codes/code_of_ordinances?nodeId=TIT21TRCO
Chapter 2101 – DEFINITIONS https://www.municode.com/library/oh/columbus/codes/code_of_ordinances?nodeId=TIT21TRCO_CH2101DE
Chapter 2113 – TRAFFIC CONTROL DEVICES https://www.municode.com/library/oh/columbus/codes/code_of_ordinances?nodeId=TIT21TRCO_CH2113TRCODE
Chapter 2131 – OPERATION GENERALLY https://www.municode.com/library/oh/columbus/codes/code_of_ordinances?nodeId=TIT21TRCO_CH2131OPGE
Chapter 2171 – PEDESTRIANS https://www.municode.com/library/oh/columbus/codes/code_of_ordinances?nodeId=TIT21TRCO_CH2171PE
Ohio Revised Code – TITLE 45 – TRAFFIC CODE[9] http://codes.ohio.gov/orc/45
Chapter 4501 – MOTOR VEHICLES – DEFINITIONS; GENERAL PROVISIONS http://codes.ohio.gov/orc/4501
Chapter 4511: TRAFFIC LAWS – OPERATION OF MOTOR VEHICLES http://codes.ohio.gov/orc/4511

Source: City of Columbus, State of Ohio

Existing regulations may have implications for deployment of an in-vehicle user interface but are not expected to otherwise pose a constraint to CV deployment. Vehicle operators are expected to abide by regulations governing the operation of motor vehicles. The existing traffic control system is managed through traffic signals, static signage, dynamic message signs (DMS) (on certain roadways), and lane markings. Vehicle operators perform visual checks (e.g. determining traffic signal state, comprehending regulatory and warning signs, perceiving traffic conditions) and respond to audio cues (e.g. approaching emergency vehicle). U-turns are prohibited citywide unless designated by a traffic control device.

In addition to state and local traffic laws that outline the rules of the road for drivers, documents for standardizing traffic control devices are utilized by the state and city. The Ohio Manual of Uniform Traffic

[8] *Columbus, Ohio – Code of Ordinances (Columbus City Code). https://www.municode.com/library/oh/columbus/codes/code_of_ordinances*

[9] *Ohio Revised Code. http://codes.ohio.gov/orc/*

Control Devices (OMUTCD)[10] establishes statewide standards for the design and use of traffic control devices on any street, highway, bikeway, or private road open to public travel in Ohio. The Traffic Signal Design Manual[11] promotes uniformity in the application of traffic engineering practices, policies, and guidelines with respect to traffic signal design and coordination in the City of Columbus. The City of Columbus Traffic Management Division (part of the Department of Public Service) operates the traffic signal system and implementing signal priority/preemption strategies.

Description of Current System

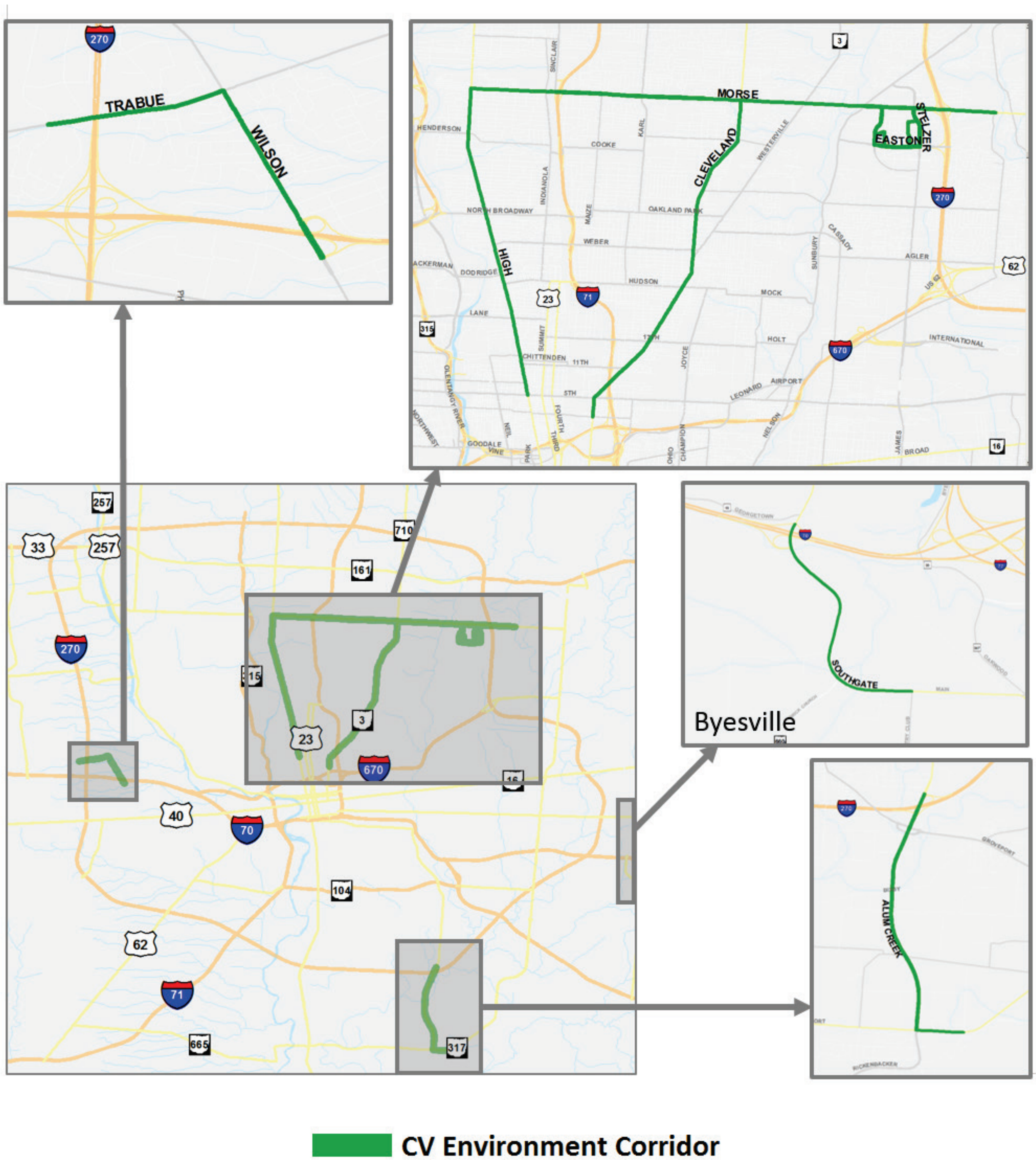
Seven major corridors/areas, as identified in the Smart Columbus USDOT Application, comprise the Smart Columbus CVE project area:

- High Street (Fifth Avenue to Morse Road)
- Morse Road (High Street to Stygler Road)
- Cleveland Avenue (Second Avenue to Morse Road)
- Easton: Roadways with signalized intersections including and contained within Morse Road, Stelzer Road, Easton Way, and Morse Crossing
- Logistics District (Southeast):
  - Alum Creek Drive (SR-317 to I-270)
  - SR-317 (Alum Creek Drive to Port Road)
- Logistics District (West):
  - Trabue Road (Westbelt Drive to Wilson Road)
  - Wilson Road (I-270 to Trabue Road)
- Logistics District (Byesville)
  - SR-209 Southgate Road (I-70 to CR-345 Country Club Road)

Figure 2: Connected Vehicle Environment Corridors shows the locations of these corridors, which were selected based on stakeholder input, regional crash data, and locations of logistics companies that are participating in DATP (see **Chapter 4, Justification and Nature of Changes**)

[10] *Ohio Manual of Uniform Traffic Control Devices. Ohio Department of Transportation. http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/OhioMUTCD/Pages/OMUTCD2012_current_default.aspx*

[11] *Traffic Signal Design Manual. City of Columbus Department of Public Service. https://www.columbus.gov/WorkArea/DownloadAsset.aspx?id=69330*



Source: City of Columbus

Figure 2: Connected Vehicle Environment Corridors

Intersections along the identified corridors/areas are either signalized or function as two-way stop-controlled intersection. In the select corridors, 113 signalized intersections will be equipped with CV RSUs. Fiber optic infrastructure comprising the CTSS allows data to be transmitted between traffic signal controllers and the TMC. The design of signalized intersections is based on the City of Columbus Traffic Signal Design Manual[12] and can vary from intersection to intersection. Intersections are typically semi-actuated using loop or video detection, and some intersections incorporate advance/dilemma zone detection along the major roadway. Generally, traffic signals in the Columbus area are timed to maximize the movement of various user groups, which may vary by location and time of day. For instance, signals along major arterials may be timed to maximize vehicular traffic, while signals downtown and densely populated neighborhoods may cycle more frequently to facilitate pedestrian movement, and signals in industrial areas may be timed to maximize the movement of freight traffic.

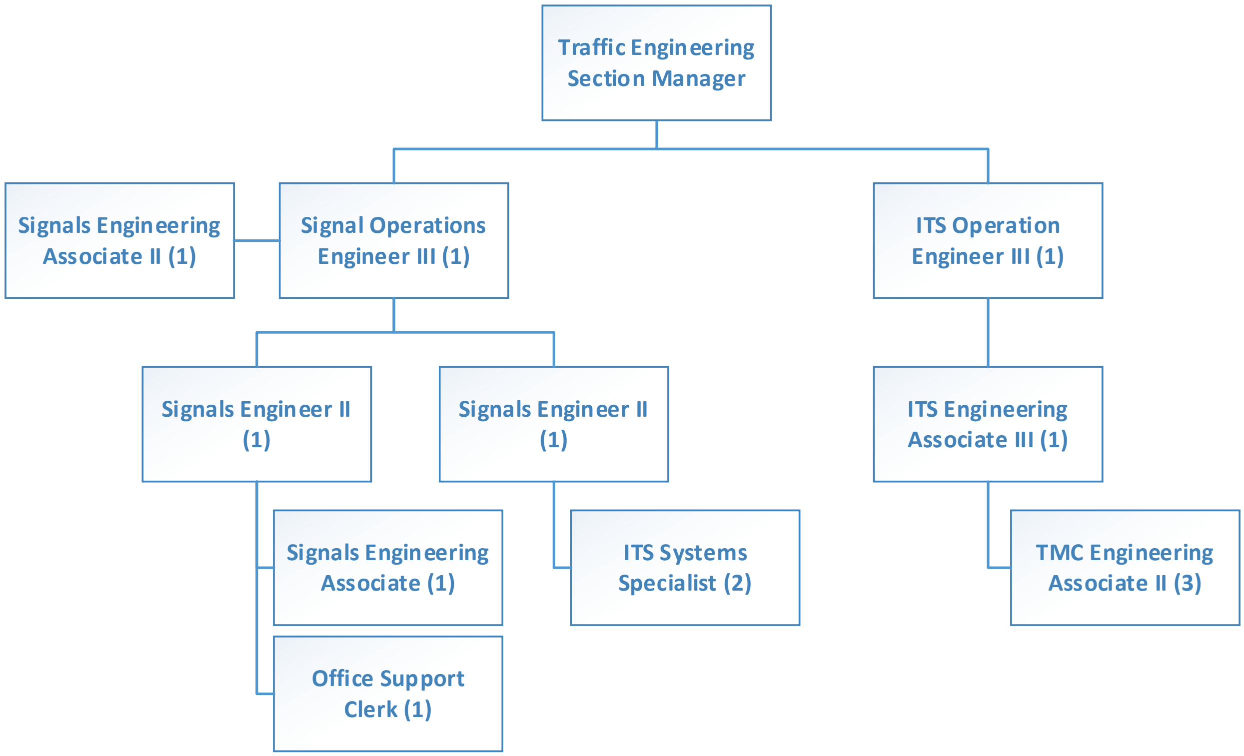
COTA, as part of its first Bus Rapid Transit (BRT) line called CMAX – in operation as of January 1, 2018 – deployed TSP along Cleveland Avenue from 2nd Avenue to Northland Plaza Drive. The system uses the Opticom GPS system, which is a vendor-specific solution that combines GNSS data and proprietary Wi-Fi (non-DSRC) communications protocols to request changes to signal timing. As it is currently implemented, the system uses only unconditional signal priority whereby the local signal controller handles all priority requests.

Freight and logistics companies that have been identified to participate in the CVE are located in the Southeast and West Logistics Districts (Rickenbacker and Buckeye Yard industrial areas, respectively). Due to agreements made with these companies, their names are not being made public at this time, and will be simply referred to Logistics Company 1 and Logistics Company 2. Logistics Company 1 utilizes the Alum Creek Drive corridor to access I-270 to transport freight to a second location on Morse Road east of I-270. Logistics Company 2 utilizes Trabue Road and Wilson Road to access I-70 to transport freight to a second location in Byesville, along SR-209, south of I-70. There is currently no freight signal priority in use at any intersections along these routes. Several of the intersections along this route are maintained by Franklin County and ODOT (specified in **Appendix G, Roadside Equipment Locations**). Agreements with these agencies will need to be established in order to deploy equipment at these intersections.

Emergency vehicles – police, fire, and emergency medical services (EMS) – use the High Street, Cleveland Avenue, and Morse Road corridors to respond to public safety issues in neighborhoods around these corridors. These corridors are major arterials that are ideal for emergency vehicles to access the neighborhoods they serve.

The Department of Public Service, Division of Traffic Management, manages the TMC and all field transportation devices. The TMC provides a central connection for networked traffic signal controllers and traffic cameras. Performance measure data is not collected on a recurring basis; however, the TMC provides one of the leading methods of safety checks to the motoring public today. The operators actively check traffic cameras to find, observe, and respond to traffic in congested areas. If the congestion could be relieved by a change in signal timing, the TMC staff can implement a temporary timing change. The staff maintains a log of these signal timing changes. TMC staff also checks construction zones for traffic congestion, as these are locations where signal timing may not necessarily best serve the demand given changes in roadway geometry due to construction. If a signal is found to be in flash when it is supposed to be cycling though a timing plan, the supervisor is alerted so that the situation can be remedied. Up to four full-time staff run the TMC between the hours of 6 a.m. and 6:30 p.m. on weekdays. Staff may work outside of these hours during special events. The part of the Division of Traffic Management responsible for operations and maintenance (O&M) of the TMC and devices connected to the CTSS are provided in **Figure 3: Division of Traffic Management Organizational Chart (TMC Operations and Maintenance)**.

[12] *Traffic Signal Design Manual. City of Columbus Department of Public Service* *https://www.columbus.gov/WorkArea/DownloadAsset.aspx?id=2147498299*



Source: City of Columbus

Note: This figure only indicates the portion of the Division of Traffic Management organization responsible for the O&M of the TMC and networked devices on the CTSS. The number inside of the parentheses indicates the number of staff at the indicated position.

Figure 3: Division of Traffic Management Organizational Chart (TMC Operations and Maintenance)

The City Department of Technology (DoT) maintains the fiber network and the managed network switches that connect the TMC to field transportation devices. The department creates connectivity reports to assess the percentage of time field transportation devices are connected to the TMC. Furthermore, DoT sets up and manages the firewall that secures the data flowing into and out of the TMC.

Existing physical infrastructure at signalized intersections will play a role in determining mounting locations for roadside CV infrastructure. Roadside equipment (defined in **Chapter 5, Concept for the New System**) will be located both in the traffic signal controller (TSC) cabinet as well as the signal support infrastructure. The identified corridors/areas have 55 signalized intersections with rigid mast arms and 58 locations using strain poles and spanwire. Most vertical poles on which traffic signals are mounted are city-owned. Vertical assets such as power line poles adjacent to some intersections are owned by utility companies. Cabinet-controller combinations also vary throughout the city. Available space in cabinets and conduit is expected to be physically constrained as many of these cabinets also contain advanced network equipment, such as layer-2 switches and fiber termination to connect with CTSS. **Table 4: Connected Vehicle Environment Corridor Summary** summarizes the existing characteristics and other safety/mobility elements of the proposed CVE corridors.

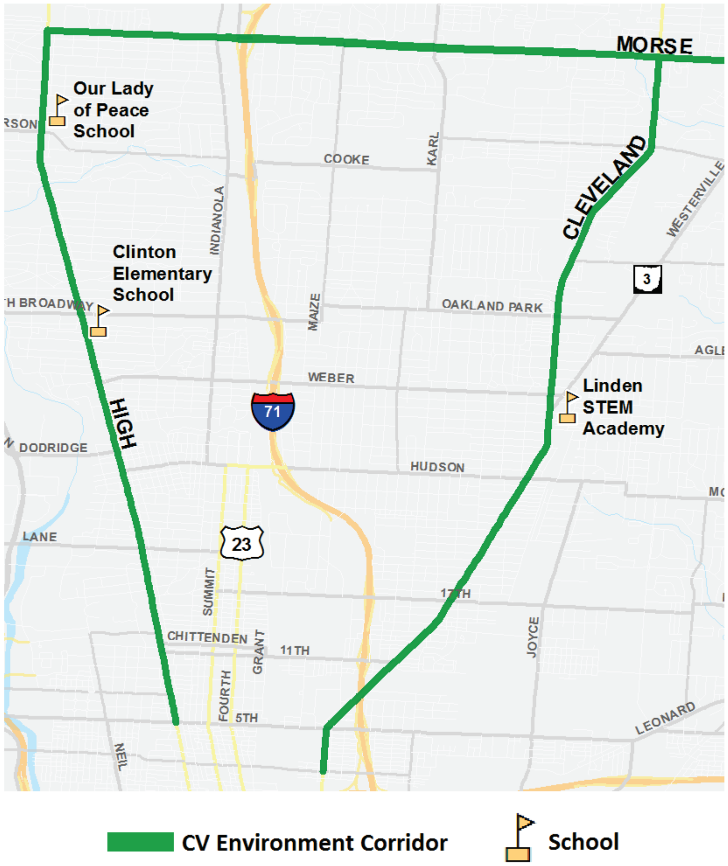
Table 4: Connected Vehicle Environment Corridor Summary

Corridor	From	To	Speed Limit	Lanes		Median	On-Street Parking		Notes*
				NB	SB		NB	SB	
High Street	Fifth Ave	Ninth Ave	25	1	1	TWLTL	Y	Y	-
	Ninth Ave	Chittenden Ave	25	1	1	TWLTL	Y	Y	Extensive pedestrian traffic, off-peak parking may be added
	Chittenden Ave	Eighteenth Ave	25	2	2	TWLTL	N	N	
	Eighteenth Ave	Lane Ave	25	2	2	TWLTL	N	N	
	Lane Ave	Dodridge St	25	1	1	TWLTL	Y	Y	-
	Dodridge St	Dunedin Rd	35	2	2	TWLTL	Y	Y	-
	Dunedin Rd	Morse Rd	35	2	2	TWLTL	N	N	-
Morse Road	High St	I-71	35	2	2	None	N	N	-
	I-71	Cleveland Ave	45	3	3	Raised (limited LT)	N	N	Bike lane
	Cleveland Ave	Westerville Rd	45	3	3	TWLTL	N	N	-
	Westerville Rd	Sunbury Rd	45	3	3	TWLTL	N	N	Bike lane
	Sunbury Rd	I-270	45	3	3	Raised (limited LT)	N	N	-
	I-270	Stygler Rd	45	3	3	TWLTL	N	N	-
Cleveland Avenue	Second Ave	Briarwood Ave	35	2	2	None	N	N	-
	Briarwood A	Minnesota Ave	35	2	2	None	N	Y	-
	Minnesota Ave	Oakland Park Ave	35	2	2	None	N	N	-
	Oakland Park Ave	Elmore Ave	35	2	2	TWLTL	N	N	-
	Elmore Ave	Melrose Ave	35	2	2	None	N	N	-

Corridor	From	To	Speed Limit	Lanes		Median	On-Street Parking		Notes*
	Melrose Ave	Cooke Rd	35	2	2	TWLTL	N	N	-
	Cooke Rd	Ferris Rd	35	2	2	None	N	N	-
	Ferris Rd	Morse Rd	35	2	2	TWLTL	N	N	-
Alum Creek	SR-317	I-270	50	2	2	Raised	N	N	No sidewalks
Stelzer Road	Easton Way	Morse Rd	40	2	2	Raised	N	N	-
Morse Crossing	Easton Commons	Morse Rd	35	2	2	Raised	N	N	-
Easton Way	Morse Crossing	Easton Square	35	2	2	Raised	N	N	-
	Easton Square	Stelzer Rd	35	3	3	Raised	N	N	-
Wilson Road	I-70 EB	I-70 WB	45	2	2	Raised	N	N	No sidewalks
	I-70 WB	Trabue Rd	45	2	2	TWLTL	N	N	No Sidewalk on NB side
Trabue Road	Westbelt Dr	Wilson Rd	45	1	1	None	N	N	No sidewalks
Southgate Road	I-70	*unnamed road*	45	2	2	None	N	N	No sidewalks
	unnamed road	Country Club Rd	45	2	2	TWLTL	N	N	No sidewalks

**Note: All roadways have sidewalks unless noted. Source: City of Columbus*

In addition to the signalized intersections, three school zones (Our Lady of Peace School, Clinton Elementary School, and Linden STEM Academy) are located along approved corridors in the Linden and Clintonville areas. The three school zones all have approaches controlled by flashing school signals that alert drivers to when the school zone is active – during which speeds are reduced to 20 mph. These tree schools are shown in **Figure 4: Map of Flashing School Signals in Linden and Clintonville**.



Source: City of Columbus

Figure 4: Map of Flashing School Signals in Linden and Clintonville

Modes of Operation

Modes of operations for signalized intersections and school zones with flashing signals include normal, degraded, and failure operations. Signalized intersections throughout the deployment areas and the corresponding signal timing plans generally comply with the City's Traffic Signal Design Manual. The modes of operation for the current system are summarized in **Table 5: Current System Modes of Operation**.

Table 5: Current System Modes of Operation

Mode	Definition
Mode 1: Normal Operating Conditions	Indicates that a signalized intersection is cycling through its programmed phases correctly and servicing all approaches, including pedestrian phases. Pre-determined traffic signal timing plans may be implemented throughout the day. Certain intersections will enter programmed flash mode when there is low demand, often

Mode	Definition
	during night time hours. School zones show normal operations when a flashing school zone signal is active during pre-determined periods.
Mode 2: Degraded Conditions	Occurs when pre-determined signal timing plans are not properly implemented, when traffic detection equipment does not function properly, or during maintenance periods when technicians are modifying equipment in the traffic cabinet. A traffic signal running a pre-determined timing plan that does not correspond to the time of day and/or day of week for which it was designed is considered a degraded operational state. For instance, a signal may be in flash mode during a period when it is supposed to be implementing a typical signal timing plan. Actuated signals experience a diminished operational state when detectors malfunction. In all cases of diminished operations at signalized intersections, motorists are still able to be serviced by the traffic signal, though they experience increased delay compared to normal operations. School zones exhibit diminished operations when a flashing school zone signal is active outside of pre-determined periods. Such operations are typically noted during school holidays, a school-closing weather event, or during a time of the year when school is not in session. While this does not typically result in a safety issue, diminished school zones operations may result in a vehicle operator decreasing speed when unnecessary.
Mode 3: Failure Conditions	Indicates a complete failure of the intersection, also known as "going dark." This primarily occurs because of loss of power but could also result from other malfunctions. In the case of an intersection where all signals are dark, motorists are expected to treat the intersection as an all-way stop and are likely to experience major delays. School zones show failure operations when a flashing school zone signal is not active during pre-determined periods. This negatively affects safety, as vehicle operators may not decrease speed when school children may be in the area.

Source: City of Columbus

Users

Table 6: Connected Vehicle Environment Stakeholders and User Classes identifies user classes affected by the existing system. Each user class is made up of one or more stakeholder groups that show common responsibilities, skill levels, work activities, and modes of interaction with the system. A given group of stakeholders can be involved in one or more user classes.

Table 6: Connected Vehicle Environment Stakeholders and User Classes

Target Stakeholders	**User Classes**						
	Light-Duty Vehicle Operator	Emergency Vehicle Operator	Heavy-Duty Vehicle Operator	Traffic Manager	Transit Vehicle Operator	Transit Manager	Network Manager
Linden Private Vehicle Owners*	X	-	-	-	-	-	-

	User Classes						
City of Columbus Light-Duty Vehicle Operators, Car Share Vehicle Operators**	X	-	-	-	-	-	-
Logistics Company 1, Logistics Company 2	-	-	X	-	-	-	-
COTA (Fixed-Route and Paratransit)	-	-	-	-	X	X	-
COTA (Supervisor Vehicle)	X	-	-	-	-	-	-
City of Columbus Fire, Emergency Medical Services (EMS)	-	X	-	-	-	-	-
City of Columbus Police	-	X	-	-	-	-	-
City of Columbus Dept. of Public Service Traffic Managers	-	-	-	X	-	-	-
City of Columbus Department of Technology	-	-	-	-	-	-	X

**Note: Linden residents are the target audience for privately-owned vehicles. Outreach may be done with other residents in the vicinity of the High, Morse, and Cleveland Avenue corridors if additional participation is needed to satisfy in-vehicle installation objectives.*

*** Car2Go, the only car-share entity operating in Columbus ended its service in the area on May 31, 2018. Should other carshare providers provide service in the area, they could be considered a potential stakeholder for the light-duty vehicle operator user class.*

Source: City of Columbus

The Light-Duty Vehicle operator user class is comprised of Linden Private Vehicle Owners, City of Columbus Light-Duty Vehicle Operators, Car Share Vehicle Operators, and COTA Supervisor Vehicle Operators. City of Columbus light-duty fleet includes vehicles such as: construction inspection vehicles, DPS pool vehicles, infrastructure management vehicles, building and zoning inspections vehicle, signage and pavement supervisor vehicles, and traffic management vehicles. In the context of the CVE, light-duty vehicle operators are expected to use the Cleveland Avenue, High Street, and Morse Road corridors as part of their typical routines. As explained in **Chapter 4, Justification and Nature of Changes**, these three corridors are responsible for a large number of crashes and contain several of the most dangerous intersections in the Columbus area. While using these corridors, it is expected that light-duty vehicle operators are exercising awareness in the roadway environment to avoid unsafe situations.

The Emergency Vehicle Operator user class is comprised of City of Columbus, Fire, EMS and Police, and must navigate the roadway network to respond to emergencies throughout the city. When actively responding to calls, these vehicle operators engage flashing lights and sirens to make their presence known to other vehicles on the roadway. In response to the lights and sirens, other drivers are expected to yield to the emergency vehicles (and to provide a clear path by pulling over or stopping at intersections) so that the emergency vehicle operator can reach the destination as quickly as possible.

The Heavy-Duty Vehicle Operator user class is comprised of drivers that operate heavy-duty freight vehicles for local freight companies. With regard to the current system, one of the logistics companies moves freight along the Alum Creek Corridor, to I-270, to Morse Road, east of I-270. The other logistic company moves freight from Trabue Road, to Wilson Road, to I-70, and SR-209 in Byesville. Moving freight in an expedient and efficient manner is very important for heavy-duty vehicle operators and the logistics companies they represent.

The Traffic Manager user class is represented by the City of Columbus DPS Traffic Managers. The Traffic Manager is responsible for actively managing the transportation devices in order modify the operations of traffic control devices (such as traffic signal timing) to improve network efficiency. DPS Traffic Managers currently use CCTV cameras to monitor traffic conditions. Based on conditions that are observed, one of several signal timing plans are implemented to alleviate the congestion that is occurring. The Traffic Manager is also responsible for the operations and maintenance of transportation network-connected devices. This includes, but is not limited to CCTVs, traffic signal controllers, and switches located in traffic signal cabinets.

The Transit Vehicle Operator user class is comprised of COTA fixed-route and paratransit vehicle operators. These operators are responsible for servicing COTA passengers along their designated routes. The Transit Manager user class is represented by COTA Transit Managers. The transit manager is responsible for making sure that transit vehicles run on-schedule, and for evaluating systems currently on-board transit vehicles and potential future on-board transit vehicle systems to determine if they can provide a benefit to the transit vehicle operator or to passengers. Because the transit vehicle operator must safely operate the vehicle, only a limited number of outputs from these systems can be provided to the transit vehicle operator without causing a distraction and reducing safety. The transit manager can evaluate the outputs that may be provided from a new system to determine if it should be implemented.

The Network Manager user class is represented by the City of Columbus DoT. They are responsible for operating and maintaining the fiber-optic network that is used to transmit data between networked devices. The current system uses fiber-optic backhaul to provide connectivity between the TMC and traffic signal controllers. The TMC uses the network to remotely specify modifications to traffic signal timing plans when congested conditions are noted. It is the responsibility of the Network Manager to establish network security protocols, enforce those protocols, and preserve connectivity or restore connectivity when outages are experienced.

Chapter 4. Justification and Nature of Changes

Justification for Changes

The CVE is intended to improve safety for vehicle operators, reduce delay for high-priority vehicle classes, and provide vehicle operations data that will complement existing data streams for use by the City, COTA and others. Input from the technical working groups, outreach to the Linden community, the transit community, and the public safety community were all used to identify areas of improvement. Summary of these engagement activities follow. Details are included in **Appendix C, End-User/Stakeholder Engagement Summary**.

Stakeholder Engagement

To best capture the needs of the proposed CVE, the City system engineering efforts included outreach and engagement activities with the Linden Community, the CVE Technical Working Group, the CEAV Technical Working Group, COTA, and the City of Columbus Department of Public Safety (DPS). Each identified and supported the needs for the CV applications included in this ConOps. Details of those engagements follow.

Linden Community

Smart Columbus Connects Linden, a strategic community event designed to understand user needs, was held February 10 and 11, 2017, to collect resident feedback about Smart Columbus projects. Linden is a neighborhood that was identified in the Smart Columbus grant application as having needs that the CVE (among other projects comprising the Smart Columbus program) can address. Subsequently, Linden residents are the target population group for recruiting participants who are willing to install CV equipment on private vehicles. Thus, engagement was performed in the Linden neighborhood, though this did not preclude residents from other neighborhoods from participating in the outreach session. Survey results show that safety is a primary concern for Linden residents. This includes the personal safety of single moms, children, and older adults riding COTA and walking home from a bus stop, and the physical safety of residents who are afraid to ride a bicycle on congested city streets. Linden residents also have privacy concerns about CV technology, specifically with the CV device and information at kiosks. The cost for the CV device is also an issue. The survey questions and responses are provided in **Appendix C, End-User/Stakeholder Engagement Summary**.

CVE Technical Working Group

The CVE Working Group members included representatives from the City of Columbus (Departments of Public Service and Public Safety), COTA, ODOT, Federal Highway Administration (FHWA), USDOT, Argonne National Lab, and Ohio State University (OSU). The group concluded that traffic safety and mobility primarily drive the user needs. They also expressed a desire to customize established technologies to meet specific needs in the Columbus area to prevent fatigue from too may alerts/warnings by only offering features that are applicable to area users. Working group meetings and public engagement identified improvement areas including vehicle operator and roadway safety, high-priority vehicle delay, school zone awareness, and data for traffic management.

The CVE Technical Working Group meetings were held December 19, 2016, February 27, 2017, and April 19, 2017, at the City of Columbus Training Facility. A combined list of attendees at these meetings is provided in **Appendix E, Working Group Attending Members**.

Related Working Groups

In addition to the CVE Technical Working Group, outcomes from the CEAV technical working group and the Driver-Assisted Truck Platooning (DATP) technical working group have also informed the CVE ConOps. In addition to the primary function of both the CEAV and the DATP, both of these projects intend to integrate with and leverage the CVE for specific functionality, as described below. Please note that the CVE ConOps only documents the features of the CEAV and DATP that utilize the CVE, and all other features related to these two projects are captured within the respective project documentation for each.

CEAV Technical Working Group

The CEAV Technical Working Group members included representatives from the City of Columbus (Departments of Public Service and Public Safety), Steiner and Associates (property manager for the Easton area), COTA, ODOT, FHWA, USDOT, Argonne National Lab, and OSU. While the focus of this working group was related to the use and deployment of a low-speed automated shuttle, the working group did agree that the strategy to include the autonomous vehicle (AV) as a CV (both generating basic safety messages (BSMs) and utilizing received CV messages) was valuable, and that the CEAV would also benefit, in terms of safety and mobility, with the deployment of signal priority.

The CEAV Technical Working Group met three times. The meeting dates were December 19, 2016, February 27, 2017 and April 19, 2017, all at the City of Columbus Training Facility. A combined list of attendees at these meetings is provided in **Appendix E, Working Group Attending Members**.

DATP Technical Working Group

The DATP Technical Working Group members included representatives from the City of Columbus (Departments of Public Service and Public Safety), FHWA, Ohio Trucking Association, Ohio Turnpike Commission, USDOT, Battelle, Siemens, Franklin County and OSU. While the focus of this working group was primarily related to the deployment of a platoon truck, the working group did determine that traffic signal priority – both for individual freight vehicles and well as those with intent to platoon – was a major desired capability of the system and would have a positively benefit the overall performance of the platoon. The equipment used to facilitate the communications among trucks in the platoon is expected to include some of the same DSRC technology used in the CVE, and as such, in addition to the signal priority and platooning messages, the vehicles would produce BSMs.

Two DATP Technical Working Group meetings were held February 8, 2017, and May 3, 2017, all at the City of Columbus Training Facility. A combined list of attendees at these meetings is provided in **Appendix E, Working Group Attending Members**.

Central Ohio Transit Agency

In addition to their recurring participation in the CVE Technical Working Group, COTA staff from have met numerous times with City support staff to further identify the opportunities and roles of CV for COTA.

COTA has clearly indicated support for equipping their transit vehicles including revenue service, paratransit, and supervisor vehicles with CV equipment, but it has expressed concern with introducing additional user interfaces for its drivers. Further, anecdotal inputs from COTA indicate that the majority of incidents between COTA vehicles and other vehicles are the fault of the other vehicle, not COTA. As such, prior to installation of any user interface, COTA intends to gather incident-related data by equipping its fleet with CV aftermarket safety devices that produce BSMs and record any incidents the COTA-owned vehicle encounters between it and other equipped vehicles. COTA is interested in all of the identified V2V and V2I safety applications, in addition to the benefits of using CV-based TSP.

CV-specific meetings between City and COTA staff occurred at the following times and locations:

- September 26, 2016, at COTA
- January 26, 2017, at City of Columbus Training Center – Transit & Pedestrian Safety Working Group
- March 9, 2017, at COTA
- March 20, 2018, at COTA

A list of attendees from this meeting is provided in **Appendix E, Working Group Attending Members**.

City of Columbus DPS

Another department within the City that has shown a strong interest in the benefits of CV technology is the DPS, including the Division of Police and the Division of Fire. A representative of DPS has participated in all CVE Technical Working Group meetings, and the City has met separately with a broader group of DPS staff and with the Chief of Police and her direct staff. The primary outcome of these meetings was a strong interest in the efficiency and safety benefits enabled by use of emergency vehicle signal preemption; however, they also showed interest in the V2V safety applications. Like COTA, however, DPS does not desire introducing a new user interface for the drivers; therefore, its strategy will be for public safety vehicles to produce BSMs and request signal preemption when on an active run.

The dates and location of the specific meetings between the Smart Columbus team and that of DPS are:

- 3/28/2017 at DPS
- 8/21/2017 at police headquarters

Freight Community

Multiple in-person meetings, conversations, and interviews were conducted with three logistics companies operating in Columbus. These interviews were used to document the current “system” as it exists today (described in **Chapter 3, Current System)** and to develop user needs for the new system. The companies interviewed include:[13]

- **Logistics Company 1** – A Columbus-based firm that moves consumer goods between Rickenbacker Intermodal Terminal, a high-speed, international, multimodal logistics hub, and the Easton area in northeast Columbus. This company was interviewed on January 31, 2017, and it provided input about current operations and needs for the new system. The team conducted

[13] *Participating logistics companies were kept confidential for purposes of this ConOps, to preserve their anonymity and avoid disclosing potentially sensitive business information.*

several follow-up discussions with this firm to clarify details of their current operation, equipment utilization, and key performance metrics.

- **Logistics Company 2** – Another firm headquartered in Columbus and specializing in food-grade, temperature-controlled logistics and transportation, including several regional routes along I-70 that end in Columbus. This firm was interviewed on January 26, 2017, and it provided company background information, current operational data, key user needs, and route information. The team also conducted follow-up meetings with this company to identify key performance metrics for truck platooning and freight signal priority (FSP)/ platoon intent FSP (PIFSP) and clarify their needs for the system.
- **Logistics Company 3** – This company transports inbound automotive parts from Columbus to automobile factories in the region. The team interviewed this firm on April 11, 2017, and received information about its routes, equipment used, and user needs.

Local Transportation System Needs Performance

In addition to the direct engagement of citizens and other City stakeholders, crash statistics published by the Mid-Ohio Regional Planning Commission were reviewed when considering the selected CV applications and locations. The crash statistics data, and the consensus of the CVE Technical Working Group, supported strategies for general vehicle operator safety, intersection safety and school-zone safety. Details of these follow.

Vehicle Operator Safety

Crashes are costly in terms of reduced mobility (congestion due to crash), incident management, emergency response, increased insurance premiums, vehicle repair costs, roadside repair costs, medical costs, and loss of life. Generally, a lack of driver awareness (location and speed of the driver's vehicle or of other vehicles) by one or more drivers is the cause of crashes between vehicles. The current system does not have a method of improving driver alertness, especially in crash-imminent situations. Crash data from the Ohio DPS) indicates that there was an average of five non-intersection crashes per day along the proposed CV corridors during a three-year span from January 2014 to December 2016. These non-intersection crashes resulted in 1.77 injuries per day and one fatality every 219 days.

Table 7: Non-Intersection-Related Multi-Vehicle Crashes (January 2014-December 2016) breaks down the number and type of non-intersection-related multi-vehicle crashes on the corridors that are targeted for use by light-duty vehicle operators: Cleveland Avenue, High Street, and Morse Road. The table shows that rear-end, angle, and sideswipe same direction crashes are the most frequent. Rear end crashes, when not related to intersections, typically occur as the result of a vehicle operator not stopping fast enough before reaching the back of a slow-moving queue, following a leading vehicle too closely, or not being able to react in time to a sudden decrease in speed of a leading vehicle. Angle crashes may occur at access points (such as a driveway) when a vehicle crosses a traffic stream. Sideswipe crashes are likely the result of a vehicle encroaching into another vehicle's path during a lane change. The CVE could be used to enable applications targeted toward reducing these non-intersection-related crashes that are most prominent along the corridors of interest.

Table 7: Non-Intersection-Related Multi-Vehicle Crashes (January 2014-December 2016)

Crash Type	Number of Crashes (by Classification)				Resulting Number of Injuries	Resulting Number of Fatalities
	Total	Property Damage Only	Injury	Fatal		
Rear-End	1,292	1,005	286	1	438	1
Angle	820	649	169	2	257	2
Sideswipe, Same Dir	635	576	59	0	87	0
Backing	95	92	3	0	3	0
Head-On	55	29	26	0	51	0
Unknown	42	38	4	0	5	0
Sideswipe, Opp. Dir	41	29	12	0	19	0
Rear-To-Rear	6	5	1	0	1	0
Total	2,986	2,423	560	3	861	3

Source: ODPS

Intersection Safety

Traffic signals control the flow of vehicles, bicyclists, and pedestrians at signalized intersections. These signals indicate to the vehicle operator to proceed toward and through the intersection (green); to clear the intersection or prepare to stop (yellow); or slow down to a stop (red). A lack of awareness by one or more drivers caused by location and speed of the driver's vehicle or of other vehicles, or traffic control equipment, is the cause of crashes. The current system does not have a method of improving driver alertness, especially in crash-imminent situations. As the vehicle operator approaches the intersection during a given phase, the signal may change; depending on the vehicle's speed and position, the vehicle operator may not be able to properly determine if they should continue through the intersection at speed or slow down to stop at the intersection. If the vehicle operator makes the incorrect decision, it may lead to entering and passing through the intersection during a red signal or braking unnecessarily hard to stop at the intersection. If the vehicle operator has advanced information about when the traffic signal would change, then a safer decision could be made regarding whether to proceed through the intersection. Furthermore, when a driver is not aware of their surroundings, there is a possibility of entering the intersection on a red signal which has the potential to result in an incident with other conflicting movements that have the right-of-way. If the vehicle operator was provided with a warning when they are about to enter a signal on red, then they would become aware of the red signal and stop to avoid a potentially unsafe situation.

A crash is intersection-related if it occurs within, on an approach to, or exit from an intersection and results from an activity, behavior, or control related to the movement of traffic through the intersection. **Table 8: Intersection-Related Multi-Vehicle Crashes (January 2014-December 2016)** breaks down the number of multi-vehicle, intersection-related crashes along the corridors that are targeted for use by light-duty vehicle operators: Cleveland Avenue, High Street, and Morse Road. The table shows that angle and rear-end crashes are the most frequent types of intersection-related crashes. At intersections, angle crashes could be the result of a vehicle crossing the path of a vehicle making a conflicting movement. In some cases, this could be due to the improper assessment of gaps in the opposing traffic stream when making a permitted movement. This could also be due to a vehicle entering an intersection on a red signal while cross-traffic is moving. Rear-end crashes could result when two vehicles approach an intersection that turns yellow – if the first vehicle decides to come to a stop while the following vehicle decides to continue at speed though the intersection, a crash could occur. Alternatively, a vehicle operator may not notice the back of a queue stopped at the intersection, not braking promptly, resulting in a rear-end collision. The CVE could be used to enable applications targeted toward reducing these types of crashes, which are most prominent at intersections in the corridors of interest.

Table 8: Intersection-Related Multi-Vehicle Crashes (January 2014-December 2016)

Crash Type	Number of Crashes (by Classification)				Resulting Number of Injuries	Resulting Number of Fatalities
	Total	Property Damage Only	Injury	Fatal		
Angle	1,225	831	393	1	648	1
Rear-End	875	646	229	0	345	0
Sideswipe, Same Dir	189	172	17	0	22	0
Head-On	46	21	25	0	58	0
Sideswipe, Opp. Dir	27	24	3	0	4	0
Backing	26	25	1	0	1	0
Unknown	7	5	1	1	1	1
Rear-To-Rear	3	1	2	0	3	0
Total	2,398	1,725	671	2	1,082	2

Source: ODPS

Table 9: Mid-Ohio Regional Planning Commission Vehicle High-Crash Intersections on Proposed Connected Vehicle Environment Corridors shows 16 of the top 100 high-crash intersections in the Central Ohio region in 2017 are along the High Street, Morse Road and Cleveland Avenue corridors.[14] [15]

[14] *MORPC – Previous High-Crash Intersections* *http://www.morpc.org/wp-content/uploads/2017/12/001.Previous_HCL.pdf*

[15] *MORPC – Top 100 Regional High-Crash Intersections (2017)* *http://www.morpc.org/wp-content/uploads/2017/12/001.HCL_2014_2016_Top100.pdf*

Table 9: Mid-Ohio Regional Planning Commission Vehicle High-Crash Intersections on Proposed Connected Vehicle Environment Corridors

Vehicle High-Crash Locations (100 total)		
2017 Rank	**2016 Rank**	**Location**
3	8	Cleveland Avenue and Innis Road
4	18	Karl Road at Morse Road
8	22	Morse Road at Westerville Road
10	40	Cleveland Avenue at Hudson Street
11	21	Cleveland Avenue at Oakland Park
18	4	Cleveland Avenue at Morse Road
40	7	Morse Road at Northtowne Boulevard / Walford Street
41	35	Morse Road at Sunbury Road
44	29	High Street at Fifth Avenue
57	-	Cleveland Avenue at Eleventh Avenue
65	75	McCutcheon Road at Stelzer Road
68	59	Morse Road at Stelzer Road
76	79	Morse Road at Sinclair Road
88	82	Cleveland Avenue at Weber Road
94	-	High Street at North Broadway
97	80	Henderson Road at High Street
-	45	Cleveland Avenue at Fifth Avenue
-	77	Morse Road at Tamarack Boulevard
-	95	Seventh Avenue at High Street

Source: MORPC

School Zone Awareness

To enhance safety around schools, zones are established where the speed limit is reduced during certain hours of school days. These zones are typically designated by static signage that displays the maximum speed and other conditions specific to the zone (e.g. “7:30 AM to 4:30 PM MON-FRI”, “During Restricted Hours”, “When Children are Present”, “When Flashing”). In some cases, these static signs are accompanied by flashing lights that can be turned on during school zone hours. Stakeholders have said that school zone speeding is an issue, especially on corridors that have higher speed limits during non-school zone hours, such as High Street, Cleveland Avenue, and Morse Road. In some cases, vehicle operators do not notice the signs, do not pay attention to the signs, or do not properly interpret the signs. Speeding in school zones diminishes safety, specifically for school children.

Speed data was obtained for Cleveland Avenue in the school zone for the Linden STEM Academy, and for High Street in the school zone for the Our Lady of Peace School on May 30, 2018. Speeds were collected throughout the entire day, but analyzed only for the duration when each school zone was active. The Linden STEM Academy school zone is active from 7:30am until 4:30pm, and the Our Lady of Peace School is active from 7:00am until 3:30pm. These times correspond to one hour before and after school activities start and end. The results of the assessment of speeds during school zone hours are shown in **Table 10: School Zone Speeds**.

It was found that while speed compliance rates varied along each corridor and for each direction, the overall speed compliance rate (traveling at or less than 20 mph) was only 18%. About 75% of drivers drove between 20 and 35 mph (above the school zone speed limit, but less than the normal speed limit), and 7% of drivers drove faster than the posted 35 mph speed limit. These values indicate that speed compliance in these school zones is an issue, which has negative implications for pedestrian safety in these areas. The CVE could be used to enable applications targeted toward improving driver awareness of speeding in school zones along the corridors on interest to improve driver speed compliance.

Table 10: School Zone Speeds

School	Location/Time	Direction	0-20mph	20-35mph	35+mph	N
Linden STEM Academy	Cleveland Avenue, S of Manchester (5/30/18, 7:30am-4:30pm)	NB	2%	83%	15%	4,478
		SB	29%	61%	10%	4,130
Our Lady of Peace School	High Street, N of Dominion (5/30/18, 7:00am-3:30pm)	NB	10%	89%	1%	5,711
		SB	40%	59%	1%	3,723
	Total	**All**	**18%**	**75%**	**7%**	**18,042**

Note: Rows may not sum to 100% due to rounding errors. Source: City of Columbus

High-Priority Vehicle Delay

As derived from the conversations with the City's transit, freight, public safety and AV vendors, introduction of strategies to reduce delay at intersection for high-priority/specialized vehicles had merit.

For fixed-route transit service to be successful, it must be reliable with each route adhering to a schedule. Furthermore, paratransit vehicles must be able to efficiently traverse the road network to quickly transport passengers to their destinations. However, transit and paratransit vehicles may fall behind schedule for such reasons as traffic and weather. This results in this results in potential delays to transit service including increased wait times at bus stops and increased onboard travel time may not meet travelers' expectations. The six automated vehicles that will be deployed as part of the CEAV project will likely encounter similar reliability challenges. Thus, it is of interest to ensure that buses that fall behind schedule are able to get back on schedule. Furthermore, implementation of TSP, which is a strategy that can be used to keep transit vehicles on-schedule, is a requirement of federal high-capacity transit funding, such as for BRT service. High Street, Morse Road, Cleveland Avenue, and roadways in the Easton area all exhibit high-frequency COTA transit service that could benefit from reduced delay.

Similarly, for freight movement along signalized corridors, increased travel times due to congestion, incidents, and/or adverse weather conditions can reduce the ability to attract and keep industries that rely on efficient operations. The new freight platoons being introduced on the region's roadways (as part of the DATP project) heighten the need for efficient and seamless passage of freight vehicles intending to platoon through signalized intersections. Logistics companies that are expected to participate in the DATP project are expected to traverse intersections on Alum Creek Drive (between SR-317 and I-270), Trabue Road (between Westbelt Drive and Wilson Road), Wilson Road (between Trabue Road and I-70), Morse Road (east of I-270), and on SR-209 (Byesville, south of I-70). Currently, there is no standardized mechanism deployed regionally to promote efficient transit and freight movement along a route, and delays continue to propagate through the respective systems.

In a similar manner, traffic at signalized intersections reduces the ability of an emergency vehicle to quickly navigate through an intersection. When an emergency vehicle approaches an intersection with a red signal, it must slow down to ensure all conflicting movements yield before proceeding through the intersection. The ability to quickly arrive at an emergency is critical for police, fire, and emergency medical service providers. In particular, the movement of emergency vehicles along the High Street, Cleveland Avenue and Morse Road corridors is of importance, as these roadways are major arterials that provide the fastest access to neighborhoods where emergencies may be occurring.

The TSP recently deployed for CMAX vehicles on Cleveland Avenue between Second Avenue and the Northland Transit Center is not presently configured to adjust dynamically to the operating characteristics of freight vehicles (including platooned freight vehicles) and emergency vehicles. Furthermore, the current signal priority solution is proprietary and thus not interoperable with other priority systems, which limits the flexibility of adding new vehicles and intersections to the priority system.

Data for Traffic and Transit Management

Effectively managing a transportation system requires the collection of system operations data. This data can be used to implement near- and long-term operations strategies such as adjusting traffic signal timing and providing travel time data via DMS. The current traffic management system relies on loop and video detector data to detect the presence and speed of vehicles at fixed locations and to manually assess conditions through closed-circuit video feeds. The primary drawback to this traffic management approach is that video feeds are only available in locations where CCTV cameras are located.

As an alternative to traditional systems operation data, third-party companies gather probe data to estimate vehicle counts and speeds. While this data is generally regarded as higher-resolution and more comprehensive compared to other existing data collection methods, these third-party organizations typically require payment to access such data. Ideally, the Traffic Manager is able to receive low-cost comprehensive vehicle location and motion data that can be used to generate operational metrics which can be used by Traffic Managers to improve system operations.

Transit Managers at COTA have indicated an interest in assessing the safety of transit vehicle operations. The current system uses hard braking events to trigger the recording of camera footage on transit vehicles. However, it is anticipated that this may not capture all driver activity in the vicinity of transit vehicles that may result in safety issues as they operate in the roadway environment. Furthermore, transit managers are interested in assessing the number of alerts or warnings that may be issued to a transit vehicle operator during the normal course of operations to determine if safety systems (such as those proposed in the CVE) should be deployed in transit vehicles.

Description of Desired Changes

The desired changes associated with the existing system include the exchange of information through the deployment of CV technology on the roadside and in vehicles to enable communication between vehicles and between vehicles and roadside ITS equipment. The CV technology will provide information that will help to reduce crashes along the target corridors, improving safety for vehicle operators, transit drivers, passengers, and public safety personnel.

Another desired change is to implement systems to maintain the safe and efficient movement of transit, freight, and emergency vehicles. TSP at intersections will allow a bus to receive early or extended green time to maintain its schedule. In addition, a freight priority scheme at signalized intersections will improve freight mobility and consequently deliver goods faster and more efficiently. With the new freight platoons that will be introduced on the region's roadways, it will be critical to implement a specialized version of this priority scheme that adjusts signal timing to improve platoon mobility and prevent vehicles intending to platoon from being separated while on surface roads. Furthermore, a signal preemption strategy will provide right-of-way to emergency vehicles and allow safe, efficient passage through intersections.

The final desired change is to improve traffic management throughout the City of Columbus. Ideally, the CVE will enable state and local agencies to collect low-cost, comprehensive, high-quality data that can be used in conjunction with data collected from traditional and third-party sources to support enhanced traffic management activities. Archiving select data from the CVE into Operating System will further enhance the integration of transportation data into network management and long-term transportation planning.

User Needs

Collectively, feedback from the working groups, the Linden community, COTA, the public safety community and the freight community culminated in a list of specific user needs, as summarized in **Table 11: User Needs**Table 11. These user needs are expected to be supported through the deployment of CV applications. Ideally, these applications have already been demonstrated in other pilots and would require only minor modification, if any, to deploy locally. The technology readiness level for applications that has been proposed to satisfy these user needs are discussed in **Appendix F, Proposed Application Technology Readiness Level Assessment**.

Table 11: User Needs

Identification	Title	Description	Rationale	Priority
		Light-Duty Vehicle Operator User Needs		
CVE-UN110-v02	Vehicle Collision Avoidance	A light-duty vehicle operator needs to know of an event that may lead to a crash with a CV-equipped vehicle.	To reduce the likelihood of a crash.	Essential
CVE-UN111-v02	Emergency Braking Ahead	A light-duty vehicle operator needs to know when a CV-equipped vehicle in its path of travel is braking in an emergency fashion.	To reduce the likelihood of a rear-end crash.	Essential
CVE-UN112-v02	Safe Following Distance	A light-duty vehicle operator needs to be informed if their following distance is too close.	To reduce the likelihood of a rear-end crash.	Essential
CVE-UN113-v02	Monitor Vehicle Trajectories at Intersection	A light-duty vehicle operator approaching an intersection needs to be aware of CV-equipped vehicles on intersecting trajectories.	To reduce the likelihood of angle, sideswipe, head-on, and angle crashes.	Essential
CVE-UN114-v02	Lane Change Collision Warning	A light-duty vehicle operator needs to be warned if they are changing lanes into the path of another CV-equipped vehicle.	To reduce the likelihood of a sideswipe crash.	Essential
CVE-UN120-v02	Vehicle in Blind Spot	A light-duty vehicle operator needs to be notified if another CV-equipped vehicle is in their blind spot.	To improve awareness of other vehicles on the roadway and to reduce the likelihood of a crash.	Desirable
CVE-UN130-v02	Stop on Red Signal	A light-duty vehicle operator needs to know if a signal will be red when the vehicle is expected to enter a CV-equipped intersection.	To reduce the likelihood of running a red light and colliding with another vehicle.	Essential
CVE-UN140-v02	School Zone/ Decrease Speed	A light-duty vehicle operator needs to know when they are exceeding the school zone speed limit in an active school zone that is CV equipped.	To reduce the likelihood of a crash with a pedestrian in the school zone.	Essential
		Emergency Vehicle Operator User Needs		

Identification	Title	Description	Rationale	Priority
CVE-UN220-v02	Emergency Vehicle Intersection Priority	An emergency vehicle operator needs preemption service at CV-equipped signalized intersections.	To allow queued traffic to dissipate and to reduce delays at signalized intersections for emergency vehicles when responding to emergency calls.	Essential
		Heavy-Duty Vehicle Operator User Needs		
CVE-UN310-v02	Heavy-Duty Vehicle Intersection Priority	A heavy-duty vehicle operator needs priority service at CV-equipped signalized intersections.	To avoid fuel waste and pollution to restart a heavy-duty vehicle.	Desirable
CVE-UN320-v02	Freight Signal Priority with Platoon Intent	A heavy-duty vehicle operator needs to follow (or be followed by) other CV-equipped heavy-duty vehicles that it intends to platoon with.	To keep heavy-duty vehicles that intend to form platoons together as they travel through intersections on arterial roadways.	Desirable
		Traffic Manager User Needs		
CVE-UN410-v02	Monitor Performance	A traffic manager needs the ability to monitor the status of traffic by obtaining data from the CVE.	To improve the ability to know when to implement strategies to improve system performance.	Essential
CVE-UN420-v02	Update Static Messages	A traffic manager needs the ability to update static messages within the CVE.	To communicate modifications in intersection geometry and school zone schedules to drivers.	Essential
CVE-UN430-v02	Configure and Monitor Roadside Devices	A traffic manager needs to configure and monitor the status of roadside devices for operation within the CVE.	To confirm that applications hosted on roadside devices are operating as intended.	Essential
CVE-UN440-v02	Data Archive Configuration	A traffic manager needs to configure the mechanism that is used to archive data.	To archive data received on the roadside to support performance monitoring.	Essential
		Transit Manager User Needs		
CVE-UN510-v02	Service Management	A transit manager needs to keep buses on schedule by reducing delays experienced at signalized intersections.	To provide on-time service.	Desirable

Identification	Title	Description	Rationale	Priority
CVE-UN520-v02	On Schedule Status	A transit manager needs to know if any of its fleet in operation is behind schedule resulting from heavy traffic or increased passenger loads.	To increase the priority of late vehicles.	Desirable
CVE-UN530-v02	Monitor Transit Vehicle Interactions	A transit manager needs to assess interactions between transit vehicles and other CV-equipped vehicles on the roadway.	To monitor the safety of operations of Transit Vehicles in the CVE.	Desirable
CVE-UN540-v02	Transit Vehicle Operator CVE Output	A Transit Manager needs to understand the number of alert and warnings that will be issued to Transit Vehicle Operators.	To assess whether a UI should be implemented on Transit Vehicles.	Desirable
		Pedestrian User Needs		
CVE-UN610-v02	School Zone Pedestrian Safety	A pedestrian in a school zone needs vehicles to travel at or below the school zone speed limit during active school zone hours.	To foster a safe environment in which to walk during active school zone hours reduce the likelihood of a pedestrian crash in a school zone.	Essential
		Network Manager User Needs		
CVE-UN710-v02	Maintain Connectivity	A Network Manager needs to maintain connectivity between CVE devices that communicate via backhaul.	To preserve time-critical communications and ensure the system operates as intended.	Essential
		General System Needs		
CVE-SN810-v02	Operating System Connectivity	A roadside device needs to be connected to the Operating System.	To support the transmission of data that supports management activities and performance monitoring.	Essential
CVE-SN820-v02	Roadside Device Wireless Communications Security	A roadside device needs to be connected to the SCMS.	To support security protocols for roadside DSRC devices.	Essential
CVE-SN830-v02	In-Vehicle Positioning	An in-vehicle device needs to have available position information.	To be used as an input for in-vehicle applications, and to populate messages that	Essential

Identification	Title	Description	Rationale	Priority
			require vehicle location and motion information.	
CVE-SN840-v02	In-Vehicle Time Synchronization	An in-vehicle device needs to be synchronized with a common time source.	To be synchronized with other in-vehicle devices and roadside devices.	Essential
CVE-SN850-v02	Roadside Time Synchronization	A roadside device needs to be synchronized with a common time source.	To be synchronized with in-vehicle devices.	Essential
CVE-SN860-v02	Position Correction	A roadside device needs to have access to position correction information.	So that position correction information can be sent to vehicles so that vehicles can correct their position.	Essential
CVE-SN870-v02	In-Vehicle Device Wireless Communications Security	An in-vehicle device needs to be able to maintain access control lists and obtain new certificates when necessary.	To support security protocols for in-vehicle DSRC devices.	Essential

867 *Source: City of Columbus*

Related Performance Measures

Table 12: Connected Vehicle Environment Performance Measure Overview presents a preliminary list of performance measure objectives that will be used to assess the effectiveness of the CVE. These objectives are subject to change, and baseline and target quantities have not yet been established. The final set of measures, baselines, and targets are currently being developed and will be finalized upon the completion of the Performance Measurement Plan. The final set of performance measures will be developed such that they capture the ability of the system to effectively address the goals and objectives of the program and can be calculated from data that can be collected from the system or from external sources. CVE applications focus on two of the six Smart Columbus program-level goals: improving safety and increasing mobility (other program-level goals include providing access to opportunities, reducing impacts to the environment, increasing public agency efficiency, and increasing customer satisfaction). Due to the sensitive nature of saving alert and warning information for assessing the performance of V2V Safety applications, data will not be collected in private vehicles, and therefore limits the ability to develop a proper performance measure for these applications. The table also lists the hypothesis, performance measure, and the data source(s) associated with each performance measure objective, as stated in the Performance Measurement Plan.

Recall that the CVE is a project that focuses on the deployment of technology that improves safety and mobility of travelers. As explained in **Chapter 1, Project Scope**, the CVE intends to deploy a number of OBUs and RSUs as outlined in **Table 1: Connected Vehicle Environment Project Scope**. Applications installed on CV equipment provide a means of demonstrating benefits to users of the CVE. The deployment of CV technology may not be able to demonstrate statistically significant results for all issues faced by stakeholders (as described in **Chapter 4, Project Scope**). However, a “with-without” analysis among CV drivers could be performed to assess the ability of the system to address these issues.

891 **Table 12: Connected Vehicle Environment Performance Measure Overview**

Objective	Hypothesis	Perf. Measure	Data Source	Baseline	Treatment
Improve reliability of transit vehicle schedule adherence	The Traffic Signal Priority/Preemption application will help transit vehicles stay on schedule.	On-time performance, running time, headway reliability	COTA CAD/AVL data, user surveys	One year prior to implementation	Deployment Observation Period
Improve emergency response times	The Traffic Signal Priority/Preemption application will improve emergency response times by reducing delay at intersections.	Emergency response times	City of Columbus DPS data	One year prior to implementation	Deployment Observation Period
Reduce truck wait (delay) time at signalized intersections	Freight Signal Priority/Platoon Intent Freight Signal Priority will save travel time for trucks passing through equipped intersections by modifying signal timing.	Travel time through intersection	Operating System data, Truck Platoon Network Operations Center (NOC)	Six months following deployment before implementation	Deployment Observation Period
Increase number of truck turns per day	Freight Signal Priority/Platoon Intent Freight Signal Priority will improve logistics efficiency in Columbus by allowing logistics companies to move more loads through their networks.	Number of daily truck turns	Participating logistics companies	Six months following deployment before implementation	Deployment Observation Period
Improve motorists' adherence to red lights	The Red Light Violation Warning application will foster reduction in the number of red light violations and collisions	Driver behavior change in the corridor	Operating System data	*TBD*	Deployment Observation Period
Improve adherence to speed limits in school zones	The Reduced Speed School Zone (RSSZ) application will	Driver behavior change in the corridor	Operating System data	*TBD*	Deployment Observation Period

Objective	Hypothesis	Perf. Measure	Data Source	Baseline	Treatment
	foster reduction of vehicle speeds in school zones				
Improve traffic management capability	*Vehicle Data for Traffic Operations*	*TBD*	*TBD*	*TBD*	*TBD*
Improve transit management capability	*Transit Vehicle Interaction Event Recording*	*TBD*	*TBD*	*TBD*	*TBD*

No performance measures are planned for V2V applications (FCW, LCW/BSW, EEBL, and IMA). Source: City of Columbus

Priorities Among Changes

The user needs listed in **Table 11: User Needs** are classified below in **Table 13: Priorities Among Changes** as essential, desirable, or optional. The general framework for classification is that vehicle and vulnerable road user (VRU) safety needs are considered essential, while features that enhance mobility or promote the awareness of activity on the roadside (such signal priority) are considered desirable.

Table 13: Priorities Among Changes

Rank	Title	Priority Classification	User Need
1	Vehicle Collision Avoidance	Essential	CVE-UN110-v02
2	Emergency Braking Ahead	Essential	CVE-UN111-v02
3	Safe Following Distance	Essential	CVE-UN112-v02
4	Monitor Vehicle Trajectories at Intersection	Essential	CVE-UN113-v02
5	Lane Change Collision Warning	Essential	CVE-UN114-v02
6	Stop on Red Signal	Essential	CVE-UN130-v02
7	School Zone/Decrease Speed	Essential	CVE-UN140-v02
8	Emergency Vehicle Intersection Priority	Essential	CVE-UN220-v02
9	Monitor Performance	Essential	CVE-UN410-v02
10	Configure and Monitor Roadside Devices	Essential	CVE-UN430-v02
11	Data Archive Configuration	Essential	CVE-UN440-v02
12	School Zone Pedestrian Safety	Essential	CVE-UN610-v02
13	Maintain Connectivity	Essential	CVE-UN710-v02
14	Smart Columbus Operating System Connectivity	Essential	CVE-SN810-v02
15	Roadside Device Wireless Communications Security	Essential	CVE-SN820-v02
16	In-Vehicle Positioning	Essential	CVE-SN830-v02
17	In-Vehicle Time Synchronization	Essential	CVE-SN840-v02
18	Roadside Time Synchronization	Essential	CVE-SN850-v02
19	Position Correction	Essential	CVE-SN860-v02
20	In-Vehicle Wireless Communications Security	Essential	CVE-SN870-v02
21	Vehicle in Blind Spot	Desirable	CVE-UN120-v02
22	Heavy-Duty Vehicle Intersection Priority	Desirable	CVE-UN310-v02
23	Freight Signal Priority with Platoon Intent	Desirable	CVE-UN320-v02
24	Update Static Messages	Desirable	CVE-UN420-v02
25	Service Management	Desirable	CVE-UN510-v02

Rank	Title	Priority Classification	User Need
26	On-Schedule Status	Desirable	CVE-UN520-v02
27	Monitor Transit Vehicle Interactions	Desirable	CVE-UN530-v02
28	Transit Vehicle Operator CVE Output	Desirable	CVE-UN540-v02

Source: City of Columbus

Changes Considered but not Included

The CVE lays the foundation for a fully interoperable, open, wireless environment for enhancing safety and mobility for vehicles, pedestrians, and bicyclists. Many of the safety and mobility benefits are now capable of being realized because of the advent of new CV technology, a product of an ecosystem where every vehicle and potentially every VRU has the potential to interact within this network. Some of the applications that have been developed to utilize CV data have been tested and are ready to implement and integrate in an operational CVE; however, some CV applications are in various stages of development and are not considered to be deployment ready. It is the intent of the CVE to implement deployment-ready applications. Furthermore, other applications that are being considered are available in other forms, such as TSP, but these are often single-purpose applications using proprietary systems. The CVE enables these applications to operate on the same network, eliminating the need for redundant systems.

This ConOps is focused on enabling as many CV features as possible to support the identified user needs, as well as to expand current capabilities by introducing new features/capabilities that would not previously have been available without considerable, separate investments. Below are several alternative solutions considered within the CVE target areas. Some non-CV alternative solutions were given consideration due to their maturity compared to CVE solutions while other CV-enabled solutions had the ability to improve safety and mobility from a conceptual standpoint, but due to development and operational limitations, were considered but not included in the CVE. Furthermore, a set of specific CV applications, which were originally identified as of interest, but for which the risk and cost to deploy could not be rationalized, are also included. Note that some user needs that would be supported by the solutions described in this section are not considered in the scope of the CVE as they did not adhere to project constraints associated with the implementation of deployment-ready applications.

Non-CV Solutions Considered

Transit Signal Priority (Opticom Solution) – Prior to the Smart Columbus program, COTA planned to deploy a non-CV TSP solution as part of the CMAX BRT implementation on Cleveland Avenue. The TSP solution, procured from Opticom, is traditionally enabled though an infrared strobe or a Wi-Fi-enabled, GPS-position-based solution. Both products have demonstrated success; however, neither Opticom product is open in terms of its interfaces. The messages it communicates are proprietary and do not use industry standards such as SAE J2735 or NTCIP 1211, both of which support an open approach to TSP. Furthermore, the Wi-Fi hardware that is installed on the roadside and on the transit vehicle is limited to TSP and other signal preempt/priority strategies. Normally, Wi-Fi would be open, but the proprietary nature constrains its use in a vehicular environment (with fast approaching vehicles).

Moving toward a CVE, the current but dated use of physical interrupts to place a call for TSP is very limited. The CV-based TSP solution allows a more sophisticated approach due to the improved ability to detect all vehicles arriving at and departing from the intersection and to adapt timing accordingly. With the

CV approach to TSP, Wi-Fi from the Opticom system described above is replaced with DSRC, a communications medium designed to be used in a vehicular environment. In addition to supporting preemption and prioritization needs, DSRC can provide signal phase and timing data, traveler information messages, or other critical safety information. Because the J2735 SRM is the only standardized transit priority request message, there is insignificant risk for adopting CV-based signal priority for transit operations. CV-based TSP includes the security certificates and standardized messages not offered by proprietary solutions.

In conjunction with the CMAX project, COTA has already deployed the Opticom system. The Smart Columbus CV-based TSP will be deployed alongside this functioning Opticom system. Should COTA decide to continue using the Opticom system to support signal priority for its buses, then all functions and communications required of the CV-based signal priority application will continue to be enabled, except outputs to the vehicle operator (if any) or outputs to the traffic signal controller. While this effectively eliminates any impact of the CV approach on the traffic signal, it allows operations test data to be collected, which can be compared against test data from the Opticom system to assess the differences between the two systems.

Emergency Vehicle Preempt (EVP) (Opticom Solution) – Similar to TSP, the majority of EVP systems deployed today are closed, propriety Opticom solutions. DSRC is also capable of providing EVP while supporting the full range of CV and emerging automated vehicle (AV) applications. The Multi-Modal Intelligent Traffic Signal System (MMITSS)[16] demonstrations conducted in Anthem, Arizona and in Berkeley, California provide evidence that CV technology can be utilized to support EVP. It is expected that a successful demonstration of EVP using DSRC along the Smart Columbus corridors will allow for a similar solution to be used on future implementations. Also, the standardized CV preemption provides interoperability during mutual response situations so that emergency vehicles using a common RF band, common security certificates and common messages can operate outside of their home district.

Pedestrian and Bicyclist Safety (Mobileye Solution) – This category of strategies relates to the detection of pedestrian and bicyclists and warning vehicle operators of potential conflicts. One alternative for achieving similar outcomes for pedestrian and bicyclist safety is the Mobileye Shield + system. Mobileye is a USDOT Smart City partner and its Shield + product was targeted for the entire COTA fleet. Mobileye is a vehicle-based system comprised of multiple cameras, displays, and an onboard processing unit. Mobileye has been effective in many other cities, and it is expected to be effective in Columbus. For transit or other heavy vehicles with long service lives that are typically retrofitted with aftermarket devices, Mobileye is a viable solution. Further, the cost of a Mobileye installation (including equipment) is about $9,500 per vehicle, and the equipment is not designed for aftermarket deployment on light-duty vehicles. Considering these costs, both for COTA and for the 2,000+ CV-equipped vehicles, an infrastructure-based solution still emerges as the more versatile and affordable option.

A second alternative to achieving pedestrian and bicyclist safety is the installation of external vehicle annunciators, which can announce to pedestrians and bicyclists that the vehicle is turning. Like Mobileye, this technology is best deployed on buses and other heavy-duty fleet vehicles. Deployment on light-duty vehicles is impractical because of cost, installation requirements, and the potential nuisance to other vehicle operators and society if all vehicles announce their intent externally.

[16] *MMITSS ConOps.* *http://www.cts.virginia.edu/wp-content/uploads/2014/05/Task2.3._CONOPS_6_Final_Revised.pdf*

CV Solutions Considered but not Ready for Deployment

Bicycle Approaching Indication (CV Solution – not deployment ready) – This application warns the vehicle operator that a bicycle is approaching, whether from behind, or moving across the vehicle's path at an intersection. This application intends to improve driver awareness to the presence of bicycles to address crashes between vehicles and bicycles. This application was not included in the CVE as it was not considered deployment-ready. **Appendix F, Proposed Application Technology Readiness Level Assessment** provides an assessment of the readiness of this application.

Emergency Vehicle Alert (CV Solution – not deployment ready) – This application alerts the vehicle operator about the location of and the movement of public safety vehicles, so the vehicle operator does not interfere with the emergency response. This application will also inform emergency vehicle operators of the location and movement of other emergency vehicle operators to reduce "blue-on-blue" crashes. The application can do this by receiving information about the location and status of nearby emergency vehicles. This application addresses emergency vehicle operator safety and emergency vehicle delay. This application was not included in the CVE as it was not considered deployment-ready. **Appendix F, Proposed Application Technology Readiness Level Assessment** provides an assessment of the readiness of this application.

Transit Vehicle at Station/Stop Warning (CV Solution – not deployment ready) – This application informs nearby vehicle operators of the presence of a transit vehicle at a station or stop. The application indicates when a transit vehicle is pulling into or out of a station/stop. This also includes school buses, which requires drivers to come to a complete stop when stopping to pick-up or unload school passengers. This application addresses crashes between vehicles and transit vehicles. This application was not included in the CVE as it was not considered deployment-ready. **Appendix F, Proposed Application Technology Readiness Level Assessment** provides an assessment of the readiness of this application.

Vehicle Turning Right in Front of a Transit Vehicle (CV Solution – not deployment ready) – This application determines the movement of vehicles near a transit vehicle stopped at a transit stop, and it indicates that a nearby vehicle is pulling in front of the transit vehicle to make a right turn. The application improves safety for both the passengers of the transit vehicle as well as third-party vehicle occupants by providing warnings and alerts to the transit vehicle operator of a vehicle passing and navigating through the blind zone and ultimately turning into the transit vehicle's direction of travel. This application was not included in the CVE as it was not considered deployment-ready, and there was concern about providing outputs to transit vehicle operators. **Appendix F, Proposed Application Technology Readiness Level Assessment** provides an assessment of the readiness of this application.

Pedestrian in Signalized Crosswalk Warning (CV Solution – not deployment ready) – This application provides information indicating the possible presence of pedestrians in a crosswalk at a signalized intersection. The application improves pedestrian safety by providing alerts and warnings to the vehicle operator of a pedestrian in the crosswalk. Pedestrian detection equipment is used to determine when a pedestrian is in a crosswalk, and this information is broadcast to vehicles, which display warnings to the vehicle operator. This application addresses crashes between vehicles and pedestrians. This application was not included in the CVE as it was not considered deployment-ready. **Appendix F, Proposed Application Technology Readiness Level Assessment** provides an assessment of the readiness of this application.

Transit Pedestrian Indication (CV Solution – not deployment ready) – This application informs pedestrians at a station or stop about the presence of a transit vehicle. In addition, this application informs the transit vehicle operator about the presence of pedestrians and those waiting for the bus. This application's goal is to prevent collisions between transit vehicles and pedestrians by alerting pedestrians at a major bus stop of approaching transit buses, alerting pedestrians at a major bus stop of departing transit buses, and alerting transit vehicle operators of a pedestrian potentially in harm's way at a major bus stop via a driver-vehicle interface. This application was not included in the CVE as it was not considered deployment-ready, and there was concern about providing outputs to transit vehicle operators. **Appendix F, Proposed Application Technology Readiness Level Assessment** provides an assessment of the readiness of this application.

Warnings about Upcoming Work Zone (CV Solution – operational challenges) – This application provides approaching vehicles with information about work zone activities that may present safety concerns, such as obstructions in the vehicle's travel lane, lane closures, lane shifts, speed reductions or vehicles entering/exiting the work zone. This application would have addressed issues regarding work zone awareness, but ultimately it was not included in the CVE due to anticipated operational challenges. **Appendix F, Proposed Application Technology Readiness Level Assessment** provides an assessment of the readiness of this application.

Chapter 5. Concept for the New System

The CVE is expected to deliver exceptional situational awareness and responses, setting a new standard in traffic management and operations, launching the next generation of ITS safety and mobility with advanced CV equipment on the network. The CVE will deploy CV infrastructure on the roadside and CV equipment in vehicles. The CV infrastructure deployment will occur on seven major corridors/areas in the City and in school zones. The deployment of in-vehicle devices will be targeted toward populations and VRUs who are located near the infrastructure deployment. The CVE will also provide sources of high-quality data for traffic management purposes. The following sections cover background, operational policies and constraints, description of the proposed system, modes of operation, user classes, and the support environment, and they touch on security and privacy concerns.

Background, Objectives and Scope

The Smart Columbus program has six 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 ITS 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 objectives established in the Performance Measurement Plan have been developed based on the needs of CVE stakeholders and are listed below.

- Improve reliability of transit vehicle schedule adherence
- Improve emergency response times
- Reduce truck wait (delay) time at signalized intersections
- Increase number of truck turns per day
- Improve motorists' adherence to red lights
- Improve adherence to speed limits in school zones
- Improve traffic management capability

The CVE will leverage planned improvements to build a safe, optimal demonstration of the system. The CVE will meet these objectives by deploying CV technology in vehicles and on the roadside. This technology will allow data to be exchanged among multiple vehicles and between vehicles and infrastructure to improve transportation system safety, mobility, and data collection capability.

Operational Policies and Constraints

This section discusses operational policies and constraints that must be considered prior to the design of the Smart Columbus CVE. Such concerns include consistency in safety critical situations, location and design constraints, and permits involving the installation of CV technology in vehicles and on the roadside.

System Architecture and Standards

The USDOT has developed architecture (CVRIA) for the design and implementation of CV systems. Furthermore, communication standards have been developed for CV data frames/elements (SAE J2735), performance requirements (SAE J2945), security services (IEEE 1609.2), networking (IEEE 1609.3), and multichannel operations (IEEE 1609.4). The CVE system will adhere to the CV architecture set forth by USDOT and standards developed for CV communications.

All projects associated with the Smart Columbus program (including the CVE) will be connected to the Operating System to archive all relevant systems operations data. This includes data that is generated or captured by roadside components of the CVE. The role of the Operating System in the context of the CVE is further described in **Chapter 5, Concept for the New System** under **Description of Proposed System**. Finally, the CVE will utilize a wireless communications security system to allow trusted and secure DSRC communications between devices (Note that the SCMS Proof-of-Concept developed by the USDOT will not be used as it is expected to be decommissioned on September 30, 2018. This is prior to the deployment of the CVE).

MORPC maintains the Central Ohio Regional ITS Architecture[17], which is based off the National ITS Architecture. This architecture ensures that the region can receive the greatest possible benefit resulting from the integration of multiple ITS components in the regionwide system and provides a framework for the integration and interoperability of ITS systems in the region. For the CVE to work seamlessly with existing and future ITS systems in the region, it will need to adhere to or modify the regional architecture. To this end, ODOT has updated the Ohio ITS architecture, and is coordinating with MORPC to make updates on the regional level. It will be important to ensure that any changes to the regional and state ITS architectures are finalized prior to the deployment and operation of any equipment associated with the CVE.

Limitations of the Connected Vehicle Environment Within the Operational Environment

V2V applications only work as intended when a host vehicle and a remote approaching vehicle (defined in **Chapter 5, Concept for the New System** under **Description of Proposed System**) have onboard equipment installed. Because not all vehicles in Columbus will be equipped with OBUs, the system will give feedback in some (but not all) safety-critical situations. Vehicle operators must be trained to make the same visual checks they usually do, and not to rely on alerts and warnings to safely navigate the roadway network.

V2I applications only work on roadways where roadside infrastructure is installed and only for vehicles equipped with an OBU. Even on CV-equipped corridors, certain applications may not be supported depending on the equipment installed at each location. For instance, CV equipment will only be installed in select school zones (i.e. school zones with flashing lights and power connection). Vehicle operators must be trained to observe posted school zone signage and not to rely on school zone alerts from the OBU. Another issue surrounding school zones is the physical school zone boundary. It is important to place roadside DSRC radio antennas to cover all approaches to a school zone, including side streets. Some existing school zone signage is vague, leading to confusion about how rules are enforced.[18] Some signage indicates that vehicle operators must travel at the posted speed “when children are present,” which is a situation that cannot be supported with the RSSZ application. Furthermore, drivers must obey

[17] *MORPC – Central Ohio Regional ITS Architecture. http://www.morpc.org/itsArchitecture/*

[18] *Columbus Dispatch – When are Speed Restrictions in School Zones in Effect? 11/11/13. http://www.dispatch.com/content/stories/local/2013/11/11/school-zones-not-uniform.html*

the school zone speed limit during recess and while children are going to or leaving school (Ohio Revised Code (ORC) 4511.21), in addition to any conditions that are posted on school zone signage. Vehicle operators must be trained to observe these signs and understand which types of school zones are supported.

The situations described above require the vehicle operator to be trained to drive as usual to minimize the likelihood of a safety issue resulting from reliance on CV applications in areas where they are not supported. If the vehicle operator must always make the same visual checks as they currently do, then such safety warnings may be perceived as superfluous and may be ignored after time. The best solution is to train vehicle operators on how the system works and why alerts or warnings will be given only in certain situations and/or in certain locations. Training explains that alerts and warnings are not intended to replace safety checks that are typically made. While training can inform vehicle operators that this is the case, it is only natural that the vehicle operator could begin to rely on alerts and/or warnings to inform them of certain imminent safety-compromising events. Thus, training must also focus on making sure drivers do not become over-reliant on the system. The CVE only intends to increase vehicle operator awareness in certain situations and locations, and it provides additional information to improve safety.

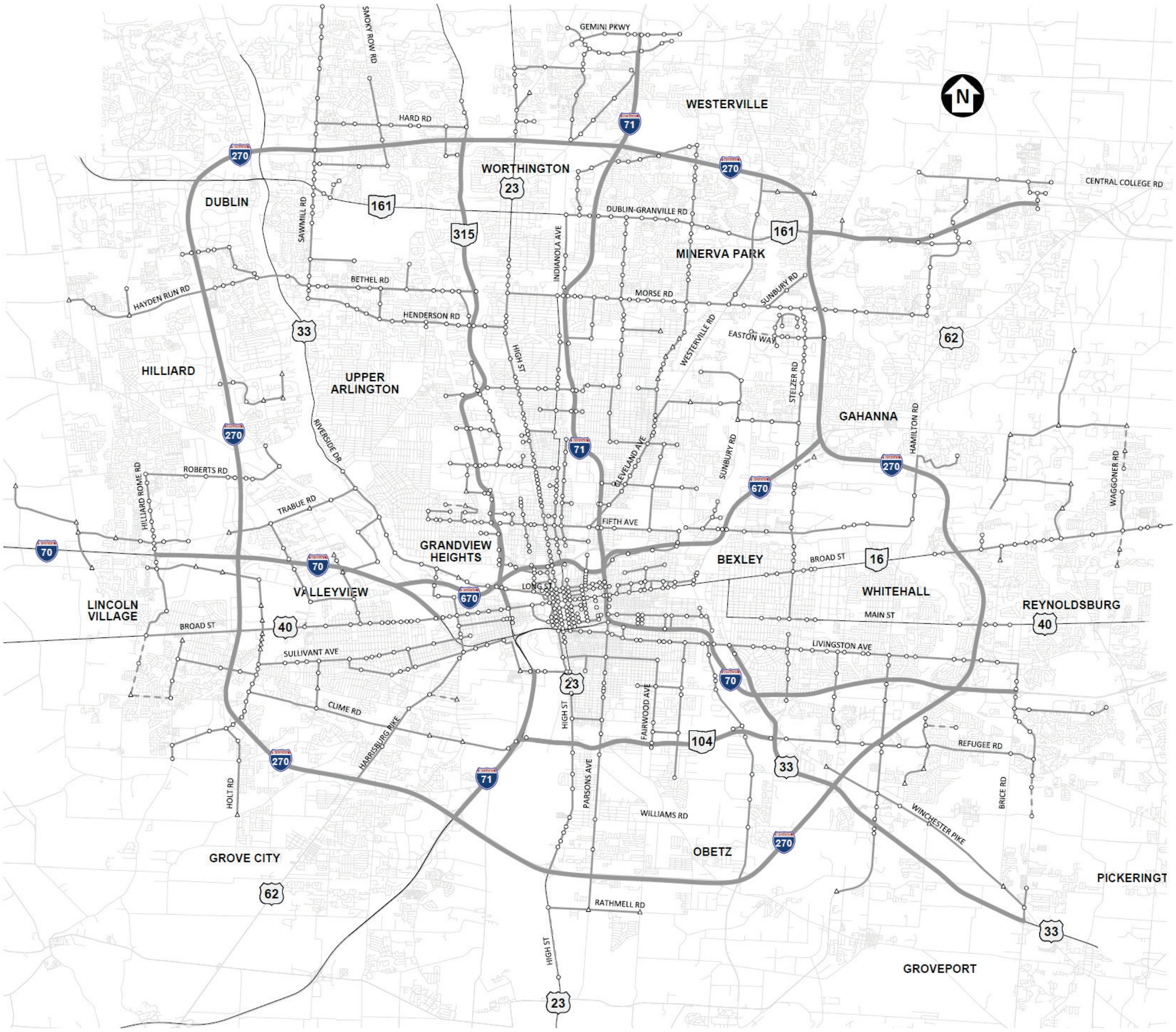
Signal priority applications will only work at intersections on CVE corridors. However, this will not have an impact on driver behavior as these applications send service request messages in the background, and vehicle operators do not have an expectation that they will receive priority – thus drivers will exhibit the same behavior approaching intersection as they currently do. The issues surrounding signal priority and preemption applications may involve changes to current signal timing plans. For EVP to work with maximum efficiency, the City of Columbus must implement updated signal plans (i.e. a nonstandard intersection phase sequence for signal preemption). Although less challenging, the city must also allow advances through the phases (early green) or modify the length of phases (extended green) to support priority applications (transit, freight, and platoon).

Vehicle Operation Regulations

Policies governing driver behavior in the context of the CVE are the same as the existing operational polices described in **Chapter 3, Current System**. The CVE will be designed to provide alerts and warnings to drivers that complement these existing regulations. There are no regulations in place that require the driver to react to alerts or warnings from a CV system; however, drivers will be expected to adhere to existing regulations associated with traffic control devices (e.g. traffic signals, signage, and lane markings). Any changes that the CV system makes to ITS devices – such as the modification of traffic signal timing plans – must adhere to state and city design documents, including the OMUTCD (adoption required by ORC 4511.09) and the Traffic Signal Design Manual. Furthermore, any modifications to, or interfaces with, existing ITS systems need to be documented and shown in the regional and statewide ITS architectures.

Roadside Equipment Location and Design Constraints

Fiber optic infrastructure comprising the CTSS is needed to transmit data between roadside infrastructure and the Operating System to support the CVE. Locations where the CVE can be supported will be limited to the extent of the CTSS. Intersections connected to the CTSS are shown in **Figure 5: City of Columbus Traffic Signal System Equipped Intersections (Current)**. An expansion of the CTSS (Phase E, also shown in **Figure 5: City of Columbus Traffic Signal System Equipped Intersections (Current)**) is currently underway and the locations necessary to support the Easton portion of the CVE are expected to be complete prior to implementation of the CVE. The CTSS expansion will include the intersections and school zones included in the CVE. Furthermore, other systems utilize the fiber network to transmit data for various purposes. Transmission of CVE data over the fiber optic network will be accomplished in a way that does not interfere with other communications over the network.



Source: City of Columbus

Figure 5: City of Columbus Traffic Signal System Equipped Intersections (Current)[19]

The design constraints and considerations generally limit the installation of the Roadside Unit (RSU) to vertical assets including, but not limited to vertical strain poles, spanwire, or a mast arm on which signal heads are installed. It is preferable to install RSUs overhead on rigid vertical strain poles and mast arms compared to spanwire. However, if acceptable transmission ranges cannot be achieved from these strain poles or mast arms, a bracket arm could be affixed to the strain pole to mount the RSU or a spanwire

[19] *City of Columbus Traffic Signal System (CTSS) Phase E. 23 CFR 940 System Engineering Analysis Document*

mounting location will be considered. The RSU must be placed at a location less than 328 feet[20] from the traffic signal controller (Power-Over-Ethernet networking standard – IEEE 802.3-2015). Alternatively, an RSU could be placed in the TSC cabinet while the antenna is mounted on the spanwire or mast arm. In this case, the cable length will be limited by the type and gauge of the cable connecting the RSU to the antenna.

The placement of the RSU plays a role in the resulting DSRC reception range – and effectively the area where V2I applications can be supported. Static objects in the roadway environment that will affect DSRC signals include but are not limited to buildings, foliage, and other physical objects on the side of and above the roadway. Horizontal and vertical roadway curvature also play a role in DSRC reception range. Furthermore, building offset and street trees alongside and in the median of roadways have the potential to affect DSRC range. The RSU should be placed to maximize the area of roadway that has an uninterrupted line-of-sight with the RSU.

Permit Requirements/Licenses

Because CV hardware has not been installed on public roadways in Ohio, testing permits from the State or the City may be required before any CV hardware is deployed. Though it contains ITS equipment, CV hardware is currently not on the ODOT Traffic Authorized Products List[21]. Obtaining the testing permit may include the installation and demonstration of the CVE at a test facility. One test facility that has been identified is the CV/Autonomous Vehicle (CV/AV) test track at the Transportation Research Center (TRC). ODOT also maintains an ITS lab which could be used. Further, ODOT has recently embarked on a detailed systems engineering analysis for CV that is expected to help facilitate and streamline this process statewide.

Prior to deployment, a system verification plan should be developed and performed to test if system requirements are being met and unit tests should be developed and performed to ensure the system has been designed and built as intended. Further, a system validation plan should be developed to assess system performance and to ensure the system addresses the needs of the stakeholders as outlined during the development of the system concept. It may be advantageous to perform these tests in a closed environment to gain deployment expertise, minimize the likelihood of unintended operations, and to allow revisions to be made to the system. Furthermore, as system components (including firmware) are updated, they may be tested in a closed environment to ensure the system continues to operate as intended once updates have been made.

Finally, operation of DSRC radios (RSU and OBU) in the CVE is dependent on the acquisition of Federal Communications Commission (FCC) licenses. The CVE will only be able to legally operate if each DSRC broadcasting device has a valid, non-expired FCC license. The Department of Public Service is familiar however with the process from other licensing needs and not major impacts are expected. However, any potential impacts of the FCC license application process are discussed in **Chapter 7, Summary of Impacts**.

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[20] *Measured along the path taken by a Cat 6a Ethernet cable that links the RSU to the switch connected to other equipment in the TSC. This includes service loops.*

[21] *ODOT – Qualified Products List (QPL).*

http://www.dot.state.oh.us/Divisions/ConstructionMgt/Materials/Pages/QPL.aspx

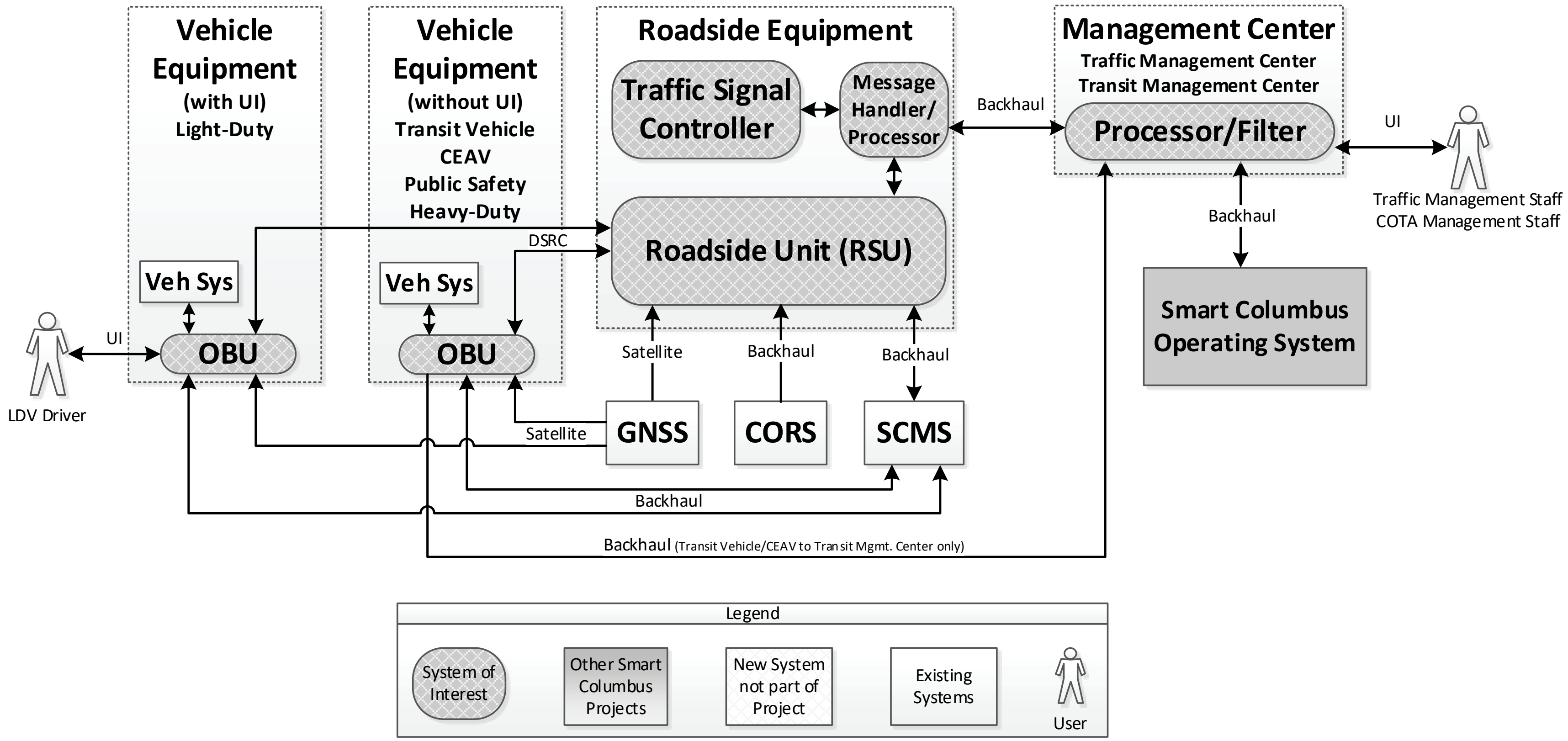
Information Technology and Data Security

Due to the networked nature of devices in the CVE, a number of policies and constraints regarding information technology and data security are anticipated to be developed as part of the deployment. Information technology service management must be modified from existing practices to accommodate the addition of CV technology to design, plan, deliver, operate, and control the information technology services that must be provided to maintain these devices. The CVE will result in the generation of new IT processes, policies, and data governance plans to manage the system. These policies may be formally or informally documented. Furthermore, the CVE will result in policies surrounding the integration of the SCMS, cyber-threat intelligence, and methods for identifying, protecting, detecting, responding, and recovering from potential threats to devices connected to the CVE. Examples of some of these policies are discussed in this chapter below.

Description of Proposed System

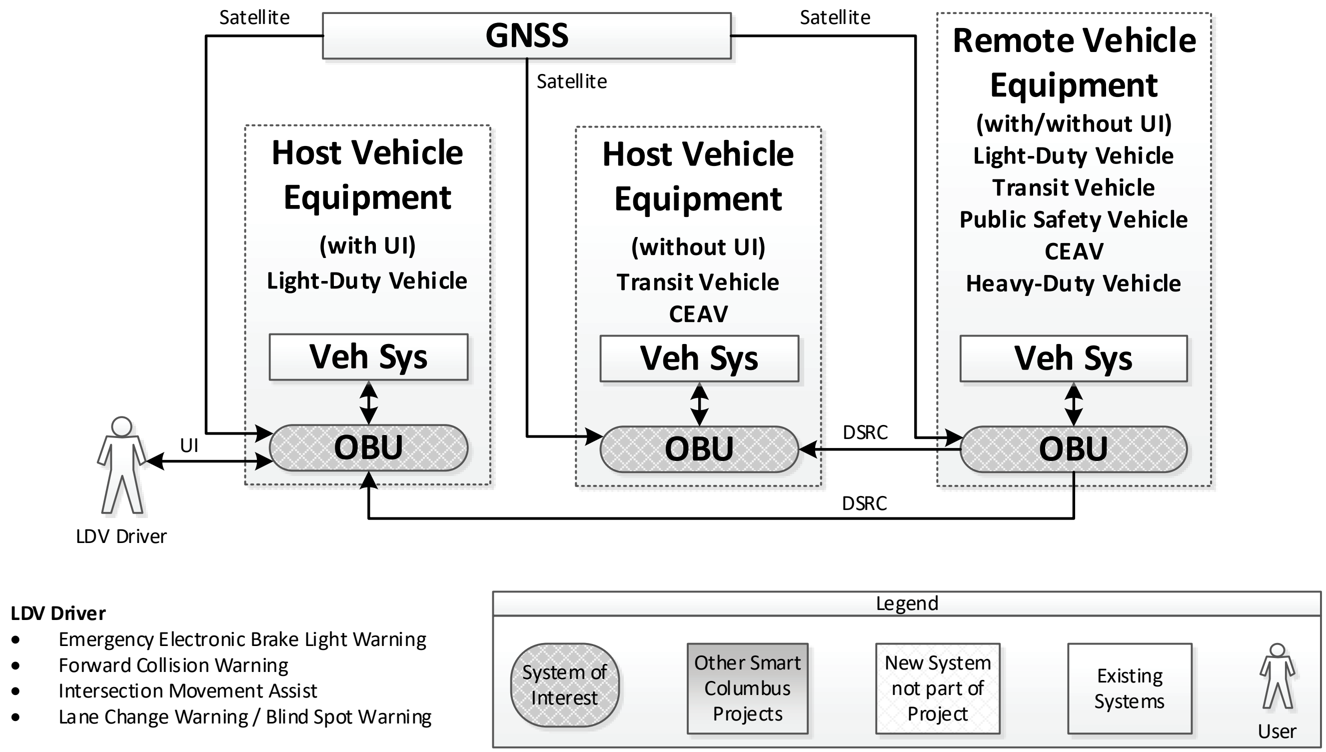
The CVE can be described as a combination of subsystems that work together: a system of roadside equipment, a system of in-vehicle equipment, and a system of backhaul networks for agency data. On the roadside, the fundamental functions of the RSUs are to obtain various types of status information from roadside ITS devices and broadcast this information to vehicles in the vicinity. Intersections identified for the deployment of roadside CV equipment presumably contain necessary physical cabinet and conduit space for the proposed CV equipment, and that the distance between the cabinet equipment and overhead RSU mounting locations conform to distance constraints for physical communication between locally networked devices. Upon the completion of detailed engineering plans, any necessary remedies will be addressed. Subsequently, in a vehicle, the fundamental functions of OBUs are to obtain various types of status information from the vehicle and broadcast this information to other vehicles and infrastructure in the vicinity. The OBU may utilize status information from the vehicle (this includes interfaces with other in-vehicle devices deployed as part of the Smart Columbus program), the roadside, other vehicles, and location and time data (obtained from a location and time source, such as GNSS) to support safety and mobility applications. Similarly, the RSU exchanges information with the roadside ITS equipment, vehicles, and location and time data to support mobility applications. Both the OBU and RSU utilize the SCMS to make sure that it is working with data from trusted sources, and the roadside device saves operational data on the Operating System.

The context diagram showing V2I communication between vehicles and roadside devices (via DSRC) and communication between roadside devices and data management systems (via backhaul) is shown in **Figure 6: Connected Vehicle Environment V2I Context Diagram** and the context diagram showing V2V communication between onboard devices (via DSRC) is shown in **Figure 7: Connected Vehicle Environment V2V Context Diagram**. Details regarding the roadside context diagram and in-vehicle context diagram including, interfaces, hardware, communications, messages sent between devices, and facilities are described in the following sections. Additional details regarding the physical security, system/data security, proposed applications, proposed roadside equipment locations, and proposed in-vehicle equipment installations are also provided. A summary of interfaces, hardware, facilities, communications, and messages used in the system is provided in **Table 14: Connected Vehicle Environment Proposed System Elements and Interfaces**. The reader should reference these figures and table throughout this section to foster a better understanding of the system concept.



Source: City of Columbus

Figure 6: Connected Vehicle Environment V2I Context Diagram



Source: City of Columbus

Figure 7: Connected Vehicle Environment V2V Context Diagram

1248 **Table 14: Connected Vehicle Environment Proposed System Elements and Interfaces**

	Legend	TO							
	Communications Media Transmitted Messages	OBU	RSU	TSC	Message Handler/ Processor	Smart Columbus Operating Sys	LDV Driver	Traffic Management Center	Transit Management Center
FROM	**OBU**	DSRC BSM	DSRC BSM, SRM	-	-	-	UI Warning, Alerts	-	(COTA Only) Backhaul BSM, App Output
FROM	**RSU**	DSRC SPAT, MAP, RTCM, SSM, TIM	-	-	Local BSM, SRM	-	-	-	-
FROM	**TSC**	-	-	-	Local SPaT, SSM	-	-	-	-
FROM	**Message Handler/ Processor**	-	Local SPaT, MAP, RTCM, SSM, TIM	Local SRM, Signal Timing Plan	-	-	-	Backhaul Operations Data, Status Data	-
FROM	**GNSS***	Satellite Time and Location	Satellite Time and Location	-	-	-	-	-	-

	Legend	TO							
FROM	**CORS***	-	Backhaul RTCM Data	-	-	-	-	-	-
	SCMS*	Backhaul SCMS Certificates	Backhaul SCMS Certificates	-	-	-	-	-	-
	Vehicle System	OBD-II Data	-	-	-	-	-	-	-
	Traffic Management Center	-	-	-	Backhaul Signal Timing Plan, MAP, TIM	Backhaul Signal Timing Plan, MAP, TIM	-	-	-
	Transit Management Center	-	-	-	-	(COTA Only) Backhaul Interaction Data	-	-	-

**External system. Source: City of Columbus*

Interfaces

Host vehicle OBUs must be able to receive BSMs broadcast from a remote vehicle's OBU. Vehicle onboard equipment must be capable of receiving and decoding SPAT, MAP, Signal Status Messages, and Traveler Information Messages (TIMs) broadcast from the RSU to support V2I Safety applications. Host vehicle OBUs (light-duty vehicles only) will also have a user interface that allows it to provide information, alerts, and warnings to a vehicle operator. This interface could potentially include audio, visual, and haptic feedback, and used to provide information, alerts, and warnings to vehicle operators – the output of vehicle-hosted applications. Host vehicle OBUs may also need to communicate with existing vehicle systems. An OBU can interface with vehicles via the controller area network (CAN) bus, often via the onboard diagnostics (OBD-II) port to access live telematics data and other data produced by the vehicle. An OBU may utilize CAN bus output to obtain the vehicle data it needs to populate CV messages and enable in-vehicle applications. Every vehicle makes available a standard set of OBD-II PIDs which does not vary by manufacturer. These data items are standardized in SAE-J1979. However, if it is decided that BSM Part 2 messages are to be sent and vehicle data not specified by this standard are needed, then libraries from vehicle manufacturers will be needed to decode this data made available by the vehicle.

Furthermore, certain vehicle OBUs may need to interface with other in-vehicle equipment deployed as part of the Smart Columbus program. Most notably, this includes interfaces between the platooning trucks' onboard systems and its OBU and between the CEAV OBU and navigational/computational systems on board the CEAV. It should be noted, that in no case does the OBU expect to write to the CAN bus.

Enabling signal priority for trucks that intend to platoon requires an interface with the system that will be deployed for the DATP project. The parameters with which signal priority is requested (e.g. duration of service requested) depends on if a heavy-duty vehicle is by itself or if it is being followed by another heavy-duty vehicle with which it intends to form a platoon. To ascertain these details, the CVE will need to interact with the DATP system (this could potentially be data from the DATP network operations center) to exchange platoon detail information. An interface will also be required between the CVE and the CEAV to allow the CEAV to make use of CVE data as an additional source of data that improves its ability to understand its surroundings and navigate the roadway environment. (CEAV sensors may have limitations in detecting roadway conditions in certain circumstances.)

The RSU must interact with vehicle OBUs to receive BSMs and SRMs broadcast by vehicle OBUs. The roadside Message Handler/Processor processes this information and passes it onto ITS devices (such as the traffic signal controller) to enable roadside CV applications – which provide outputs to vehicles via DSRC and modifying the operations of roadside ITS devices.

Both roadside equipment and vehicle onboard equipment must interface with GNSS to receive location and time information sent from GNSS. GNSS data allows time synchronization between devices, roadside equipment to provide position correction information, and vehicle onboard equipment to position itself in the context of the CVE.

Roadside equipment must interface with a Continuously Operating Reference Station (CORS) to receive localized RTCM data that is used to populate RTCM messages. The RSU forwards this RTCM data to onboard equipment so that vehicles may accurately position itself in the roadway environment.

Both roadside equipment and vehicle onboard equipment must be capable of receiving updated security certificates and protocol from the SCMS. They must also be capable of reporting bad actors to the SCMS to allow the system to revoke any invalid certificates.

The Operating System, at the center of the Smart Columbus program, serves as the central data repository for all data. The Operating System is at its core, a data management platform built to handle big data. It will consume, transform, store, and publish data in a secure fashion. The Operating System must be capable of receiving and archiving status information, event messages, raw or filtered traffic situation data (safety and priority request messages) from equipment on the roadside. Data in the Operating System can be accessed by the TMC for transportation management purposes and by a fleet management center, first responder dispatch center, or transit management center for fleet management purposes. Status information, event messages, and traffic situation data are sent from the equipment on the roadside to the Operating System to support system performance management. Equipment on the roadside must be capable of receiving application parameter information (e.g. traffic signal timing plans, etc.), and data collection parameters specified by Traffic Managers in the TMC.

Hardware

Vehicle Onboard Equipment

“Onboard equipment” is the term used for all equipment that is installed in the vehicle. Any or all of the following items can comprise onboard equipment: GNSS receiver, vehicle data bus (OBD-II port), a DSRC radio, a processing unit, power management system, and a display (vehicle operator interface).

Communications devices along with other affiliated equipment located in the vehicle as part of the CVE are collectively known as the OBU. In the CVE, the OBU is envisioned to consist of a DSRC radio and a processing unit, and potentially a GNSS receiver and display (the existing vehicle system may already have a GNSS receiver and display that could be utilized). Further, it includes any software installed on these devices to enable their functions and that of CV applications. In-vehicle sensors or the OBDII port could capture the vehicle’s acceleration and angular rotation while the GNSS captures the vehicle’s position, speed, and heading. In addition to the OBD-II port, the OBU may communicate with other in-vehicle equipment that is expected to be deployed for other projects as part of the Smart Columbus program. Primarily, this consists of the OBU in the CEAV communicating with navigational systems on the CEAV, and the OBU in a heavy-duty vehicle communicating with platooning systems deployed as part of the DATP project.

To maintain a consistent point of reference, in-vehicle sensors and the GNSS receiver must remain stationary (fixed to the vehicle). This data is used to populate safety (and other) messages that are broadcast by the vehicle. The OBU broadcasts and receives messages to/from RSUs and other (remote) OBUs. The processing unit performs various tasks with the data received from in-vehicle sensors, GNSS, and message data received via the OBU. Finally, the in-vehicle display provides alerts and/or warnings to the vehicle operator based on outputs from the processing unit.

Roadside Equipment

Equipment on the roadside can be comprised of any or all the following items: TSC, GNSS receiver, a DSRC radio (also known as Roadside Unit, or RSU), and/or a message handler/processing unit. It is important to note that the message handler/processor can take multiple forms – it could be incorporated into the TSC or the RSU, or it could be its own dedicated component. Only a device that contains a message handler/processing unit is capable of interfacing with remote equipment via backhaul. Furthermore, the TSC must be capable of providing traffic signal data as an output – NTCIP 1202[22] compliant traffic signal controllers are capable of generating a uniform output that contains signal data used to support CVE applications.

[22] *NTCIP 1202 – NTCIP Object Definitions for Actuated Traffic Controllers*

Communications devices and other affiliated equipment installed on the roadside as part of the CVE are collectively known as roadside equipment. In the CVE, the roadside equipment is envisioned to consist of a GNSS receiver, DSRC radio, and possibly the processing unit (which could be contained on the RSU or other roadside equipment such as the TSC or an intermediate dedicated processing device). GNSS data is used to determine position correction for the intersection. GNSS data, along with data received from traffic control equipment is populated into various messages – SPAT, MAP, TIM, RTCM, etc. The RSU broadcasts and receives messages to/from vehicle OBUs. The processing unit performs various tasks with the data received from the GNSS, traffic control equipment, and message data received via the RSU. In addition to providing traffic control data for the processing unit, the traffic control equipment receives outputs from the processing unit that affect the operations of the signal(s) that it is controlling.

Communications/Backhaul

A variety of communications media is used in the CVE. Communication between most devices is constrained by either communication standards or by the availability of infrastructure. The standardized means of communication between OBUs and between an OBU and an RSU is DSRC. DSRC is a designated bandwidth (5.850-5.925 GHz) reserved for vehicle safety applications. It is a two-way, short- to medium-range wireless communications characterized by low data transfer latency, high data transmission rates, and dependability in extreme weather conditions.[23] All equipment on the roadside are connected by a local connection such as Ethernet or other data transfer cables (with standardized external interfaces). Backhaul connections provide communication between the message handler/processor and management centers (such as the Operating System and TMC) and are typically found in the form of fiber-optic cable. Backhaul fiber optic cable either already exists or will be expanded to include areas where CV-compatible RSUs will be installed. Satellite communications are used for the transmission of time and location data from GNSS satellites. The SCMS is expected to provide certificates to the OBU over-the-air or may be pre-loaded onto onboard devices on a one-time basis. A summary of communications media between devices is provided in **Table 15: Communications Media between Devices in the Connected Vehicle Environment**.

[23] *USDOT – Intelligent Transportation Systems – DSRC the Future of Safer Driving Fact Sheet.* *https://www.its.dot.gov/factsheets/dsrc_factsheet.htm*

Table 15: Communications Media between Devices in the Connected Vehicle Environment

Device Pair		Communications Media
Host OBU	Remote OBU	DSRC
OBU	RSU	DSRC
RSU	SCMS	Backhaul
RSU	CORS	Backhaul
OBU	SCMS	Backhaul + DSRC/Wi-Fi
TSC | RSU	Message Handler/Processor	*Local Connection*
Message Handler/Processor	Operating System Traffic Management Center	Backhaul
OBU (Transit Vehicle and CEAV)	Transit Management Center	Backhaul
Traffic Management Center	Operating System	Backhaul
Transit Management Center	Operating System	Backhaul
Operating System	Mgmt. Center	Backhaul
RSU	GNSS	Satellite
OBU	GNSS	Satellite

Source: City of Columbus

DSRC Messages

Messages transmitted via DSRC are used to communicate data between vehicles, personal devices, and infrastructure. The DSRC Message Set Dictionary (SAE J2735) enumerates message types that must be used in CVEs, along with the data frames and data elements of which they are comprised.

Basic Safety Message (BSM)

The BSM conveys safety information about a given vehicle. Broadcast from a vehicle, the BSM data is organized into two parts. Part I data is comprised of required data elements including but not limited to vehicle size, position (latitude/longitude), speed, heading, acceleration, and brake system status. This data is used to support safety-critical applications that rely on frequent transmission of data. BSM Part II data is comprised of optional data elements that provide weather data (e.g. roadway surface condition, temperature, air pressure) and vehicle data (e.g. vehicle classification, wiper status, traction control status, exterior lights status). Some of the data items used to populate these messages can be obtained from the vehicle CAN bus. Data made available by the vehicle that is not standardized under SAE-J1979 will require CAN bus libraries to be obtained from vehicle manufacturers if it is to be utilized to populate data elements in the BSM.

Signal Phase and Timing (SPAT) Message

The SPAT message is used to communicate information regarding the signal state of a given intersection. It contains the signal indication for every phase of the intersection, phase timing information, crosswalk status, and a movement number, which allows the data to be paired to the physical layout of the intersection described in the MAP message, described below. This data can be used to support intersection-related safety applications. The data that is used to populate this message can be found in NTCIP 1202-compliant traffic signal controller outputs.

Map Data (MAP) Message

The MAP message contains the intersection geometry, the layout of all approaches/receiving lanes, crosswalks, vehicle pathways through an intersection, and provides recommended movement speeds. Phase numbers are defined for each approach lane – this phase number is used to pair SPAT data with the appropriate approach. MAP data is used to position a vehicle with respect to roadway geometries that are identified in the MAP message. The data for this message is manually acquired though surveys – some agencies may already have geometry data on-hand that must be converted into the MAP Message format.

Radio Technical Commission for Maritime (RTCM) Services Corrections Message

The RTCM Service Correction message contains data that is used to correct the position of vehicles that use GNSS to determine position. Various atmospheric conditions result in false interpretation of position based on GNSS data. Changes in these atmospheric conditions must be accounted for so a vehicle can be properly positioned within the roadway geometry (as defined by the MAP message). RTCM Services Corrections messages are broadcast from static roadside equipment. RTCM data is typically acquired from a local Continuously Operating Reference Station (CORS), which is available via the internet.

Signal Request Message (SRM)

The Signal Request Message (SRM) contains data that is used to request signal preemption or signal priority from a signalized intersection. This data includes the desired movement, the priority type (priority or preempt), and the priority level. Additionally, The SRM includes estimated time of arrival and duration of service data fields. These data items are essential to ensuring that all vehicles traveling in a platoon can be accommodated in the priority request and move through the intersection at once if the request can be granted. This message is sent from vehicles that require preemption or priority at an intersection and are received by RSUs. When SRMs are received from multiple vehicles, the TSC or other processing equipment must arbitrate the requests based on the priority level of the request.

Signal Status Message (SSM)

The Signal Status Message (SSM) contains data regarding the operations state of the intersection (e.g. normal, priority, preempt). This message is sent from an intersection to relay information to a vehicle regarding whether or not the signal priority request parameters were accepted by the intersection. Data contained in this message can be populated using the output from an NTCIP 1202-compliant traffic signal controller.

Traveler Information Message (TIM)

TIMs contain advisory information used by vehicle operators. TIMs are sent from the roadside to vehicles, which must subscribe to receive the TIM. The TIM protocol provides the location and situation (e.g. vehicle speed) parameters that must be met for the TIM to be delivered to the vehicle operator. For instance, a TIM that advises a vehicle operator of a speed limit in a designated area would only be displayed to the vehicle operator when approaching the area and if the vehicle operator is traveling above the speed limit within the area. Traffic Managers must develop the TIM message – the Traffic Manager may use a program that allows them to input TIM message parameters and generates the TIM message based on those parameters to be broadcast from the roadside.

Facilities

The TMC will receive messages that are captured by Operating System roadside equipment. These messages are processed to obtain near-real-time system operations and performance data, which includes, but is not limited to, roadway speed, queue/incident detection, travel time/intersection delay, and/or CV volume. The TMC makes this operations data available to Traffic Managers to improve their ability to manage traffic through adjusting traffic signal operations, and performing other system assessments that can be used to justify other long-term operations changes. Operations data is filtered to remove PII and archived on the Operating System.

The Transit Management Center will receive application output data (actual outputs are suppressed from the transit vehicle operator) and BSMs captured by transit vehicle OBUs and CEAV OBUs. The Transit Management Center processes this data to generate vehicle interaction data – which is a concise representation of an event that would have resulted in a notification or warning issued to a transit vehicle operator. This vehicle interaction data is received by the transit manager and is used to determine if outputs from a CV system could improve safety and to determine if the transit vehicle operator can handle such outputs without negatively impacting the transit vehicle operator’s awareness of the roadway environment. This vehicle interaction data is also filtered (PII removed) and archived on the Operating System.

The Operating System is an open-source information portal for the Smart Columbus program where CVE performance data will be archived. Data stored on the Operating System may include (but is not limited to) processed vehicle position data, vehicle speed data, vehicle acceleration data, signal phase and timing information, signal operations status (normal, priority, or preempt), as well as capture adjustments to system parameters as designated by TMC staff. It is expected that data stored on the Operating System will be free of personally identifiable information (PII). The Operating System will also process CVE data for use in traffic/transit/freight/public safety management uses and filtered to calculate performance metrics that are stored on the Operating System.

Physical Security

Both roadside equipment and vehicle onboard devices must be physically protected to reduce the chance of theft or unauthorized access. Roadside ITS equipment will be located inside the TSC cabinet. There are very few instances of access to or theft of equipment resulting from TSC cabinet breaches. Cabinets containing equipment connected to the CTSS will be wired with door alarms for monitoring purposes. As stated earlier, all signal controllers will be connected to the CTSS as part of the CVE. There are provisions in the CTSS plan to connect these alarms to the network to monitor cabinet alarms when they are triggered. As a further measure of physical protection, padlocks will be installed on these cabinets to supplement the standard cabinet locks. Roadside communications devices will be mounted on spanwire or a mast arms of intersections in the CVE. Because there have been few instances of theft or access to devices that are supported by intersection mast arms or spanwire, mounting the devices in this way is expected to be sufficient.

Vehicle onboard equipment will be located in the vehicle. Door locks on the vehicle will protect this equipment. Though door locks will not prevent a determined individual from gaining access to the vehicle and removing the device by other means, this has not been an issue for the existing system. The likelihood of the theft of items from a vehicle is much greater compared to physical security threats for intersection equipment, as a thief may perceive that the vehicle's onboard device is valuable and vehicle-related theft tends to occur in a low-visibility environment. To prevent the theft of vehicle onboard equipment, vehicle operators may need to be trained to conceal the devices when not using the vehicle. Vehicle operators for agencies/systems with physical security protocols (City of Columbus light-duty vehicle operators, fire, EMS, police; car-share vehicle operators; heavy-duty vehicle operators; and COTA operators) are expected to follow the physical security protocols established by those agencies/systems to secure equipment in their respective vehicles.

System/Data Security

System and data security is expected to include the SCMS, network security, and the protection of PII, which are described in the sections below.

Security and Credentials Management System

A SCMS is designed to provide trusted, secure V2V and V2I communications. It employs highly innovative methods and encryption and certificate management techniques to ensure communications security between entities that previously have not encountered each other—but also wish to remain anonymous (as is the case when vehicle operators encounter each other on the road)[24]. This allows devices that have never encountered each other to have confidence that the data received is trustworthy. Certificates will be transmitted to RSUs via backhaul and to OBUs over the air. A version of the SCMS, known as the SCMS Proof-of-Concept (POC) is currently operated and maintained by the USDOT. However, this system is expected to be decommissioned on September 30, 2018, prior to the deployment of the CVE, and thus, will not be used. Most recently, the use of a commercial certificate provider has been introduced for the CV Pilots and will be a necessary consideration. Final details regarding use of the SCMS in the CVE will be detailed in subsequent systems engineering documents.

Network Security

A network is vulnerable to malicious attacks if not properly protected. Access to the CTSS fiber network has the potential to compromise the operations of the CVE, and security measures need to be in place to reduce the likelihood of an attack that may disrupt the system. The most common methods by which individuals with malicious intent may be expected to access the CTSS include, but are not limited to:

- Through a terminal connected to the city local network
- Through the internet

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[24] *Security Credential Management System Proof–of–Concept Implementation – EE Requirements and Specifications Supporting SCMS Software Release 1.0.*

http://www.its.dot.gov/pilots/pdf/SCMS_POC_EE_Requirements20160111_1655.pdf

End Entity Requirements and Specifications Supporting SCMS Software Release https://wiki.campllc.org/display/SCP

USDOT – Connected Vehicles and Cybersecurity. https://www.its.dot.gov/cv_basics/cv_basics_cybersecurity.htm

- Breaking into an equipment cabinet and connecting directly to the network with a personal device
- Severing physical fiber-optic wire and creating a new connection to a personal device
- Accessing the network via wireless communications media (e.g. DSRC)

These vulnerabilities can be addressed through a combination of security measures which will include the use of encrypted over-the-air messages, firewalls to prevent unauthorized access through a local network or the internet; physical security in the form of locks, cabinet alarms, and fiber connectivity alarms; and proper implementation of wireless security protocols. More specific measures may include implementing strong passwords, encryption of data sent across the network, logging and monitoring network traffic, and disabling unused ports and removing unnecessary devices from the network. Proper use of these security measures will minimize the opportunity for individuals with malicious intent to gain access to components connected the CTSS fiber network.

The CVE intends to utilize standard industry practice as a foundation for securing the network. It will be important to establish a comprehensive system security plan for the City of Columbus network to reduce the likelihood of access to the network by those who are not authorized to access the network. Given that the City DoT manages the network in Columbus, it will be important to consult with DoT to develop network security requirements. Specifics regarding network security will be developed in subsequent systems engineering documents for this project.

Protecting PII

The protection of PII is crucial for capturing the trust of system users who wish to maintain their privacy. A single BSM offers potential PII; however, use of the SCMS should limit the potential for personal identity to be deduced. 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 his/her 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) will be 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 Operating System.

Privacy and Data Security

Data will be collected and stored in the Operating System for system operation purposes. It is against the policy of such agencies to retain information that could be used to identify individuals, though there are no regulations precluding the collection of such information for internal (system) use only. Further, privacy was a concern identified by our stakeholders during outreach. Data collected from the CVE is expected to be used for research that as a general matter, may result in publication. Institutional Review Board (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 Code of Federal Regulations (CFR) Title 49, Part 11.[25]

[25] *Code of Federal Regulations (CFR) Title 49 Part 11 – Protection of Human Subjects. Government Publishing Office. https://www.gpo.gov/fdsys/pkg/CFR-2003-title49-vol1/xml/CFR-2003-title49-vol1-part11.xml*

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.

Proposed Applications

Table 16: Proposed Applications of the Connected Vehicle Environment shows a table of proposed applications for the users of the CVE. Applications are grouped into four categories: V2V Safety, V2I Mobility, and V2I Safety, and Other. Within each category, applications are listed in alphabetical order. This order is preserved throughout the remainder of this document.

Note that the list of applications in **Table 16: Proposed Applications of the Connected Vehicle Environment** includes additional applications compared with the applications included in **Table 12: Connected Vehicle Environment Performance Measure Overview**. Though it is the intent of the CVE to deploy all the applications listed in **Table 16: Proposed Applications of the Connected Vehicle Environment**, the performance of many V2V Safety applications will not be assessed due to the sensitive nature of saving alert and warning information from V2V Safety applications.

1558 **Table 16: Proposed Applications of the Connected Vehicle Environment**

Class	Application	Vehicle Type and User Class						
		Light-Duty Vehicle	Emer. Vehicle	Heavy Duty Vehicle	Transit Vehicle	-	-	-
		Light Duty Vehicle Operator	Emergency Vehicle Operator	Heavy-Duty Vehicle Operator	Transit Vehicle Operator	Traffic Manager	Transit Manager	Network Manager
V2V Safety	Emergency Electronic Brake Light Warning	H/R①	R	R	R	-	-	-
	Forward Collision Warning	H/R①	R	R	R	-	-	-
	Intersection Movement Assist	H/R①	R	R	R	-	-	-
	Lane Change Warning / Blind Spot Warning	H/R①	R	R	R	-	-	-
V2I Mobility	Transit Signal Priority*	-	-	-	①	-	①	②
	Intent to Platoon Priority*	-	-	①	-	-	-	②
	Freight Signal Priority*	-	-	①	-	-	-	②
	Emergency Vehicle Preemption*	-	①	-	-	-	-	②
	Vehicle Data for Traffic Operations	R	R	R	R	①	-	②
	Transit Vehicle Interaction Event Recording	R	R	R	R	-	①	②
V2I Safety	Red Light Violation Warning	H ①	-	-	-	-	-	-
	Reduced Speed School Zone	H ①	-	-	-	-	-	-

H	**Host (see description below)**
R	Remote (see description below)
①	This symbol indicates user classes that will primarily benefit from these applications.
②	The network manager provides system support for these applications (diagnosing issues and restoring connectivity between devices that communicate via the CTSS backhaul)
*	The Priority/Preempt applications all fall under the MMITSS bundle and are described as such below. These require back and forth communications between vehicles and equipment on the roadside. Therefore, host and remote vehicles are not designated.
-	Null Value

1559 *Source: City of Columbus*

In the case of V2V applications, which involve more than one user (i.e. multiple vehicles), it is important to differentiate between host and remote vehicles in each application. The host vehicle refers to the vehicle that issues the alert or warning in a safety-critical situation. That is, data in the form of a BSM, or a targeted alert or warning message is received and processed by the host and is used to determine if an alert or warning should be output to the host vehicle operator. The remote vehicle broadcasts the data that is received by the host vehicle. For instance, in an emergency braking situation, the leading vehicle is the remote vehicle and makes its emergency braking status known to other vehicles. A following vehicle, a host vehicle, would receive the status from the remote vehicle to display a warning to the host vehicle operator. In certain applications, alerts may be reciprocated in both vehicles – both operators may be almost simultaneously alerted, as the safety of both operators is affected by the actions of both operators. However, it is important to note that scenarios (**Chapter 6, Operational Scenarios**) are told from the point of view of a single host vehicle, and alert reciprocity is implied when necessary.

Outputs provided to vehicle operators are categorized into alerts and warnings. Alerts are intended to inform vehicle operators of an event that is not safety-critical in nature. The vehicle operator does not need to take immediate action in response to an alert to avoid a potential crash. Warnings are higher priority and are intended to inform vehicle operators of an event that may lead to a crash if the vehicle operator does not take immediate action.

V2V and V2I Safety applications will reduce injuries and crashes, and V2I Mobility applications will provide a technological innovation that improves mobility for transit, freight, and emergency vehicles. This should improve transit service, movement of goods, and emergency response times in the region, respectively. As stated in **Chapter 1, Introduction**, only deployment-ready applications have been selected to be implemented for the CVE. **Appendix F, Proposed Application Technology Readiness Level Assessment** provides an assessment of the deployment-readiness of each application.

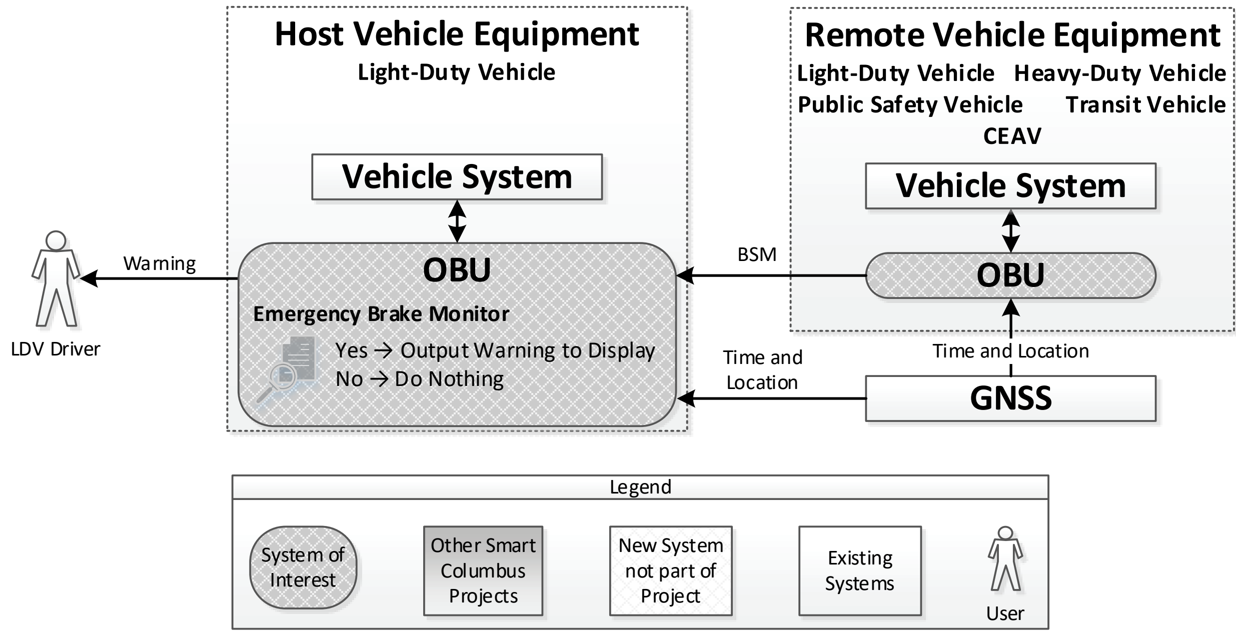
The following sections provide a brief description of each application proposed for the Smart Columbus CVE. When possible, applications that were previously researched were selected. Descriptions for these applications were obtained from the CVRIA[26] and are adapted when necessary to meet the specific needs of stakeholders for this project. Detailed scenarios, which list courses of events that take place for each application, are provided in **Chapter 6, Operational Scenarios**.

Emergency Electronic Brake Light Warning (V2V Safety)

The Emergency Electronic Brake Light (EEBL) application enables a vehicle to broadcast a self-generated emergency brake event to surrounding vehicles. Any receiving vehicle determines the relevance of the event and, if appropriate, provides a warning to the vehicle operator to avoid a crash. This application is particularly useful when any receiving vehicle operators' line of sight is obstructed by other vehicles or bad weather conditions such as fog or heavy rain. This application provides an output to drivers to improve awareness of emergency braking events in an attempt to address rear-end crashes between multiple vehicles at intersection and non-intersection locations, as described in **Chapter 4, Introduction**. This application description has been adapted from the VSC-A ConOps and the CVRIA – Emergency Electronic Brake Light Warning application description.[27] **Figure 8: Emergency Electronic Brake Light Warning Diagram** provides a context diagram for this application.

[26] *Iteris – Connected Vehicle Reference Implementation Architecture.* http://local.iteris.com/cvria/

[27] *CVRIA – Emergency Electronic Brake Light.* http://local.iteris.com/cvria/html/applications/app23.html#tab-3



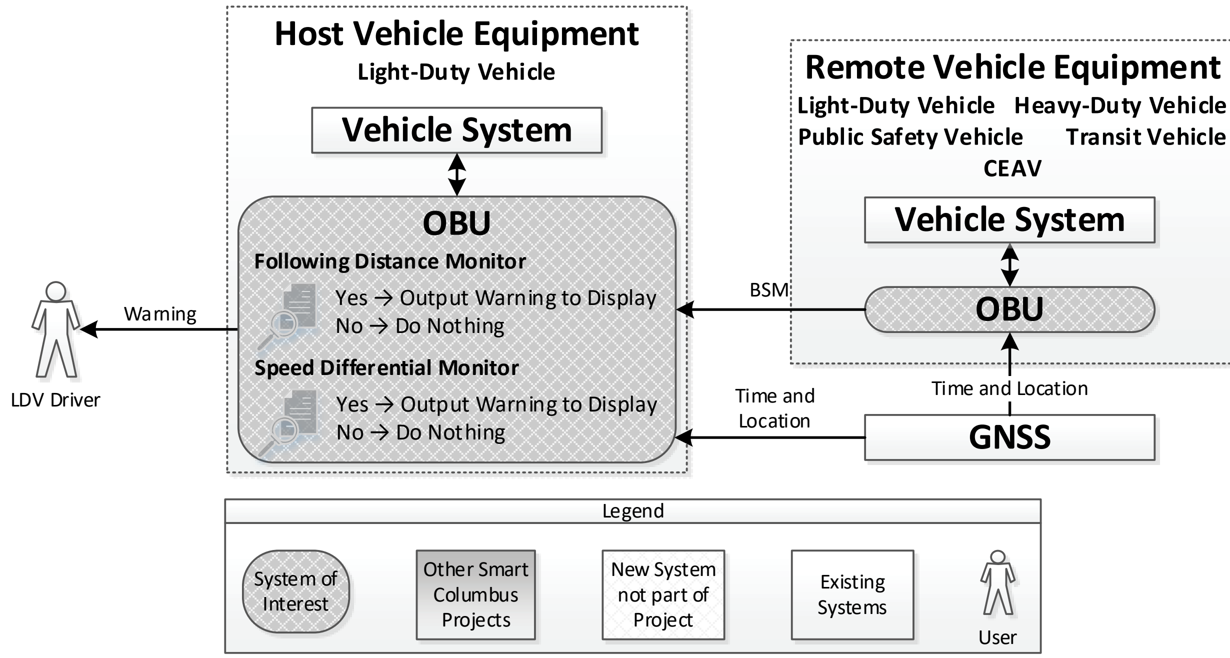
Source: City of Columbus

Figure 8: Emergency Electronic Brake Light Warning Diagram

Forward Collision Warning (V2V Safety)

The Forward Collision Warning (FCW) application warns the vehicle operator of an impending rear-end collision with another vehicle ahead in traffic in the same lane and direction of travel. The application uses data received from other vehicles to determine if a forward collision is imminent. FCW advises vehicle operators to take specific action in order to avoid or mitigate rear-end vehicle collisions in the forward path of travel in an attempt to address rear-end crashes among multiple vehicles at intersections and non-intersection locations, as described in **Chapter 4, Justification and Nature of Changes**. This application description has been adapted from the VSC-A ConOps and the CVRIA – Forward Collision Warning application description.[28] A context diagram for this application is provided in **Figure 9: Forward Collision Warning Diagram**.

[28] *CVRIA – Forward Collision Warning. http://local.iteris.com/cvria/html/applications/app31.html#tab-3*



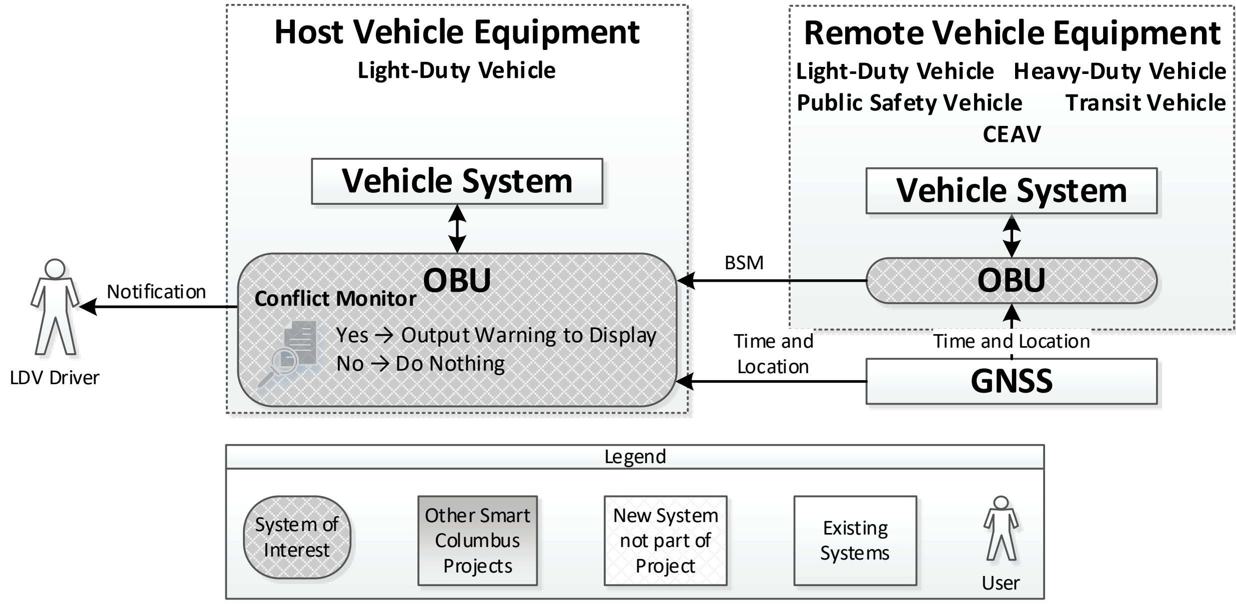
Source: City of Columbus

Figure 9: Forward Collision Warning Diagram

Intersection Movement Assist (V2V Safety)

The Intersection Movement Assist (IMA) application warns the vehicle operator when it is not safe to enter an intersection due to a high probability of collision with other vehicles at stop sign-controlled and uncontrolled intersections. This application can provide collision warning information to the driver, which may perform actions to reduce the likelihood of crashes at the intersections. This application provides an output to drivers to improve awareness of approaching vehicles on conflicting approaches in an attempt to address crashes between multiple vehicles at intersections, as described in **Chapter 4, Justification and Nature of Changes**. This application may also assist in addressing Angle Crashes between vehicles at non-intersection locations where vehicles are turning across traffic at driveway locations. This application description has been adapted from the VSC-A ConOps and the CVRIA – Intersection Movement Assist application description.[29] A context diagram for this application is provided in **Figure 10: Intersection Movement Assist Diagram**.

[29] *CVRIA – Intersection Movement Assist. http://local.iteris.com/cvria/html/applications/app36.html#tab-3*



Source: City of Columbus

Figure 10: Intersection Movement Assist Diagram

Lane Change Warning/Blind Spot Warning (V2V Safety)

The Blind Spot Warning and Lane Change Warning (BSW+LCW) application warns the vehicle operator during a lane change attempt if the blind-spot zone into which the vehicle intends to switch is, or will soon be, occupied by another vehicle traveling in the same direction. Moreover, the application provides advisory information that informs the vehicle operator that another vehicle in an adjacent lane is positioned in a blind-spot zone of the vehicle even if a lane change is not being attempted. This output raises driver awareness in an attempt to address issues associated with sideswipe crashes among multiple vehicles at non-intersection locations, as described in **Chapter 4, Justification and Nature of Changes**. This application description has been adapted from the VSC-A ConOps and the CVRIA Lane Change Warning/Blink Spot Warning application description.[30] A context diagram for this application is provided in **Figure 11: Lane Change Warning/Blind Spot Warning Diagram**.

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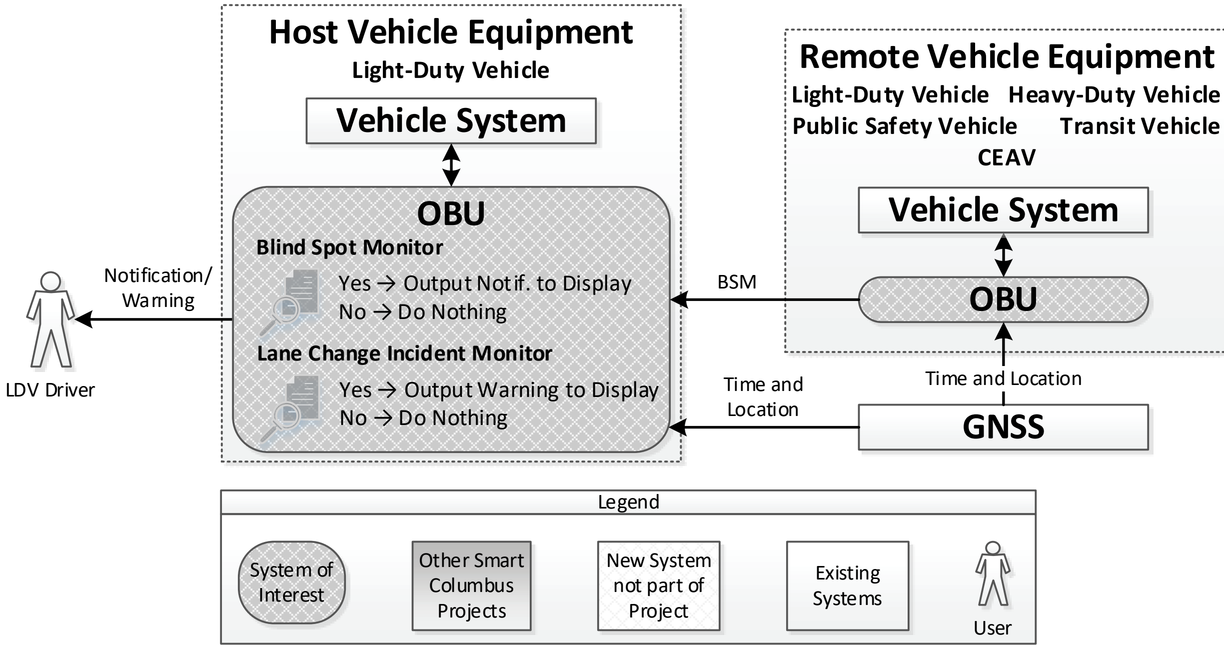
[30] *CVRIA – Blind Spot Warning+ Lane Change Warning. http://local.iteris.com/cvria/html/applications/app7.html#tab-3*



Source: City of Columbus

Figure 11: Lane Change Warning/Blind Spot Warning Diagram

Traffic Signal Priority/Preemption (V2I Mobility)

The Traffic Signal Priority/Preemption application (aka MMITSS) provides improved mobility for emergency vehicle operators, heavy-duty vehicle operators, and transit vehicle operators. Priority/preemption is able to operate in collaboration with or independently of surrounding intersections. Also, vehicles approaching from either the ‘main street’ and/or the ‘side street’ have the ability to communicate with roadside equipment at intersections to acquire priority/preemption status, though the application can be configured to limit which approaches can receive priority/preemption based on traffic management policy.

Signal preemption is provided for emergency vehicle operators. EVP provides a high level of priority for emergency first responders, and it interrupts the current intersection state to provide service to a specified phase. Clearing queues and holding conflicting phases can facilitate emergency vehicle movement. For congested conditions, it may take additional time to clear a standing queue, so the ability to provide information in a timely fashion is important. In addition, transitioning back to normal traffic signal operations after providing preemption is an important consideration.

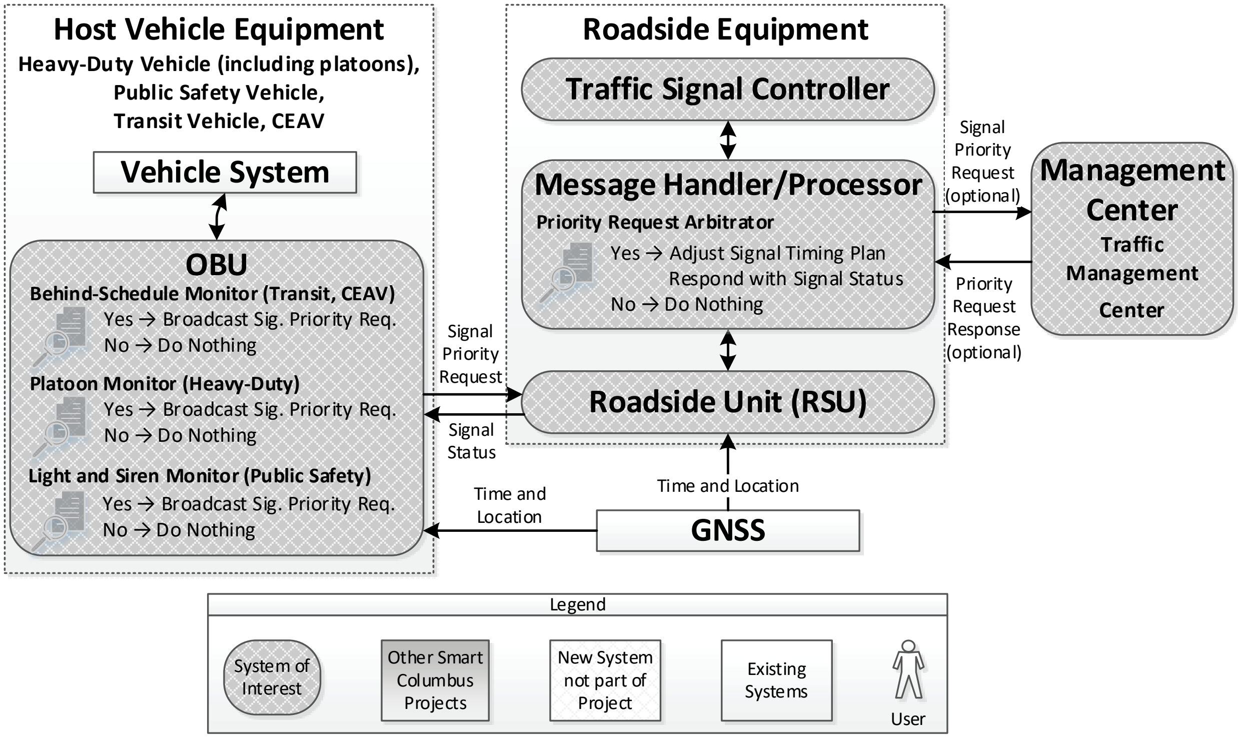
Signal priority is provided for heavy-duty vehicle (HDV) operators and transit vehicle operators, and it is considered a lower level of priority compared with the needs of emergency vehicle operators. Signal priority is characterized by providing either an early green or an extended green for a specified phase. The application also ensures the signal timing allows two HDVs that intend to form a platoon to travel through the intersection before changing to the next phase. This application accounts for the passage of contiguous HDVs through the intersection, as the passage of multiple HDVs requires more time to proceed through and clear the intersection. Enabling this feature requires an interface with in-vehicle truck platooning systems deployed as part of the DATP project.

Requesting priority could be accomplished through an automated process or initiated manually – this ultimately will be decided in the design phase of the project. Upon determining that it is approaching an intersection, the vehicle sends a Signal Priority Request message to the roadside, where it is received, and the message handler/processor (on the roadside) determines of the request should be accepted. Alternatively, the priority request could be forwarded to the TMC, which would provide a response indicating whether or not the request should be accepted. If the request is accepted, the message handler provides the priority input to the traffic signal controller via a local (Ethernet) connection. A Signal Status Message is sent from the roadside back to the vehicle to indicate whether the priority request was granted. This allows the application to provide feedback, if deemed necessary, to the emergency vehicle, freight, or transit vehicle operator indicating whether the signal priority has been granted. This application can contribute to improved operating performance of the emergency vehicle, heavy-duty vehicle, and transit vehicles by reducing the time spent stopped at a red light. This application intends to address emergency vehicle delay, transit delay, and freight/platoon delay, as described in **Chapter 4, Justification and Nature of Changes**. This application description has been adapted from CVRIA – Emergency Vehicle Preemption[31], Freight Signal Priority[32], and Transit Signal Priority[33]. A context diagram for this application is provided in **Figure 12: Traffic Signal Priority/Preemption Diagram**.

[31] *CVRIA – Emergency Vehicle Preemption. http://local.iteris.com/cvria/html/applications/app24.html#tab-3*

[32] *CVRIA – Freight Signal Priority. http://local.iteris.com/cvria/html/applications/app33.html#tab-3*

[33] *CVRIA – Transit Signal Priority. http://local.iteris.com/cvria/html/applications/app79.html#tab-3*



Source: City of Columbus

Figure 12: Traffic Signal Priority/Preemption Diagram

Vehicle Data for Traffic Operations (V2I Mobility)

The Vehicle Data for Traffic Operations (VDTO) application captures telemetry (location, speed, and trajectory) data obtained from vehicles and traffic signal data (such as signal state and signal priority requests) and Operating System makes this data available to the TMC to support traffic operations, including incident detection and the implementation of localized operational strategies. The TMC is responsible for processing and filtering data so that it can be made available to the Operating System. This processing and filtering transforms raw messages that are received by the TMC into useful operational information so that it can be used for traffic management purposes and removes PII so that operational data may be archived on the Operating System The frequency with which data is transmitted from the TMC to the Operating System depends on the data requirements of the Operating System. The processing and filtering function of the TMC is expected to produce fundamental measures of operations such as, but not limited to roadway speed, queue/incident detection, travel time/intersection delay, and/or CV volume.

Traffic management staff can use this operational data as the basis for implementing TMC-based traffic control strategies, which are outside the scope of this application. Operational data such as queue/incident detection enables transportation agencies to determine the location of potential crashes, so the agencies can respond more quickly and mitigate any negative impacts to the transportation network. Vehicle data that can be used to detect potential crashes include changes in vehicle speeds, when a vehicle's safety systems have been activated or deployed, or sudden vehicle turns or deceleration at a specific location (indicating a potential obstacle in the roadway). Operational strategies might include altering signal timing based on traffic flows or using vehicle data collected on the freeway mainline to employ speed harmonization or to optimize ramp-metering rates. This application will add capabilities to the existing traffic management system through addressing data needs for Traffic Managers, as described in **Data for Traffic and Transit Management** . This application description has been adapted from CVRIA – Vehicle Data for Traffic Operations. A context diagram for this application is provided on the following page in **Figure 13: Vehicle Data for Traffic Operations Diagram.**[34]

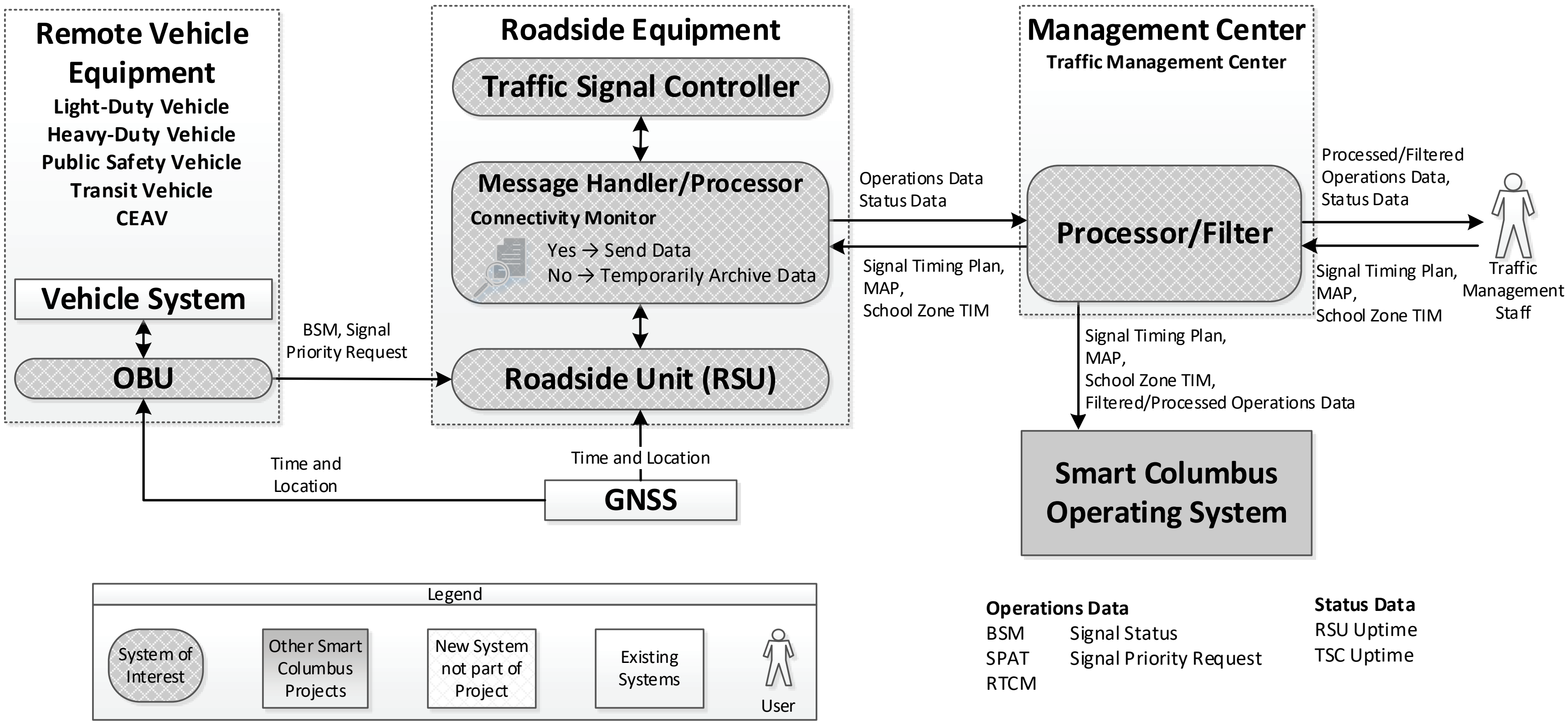
Transit Vehicle Interaction Event Recording (V2I Mobility)

The Transit Vehicle Interaction Event Recording application enables COTA Management Staff to capture output (not issued to the Transit Vehicle Operator) from applications so that it can assess the potential interactions and benefits that transit vehicle operators may receive should COTA decide to implement an UI on its transit vehicles. The application on the Transit Vehicle passively captures its own telematics data, BSMs from other vehicles and SPaT, MAP, and TIM messages from the roadside equipment in communications range.

The Transit Vehicle OBU will log these messages for a period of time before and after a warning or alert is issued from CV applications. The period of time over which this data is recorded is expected to be configurable for each alert or warning. These periods will consist of a few seconds (e.g., 10-20) prior to and a few seconds (e.g., 30-40) following the activation of the alert or warning.

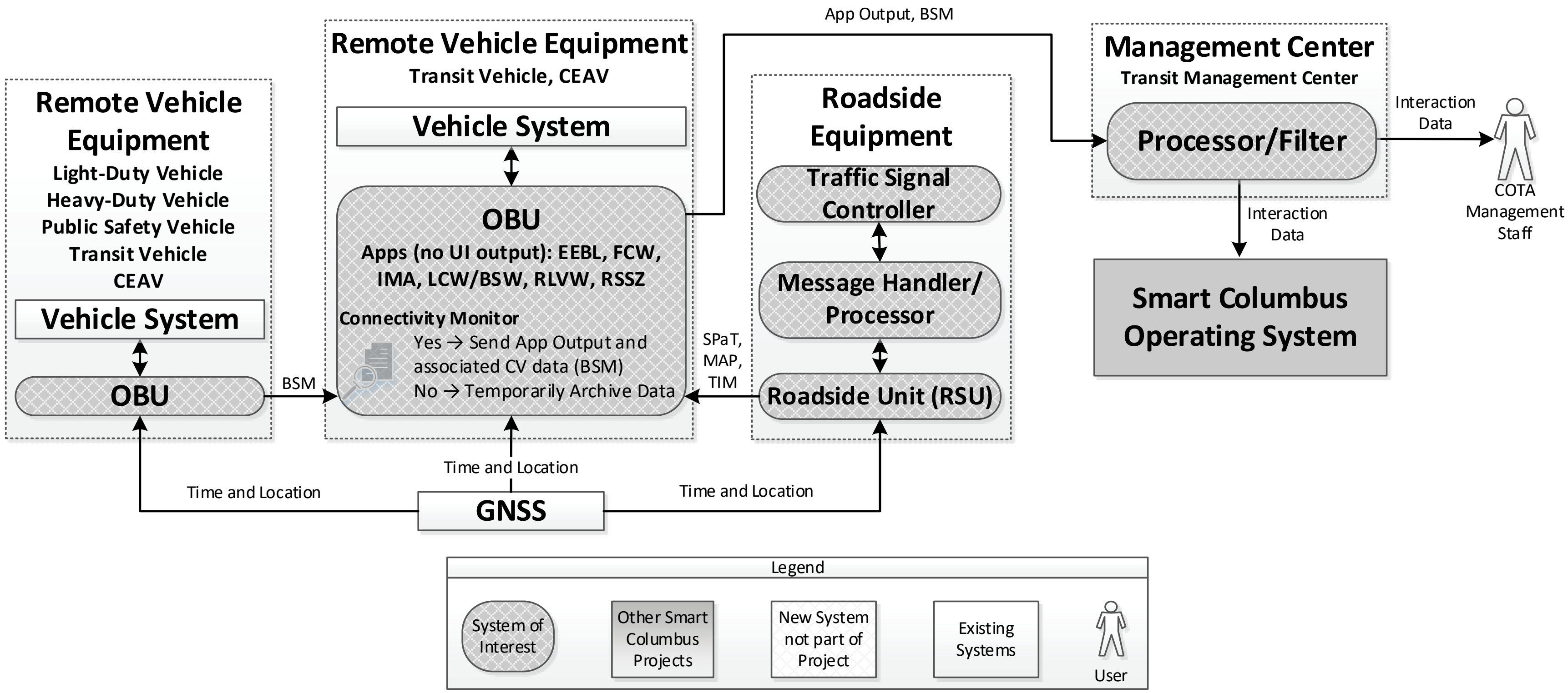
This information is provided to the Operating System Transit Management Center via a backhaul connection between the transit vehicle and the Transit Management Center. The Transit Management Center transforms raw messages that were received by the transit vehicle into vehicle interaction data: a concise representation of an event that would have resulted in a notification or warning issued to a transit vehicle operator. The Transit Management Center makes this data available to the transit management staff so that they may assess the impact of providing notifications and warnings to transit vehicle operators. A filtered version (to remove PII) of this vehicle interaction data would be made available to the Operating System. This application addresses the need for COTA to assess how other drivers are behaving around transit vehicles and to assess the potential impact of notifications/warnings on transit vehicle operators, as described in **Chapter 4, Justification and Nature of Changes**. A context diagram for this application is provided on the following page in **Figure 14: Transit Vehicle Interaction Event Capture Diagram**.

[34] *CVRIA – Vehicle Data for Traffic Operations.* *http://local.iteris.com/cvria/html/applications/app87.html#tab-3*



Source: City of Columbus

Figure 13: Vehicle Data for Traffic Operations Diagram



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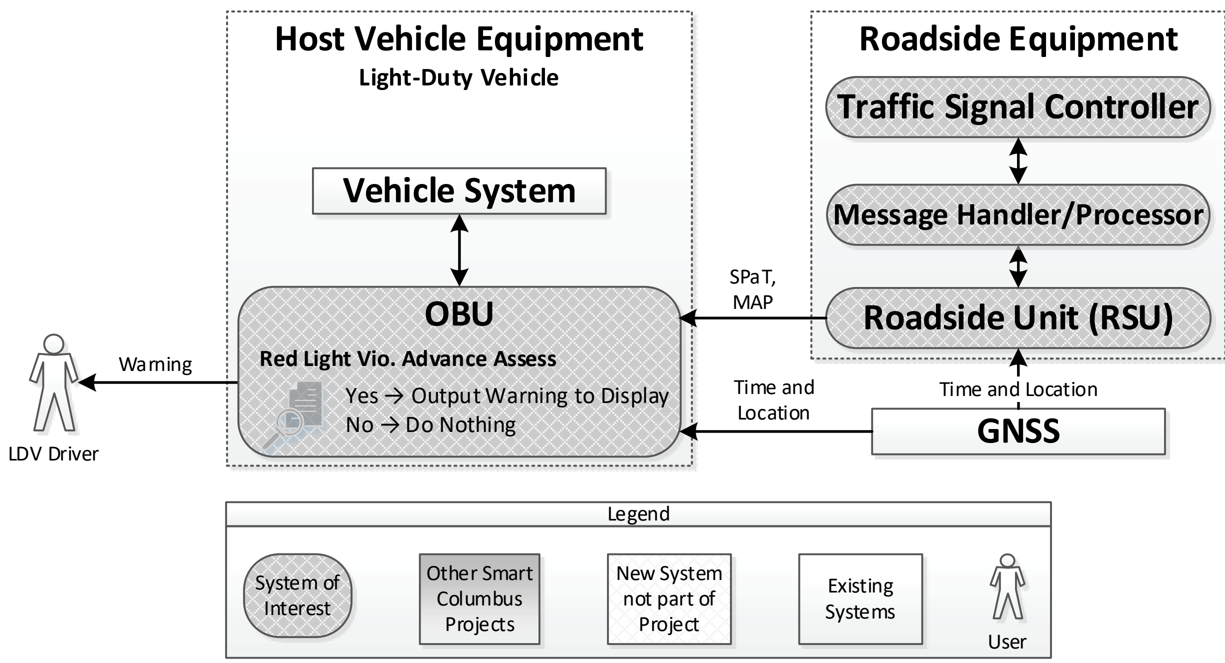
1746 *Source: City of Columbus*

1747 **Figure 14: Transit Vehicle Interaction Event Capture Diagram**

Red Light Violation Warning (V2I Safety)

The Red Light Violation Warning (RLVW) application enables a connected vehicle approaching a signalized intersection to receive information about the signal timing and geometry of the intersection. The application in the vehicle uses its speed and acceleration profile, along with the signal timing and geometry information, to determine if it appears that the vehicle will enter the intersection in violation of a traffic signal. If the violation seems likely to occur, a warning can be provided to the vehicle operator. This application provides an output to drivers to improve awareness when approaching a signal that will turn red before arriving at the intersection in an attempt to address crashes between multiple vehicles at intersections, as described in **Chapter 4, Justification and Nature of Changes**. This application description has been adapted from the V2I Safety Applications ConOps and the CVRIA – Red Light Violation Warning application description.[35] A context diagram for this application is provided below in **Figure 15: Red Light Violation Warning Diagram**.



Source: City of Columbus

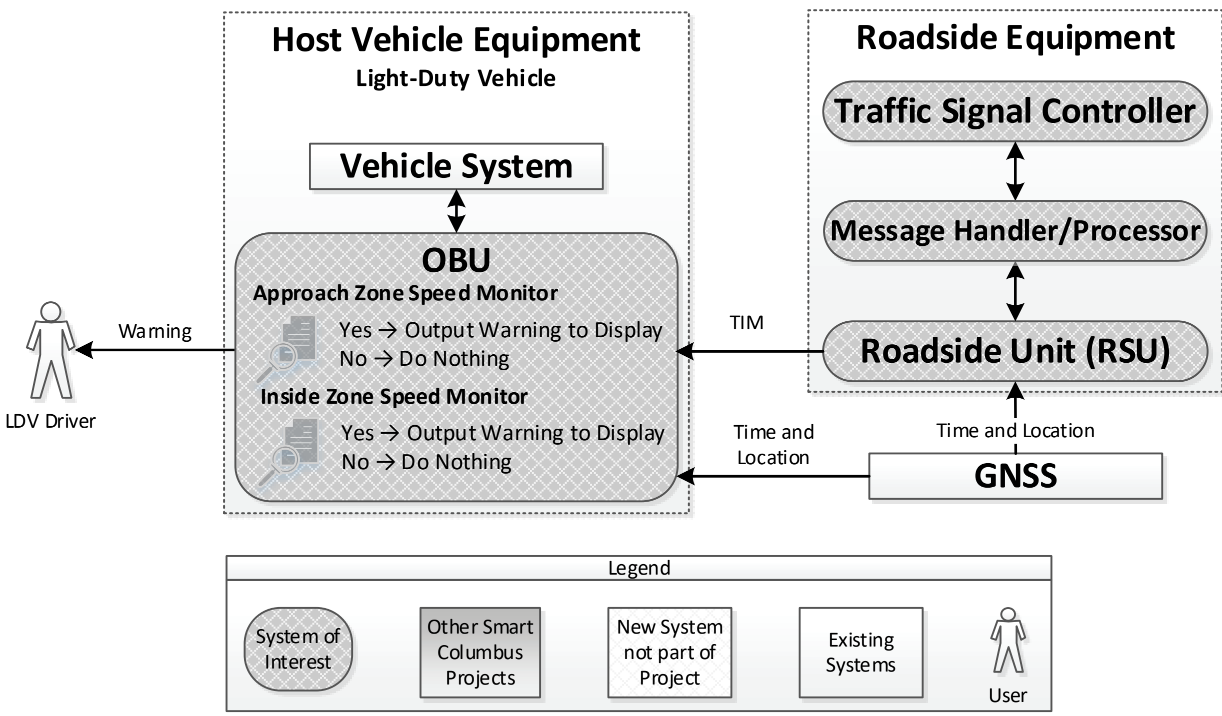
Figure 15: Red Light Violation Warning Diagram

Reduced Speed School Zone (V2I Safety)

The Reduced Speed School Zone application provides connected vehicles with information on a school zone's posted speed limit (generally 20 mph). The RSSZ application inside the CV uses the school zone location and speed limit, vehicle location, and the speed of the vehicle to determine whether to alert or warn the vehicle operator. The application will provide an alert to vehicle operators in advance when

[35] *CVRIA – Red Light Violation Warning.* *http://local.iteris.com/cvria/html/applications/app57.html#tab-3*

braking is required to reduce to the posted speed limit. This output increases driver awareness to active school zones and the school zone speed limit in an attempt to reduce speed when in school zones, as described in **Chapter 4, Justification and Nature of Changes**. This application description has been adapted from the V2I Safety Applications ConOps and the CVRIA – Reduced Speed Zone Warning/Lane Closure application description.[36] A context diagram for this application is provided below in **Figure 16: Reduced Speed School Zone Diagram**.



Source: City of Columbus

Figure 16: Reduced Speed School Zone Diagram

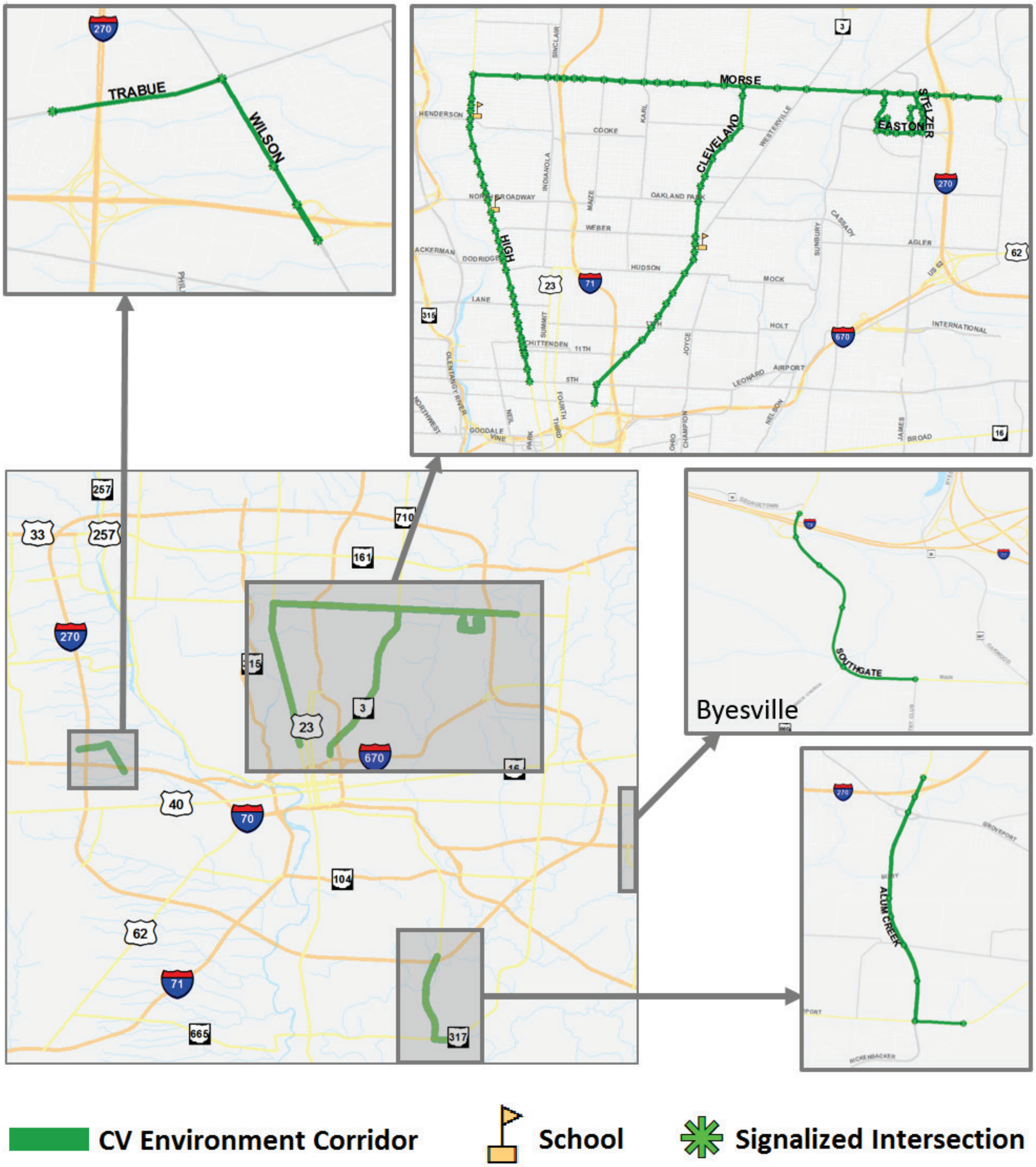
Proposed Roadside Equipment Locations

The Smart City Challenge Technical Application targets 113 locations for equipping CV technology on the roadside. CV-compatible roadside ITS and communications equipment will be located at signalized intersections along the corridors specified in **Chapter 3**, **Current System** and shown in **Figure 17: Roadside Infrastructure Proposed Installation Locations**.**Error! Reference source not found.** Wireless communications are expected to cover two school zones along the High Street corridor (Our Lady of Peace School and Clinton Elementary School) and one school zone along the Cleveland Avenue corridor (Linden STEM Academy). Appendix **G**Justification and Nature of Changesgives a detailed

[36] *CVRIA – Reduced Speed Zone Warning / Lane Closure. http://local.iteris.com/cvria/html/applications/app60.html#tab-3*

list of roadside infrastructure installation locations. a detailed list of roadside infrastructure installation locations.

Note that the exact location where the RSU will be installed at each specified location has not yet been identified. The placement of the RSU in the intersection may affect DSRC coverage. Limitations for communication between a given OBU and RSU result from distance between the two devices and attenuation due the presence of physical objects located between the two devices. Ideally the RSU can be positioned such that attenuation can be minimized and close to the center of the intersection. This would allow an OBU to communicate with an RSU when approaching along the main corridor, as well as from cross-streets.



Source: City of Columbus

Figure 17: Roadside Infrastructure Proposed Installation Locations

Proposed Vehicle Onboard Equipment Installations

The City is targeting a minimum of 1,500 and ideally 1,800 vehicles for equipping CV technology. Both public and private vehicle fleets will be used to reach this target. Vehicle fleet types may include (but are not limited to) transit vehicle fleets, city vehicle fleets, emergency vehicle fleets, and heavy-duty (platoon) vehicle fleets. The City of Columbus has confirmed that it will install in-vehicle devices in some of its vehicle fleets that operate in the deployment area. COTA has committed to include CV equipment on its entire fleet, ensuring that any bus, paratransit, or supervisor vehicle that operates in the area will be interacting with the CVE. These commitments are expected to result in about 825 OBU installations and another approximately 1,000 vehicles will need to be equipped with OBUs to reach the 1,800 OBU target. The remainder of equipped vehicles are anticipated to be comprised primarily of private vehicle owners. Outreach will be conducted to recruit these participants. **Table 17. Proposed Onboard Unit Installation Quantities** lists the various vehicle class, type, and quantity. Power management, antenna location, equipment security and integration with vehicle systems will all be consideration of the OBU installation planning.

Table 17. Proposed Onboard Unit Installation Quantities

Vehicle Type		Quantity
Light-Duty Vehicle	Private Vehicle	1,019
	City Fleet Vehicle	200
	COTA Supervisor Vehicle	25
Emergency Vehicle	Fire Truck/EMS	30
	Police Cruiser	80
Heavy-Duty Vehicle	Platoon Truck	10
Transit Vehicle	CEAV	6
	COTA Transit Bus* (fixed-route)	350
	COTA Paratransit Bus	80
	Total	**1,800**

**Quantity may vary slightly depending on operational needs. Source: City of Columbus*

Modes of Operation

The CVE is intended to complement regulations governing the operation of motor vehicles (see **Chapter 3: Current System)** and make minor modifications to operations of the existing system. That is, vehicle operators will continue to follow the rules of the road and respond to traffic control devices as they currently do (as described in **Chapter 3, Current System** under **Operational Policies and Constraints**), but will be provided with additional notifications that improve safety and mobility under certain circumstances. The CVE will modify existing signal operations through applications that contain the following functions: signal priority, signal preemption, and collecting probe data to implement more efficient signal timing plans.

The system is not intended to add to or override regulations governing the operation of motor vehicles. Vehicle operators are expected to exercise normal judgement in all situations, whether or not a notification is issued, and will not be permitted to rely on system notifications (or lack of notifications) as a means of safe and proper vehicle operation. The system is intended to function during all hours of the day. Should a vehicle's CV equipment fail, the vehicle operator will be notified through the in-vehicle system and be expected to continue to exercise normal judgement while operating the vehicle. If CV equipment fails at an intersection, the vehicle operator will not be notified, but will adhere to regulations governing the operation of motor vehicles. The modes of operation for the new CVE system are shown in **Table 18: Connected Vehicle Environment Modes of Operation**.

Table 18: Connected Vehicle Environment Modes of Operation

Mode	Definition
Mode 1: Normal Operating Conditions	Indicates the system is functioning as intended, generating outputs when necessary, and not generating outputs when unnecessary. CVE users will be expected to adhere to existing regulations associated with traffic control devices (e.g. traffic signals, signage, and lane markings) with the added benefit of alerts and warnings that complement these regulations.
Mode 2: Degraded Conditions	Represents a situation where primary functionality is lost due to nonfunctioning equipment, but an alternative (though less precise) means of accomplishing the function exists. CVE users will be expected to adhere to existing regulations associated with traffic control devices (e.g. traffic signals, signage, and lane markings) when the system is experiencing degraded conditions.
Mode 3: Failure Conditions	Represents a situation where the application will not provide the necessary outputs under a circumstance where an output would have been provided under normal operating conditions. CVE users will be expected to adhere to existing regulations associated with traffic control devices (e.g. traffic signals, signage, and lane markings) when the system is experiencing failure conditions.

Source: City of Columbus

Scenarios described in **Chapter 6**, **Operational Scenarios** will consider these various modes of operation. The system is expected to typically exhibit normal operating conditions. However, it is important to understand issues that may lead to degraded or failure conditions. Degraded or failure conditions could be the result of the degradation of various parts of the system, and they are described in **Table 19: Events that Result in Degraded or Failure Conditions**.

Table 19: Events that Result in Degraded or Failure Conditions

Event	Examples
Diminished Communications	**Loss of connectivity between roadside infrastructure devices** – Applications that focus on optimizing system (arterial) operations may rely on sharing data between various roadside infrastructure devices and the TMC. Loss of connectivity between roadside devices may limit the system to local optimization only. **DSRC attenuation** – Attenuation resulting from foliage, buildings, and vehicles reduces the range over which a device is able to broadcast DSRC messages. This has the potential to result in receiving critical information too late for a vehicle operator to take appropriate action in reaction to a situation. The magnitude of this impact depends on the effective distance at which a message can be broadcast from one device and received by another. **DSRC channel congestion** – Broadcasting high volumes of messages from many devices has the potential to congest DSRC bandwidths. When multiple messages interfere with each other, not every message broadcast is received. Critical information may be received too late for a vehicle operator to take appropriate action. The magnitude of this impact depends on the number of consecutive messages not received. **Unpowered device** – An unpowered device is unable to send/receive messages, process data, or provide alerts/warnings to vehicle operators. This impacts the ability of the system to influence the current conditions.
Deficient Onboard Equipment Data Quality	**Inaccurate GNSS data** – GNSS data is used to provide position, speed, and heading for vehicles. Inaccurate GNSS data has the largest implications for applications that depend on this information to determine when vehicles are in safety-critical situations. This could result in false positive and false negative notification outputs, which reduces the system's effectiveness and credibility. **Unsynchronized devices (time)** – Timestamps associated with messages are used to associate the position, speed, and heading of vehicles with other vehicles and the status of the infrastructure. Vehicle safety information and infrastructure status change constantly. When not synchronized, data originating from two devices may not be paired properly, resulting in false positive and false negative notification outputs, which reduces the system's effectiveness and credibility. **Inability to process data in a timely manner** – If the amount of data that needs to be processed by a given piece of CV equipment is greater than its processing capability, alerts/warnings may not be provided in time for the vehicle operator to appropriately react.

Source: City of Columbus

User Classes and Other Involved Personnel

User classes for the proposed system are the same as user classes for the current system. User classes impacted by the CVE are identified in **Table 20: Stakeholders and User Classes**. Each user class is made up of one or more stakeholder groups that exhibit common responsibilities, skill levels, work activities, and modes of interaction with the system.

Table 20: Stakeholders and User Classes

Target Stakeholders	User Classes						
	Light-Duty Vehicle Operator	Emergency Vehicle Operator	Heavy-Duty Vehicle Operator	Traffic Manager	Transit Vehicle Operator	Transit Manager	Network Manager
Linden Private Vehicle Owners*	X	-	-	-	-	-	-
City of Columbus Light-Duty Vehicle Operators, Car Share Vehicle Operators**	X	-	-	-	-	-	-
Logistics Company #1, Logistics Company #2	-	-	X	-	-	-	-
COTA (Fixed-Route and CEAV)	-	-	-	-	X	X	-
COTA (Supervisor Vehicle)	X	-	-	-	-	-	-
City of Columbus Fire, Emergency Medical Services (EMS)	-	X	-	-	-	-	-
City of Columbus Police	-	X	-	-	-	-	-
City of Columbus Dept. of Public Service Traffic Managers	-	-	-	X	-	-	-
City of Columbus Department of Technology	-	-	-	-	-	-	X

**Note: Linden residents are the target audience for privately-owned vehicles. Outreach can be done for other residents in the vicinity of CV corridors if additional participation is needed to satisfy in-vehicle installation objectives.*

*** Note: Car2Go, the only car-share entity operating in Columbus ended its service in the area on May 31, 2018. Should other carshare providers provide service in the area, they could be considered a potential stakeholder for the light-duty vehicle operator user class.*

Source: City of Columbus

Support Environment

The CVE is expected to be supported by an expansion of responsibilities of the Columbus Department of Public Service and by owners of vehicles containing OBUs.

Columbus Department of Public Service (DPS) – DPS is responsible for coordinating with TSC vendors to upgrade existing TSCs or provide new TSCs that are capable of outputting information for use in the CVE. Replacing TSCs or upgrading TSC firmware is a common practice for signal manufacturer representatives. DPS is also responsible for coordinating with signal system or ITS contractors regarding the installation of all other roadside infrastructure. The threading of cable and mounting of hardware on spanwire and mast arms is common practice for signal and ITS contractors. However, the networking of all roadside components is a task where few contractors have experience. An additional party may be needed to perform the networking tasks associated with the CVE.

Installing a large number of in-vehicle systems is a substantial responsibility of DPS. A well thought out plan will be required to complete the installation process in a reasonable amount of time. To handle such a large volume of installations, the City of Columbus anticipates procuring a contractor to install, inspect, and test in-vehicle equipment that is deployed as part of the CVE. The hired designated installation technician(s) would be responsible for installing the necessary equipment. The technician(s) would perform the installation at an installation location (pre-qualified by the City of Columbus) on a first-come, first-served basis or by appointment. It is expected that independently contracted vehicle technicians could be trained to install in-vehicle equipment; hiring locally would provide an additional economic benefit to the neighborhoods that will be impacted by the CVE. The outreach and engagement plan for recruiting participants will be developed by the CVE outreach team. Liabilities that may be faced by DPS upon the implementation of the CVE are currently being assessed. Potential liability issues will likely be mitigated though liability waivers that will be required to be signed by participants before CV equipment is installed in their vehicles. DPS will be responsible for O&M of the system. DPS will be the point of contact for vehicle fleet managers and private vehicle owners receiving and addressing reported in-vehicle equipment malfunctions/issues. DPS will also be responsible for disbursing, receiving, and recording the inventory of in-vehicle devices, as well as installing any software or firmware updates on field devices. DPS will also be responsible for monitoring the status of roadside equipment and coordinating with the appropriate contractor to restore normal operations when roadside equipment experiences degraded or failure operations. Given that O&M of CV equipment may be different from current O&M activities, it will be important to properly train traffic operations staff so they can address issues with equipment as the issues arise, and to configure and maintain the system after the CVE is implemented. In particular, it will be important to have specialized staff on-hand that possess knowledge of ITS systems and network engineering, and to develop procedures for modifying CVE Operations (e.g. modifying school zone TIMs, maintaining/updating intersection geometry data and MAP messages, and changing signal priority operations). Both the added responsibilities, and the unique qualifications necessary, are expected to result in the addition of staffing within DPS. The exact count is not yet known, but it is expected that one and possible more will be necessary to add to support this added will be coordinated in conjunction with other City needs as CTSS expansion continues as well.

Columbus DoT – DoT will continue to be responsible for maintenance of the fiber infrastructure (backhaul that provides connectivity to equipment on the roadside) and the underlying network management systems as they presently do. Should backhaul connectivity be compromised, the DoT will diagnose and repair any connectivity issues. The CVE is not expected to impact DoT staffing or responsibilities

Vehicle Fleet Managers and Personal Vehicle Owners – Fleet managers and personal vehicle owners have similar responsibilities: reporting in-vehicle equipment malfunctions/issues to O&M staff, returning in-vehicle equipment that is no longer desired or on vehicles that are no longer used on a frequent basis, and downloading security and software updates for in-vehicle devices.

1901

Chapter 6. Operational Scenarios

This section presents scenarios that capture how the system serves the needs of users when the system is operating under various modes of operation. To the extent possible, these use cases only describe external events that pertain to how the CVE is expected to benefit system users, and will minimize specifying details regarding the internal workings of the system – scenarios are developed in this fashion to allow for flexibility in the development of requirements and design of the CVE (with the exception of constraints provided in **Chapter 5, Concept for the New System**). The scenarios are grouped into use cases, which correspond to each proposed application (described in **Chapter 5, Concept for the New System**). Scenarios for each use case describe various modes of operations that are expected: normal operating conditions and degraded and/or failure conditions, as necessary. Each use case is accompanied by a process diagram (refer to Section 0) that represents the exchange of information between processes performed by the devices. Note: The two failure condition scenarios described in **Table 23: Use Case 1 – Scenario 3: Failure Condition – Diminished Communications** and **Table 24: Use Case 1 – Scenario 4: Failure Condition – Deficient OBU Data Quality** are common to many of the other use cases, and as such are referenced by these subsequent use cases versus repeating the same scenario in each.

Use Case 1: Emergency Electronic Brake Application

This use case contains scenarios associated with the Emergency Electronic Brake Light Application. **Figure 8: Emergency Electronic Brake Light Warning Diagram** provides a context diagram for all scenarios associated with this use case. Scenarios for this use case are listed below and are described in detail in tables following the context diagram. This application has a TRL-H of 7 and is considered deployment-ready.

- **Table 21: Use Case 1 – Scenario 1: Normal Operating Conditions – Roadway Obstacle**
- **Table 22: Use Case 1 – Scenario 2: Normal Operating Conditions – Low Visibility Conditions**
- **Table 23: Use Case 1 – Scenario 3: Failure Condition – Diminished Communications**
- **Table 24: Use Case 1 – Scenario 4: Failure Condition – Deficient OBU Data Quality**

Table 21: Use Case 1 – Scenario 1: Normal Operating Conditions – Roadway Obstacle

Use Case	**Emergency Electronic Brake Light Warning**
Scenario ID and Title	UC1-S1: Normal Operating Conditions – Roadway Obstacle
Scenario Objective	• Provide a warning to vehicle operators when a downstream vehicle brakes in an emergency fashion.

Use Case	**Emergency Electronic Brake Light Warning**	
Scenario ID and Title	UC1-S1: Normal Operating Conditions – Roadway Obstacle	
Operational Event(s)	• Three vehicles are following each other in a single file. Vehicle Operator 1: leading vehicle; Vehicle Operator 2: first following vehicle; Vehicle Operator 3: second following vehicle. • Vehicle Operator 1 must make an emergency stop, and the vehicle modifies the status of its safety message content to notify following vehicles.	• All vehicles are receiving GPS location and motion data and messages broadcast by other vehicles within wireless communications range. • The vehicle driven by Vehicle Operator 1 is broadcasting BSMs.
Actor(s)	Actor	Role
	Vehicle Operator 1 (remote)	Reacts to unforeseen circumstance by making a hard-braking maneuver without concern for a rear-end crash.
	Vehicle Operator 2 (host)	Safely come to a stop behind Vehicle Operator 1 by reacting to either a warning from onboard CV equipment, or as a result of Vehicle 1 brake lights.
	Vehicle Operator 3 (host)	Safely come to a stop behind Vehicle Operator 2 slowing down in response to the actions of Vehicle Operator 1.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 1	Step 1) Makes an emergency stop to avoid striking an obstacle in the road.
	Vehicle 1 OBU	Step 2) Broadcasts a BSM containing a data element that indicates that an emergency braking maneuver has occurred.
	Vehicle 2 OBU, Vehicle 3 OBU	Step 3) Receive the BSM, process it, and determine that a warning should be issued. [Issuance of warning is based on data contained in the BSM, as well as vehicle location and motion data obtained via GPS.]
	Vehicle Operator 2, Vehicle Operator 3	Step 4) Simultaneously receive an emergency brake light warning.
	Vehicle Operator 2	Step 5) Reduces speed in an attempt to avoid striking Vehicle Operator 1.
	Vehicle Operator 3	Step 6) Reduces speed in an attempt to avoid striking Vehicle Operator 2.

Use Case	Emergency Electronic Brake Light	Warning
Scenario ID and Title	UC1-S1: Normal Operating Conditions	– Roadway Obstacle
	Vehicle Operator 2	Step 7) Avoids striking Vehicle Operator 1. [Must brake hard to stop in time.]
	Vehicle Operator 3	Step 8) Avoids striking Vehicle Operator 2. [Safely comes to a stop at a lower deceleration rate.]
Post-Conditions	• Vehicle Operator 2 comes to a safe stop and is able to avoid a crash with Vehicle Operator 1. • Vehicle Operator 3 comes to a safe stop and is able to avoid a crash with Vehicle Operator 2 and Vehicle Operator 1.	• The detrimental effects of a backward-propagating congestion wave are minimized.
Policies and Business Rules	Columbus 2131.09 – Following too closely	ORC 4511.34 – Space between moving vehicles
Traceability	CVE-UN110-v02 – Vehicle Collision Avoidance	CVE-UN111-v02 – Emergency Braking Ahead
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: BSM from remote OBU. GNSS: Location and motion data.	
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions.	

Source: City of Columbus

Table 22: Use Case 1 – Scenario 2: Normal Operating Conditions – Low Visibility Conditions

Use Case	**Emergency Electronic Brake Light Warning**	
Scenario ID and Title	*UC1-S2: Normal Operating Conditions – Low Visibility*	
Scenario Objective	• Provide a warning to vehicle operators when a downstream vehicle brakes in an emergency fashion.	
Operational Event(s)	• Two vehicles are following each other in a single file. Vehicle Operator 1: leading vehicle; Vehicle Operator 2: following vehicle. • Low-visibility conditions suddenly occur.	• Vehicle Operator 1 must make an emergency stop, and the vehicle modifies the status of its safety message content to notify following vehicle.
Actor(s)	Actor	Role
	Vehicle Operator 1 (remote)	Reacts to unforeseen circumstance without concern for a rear-end crash.
	Vehicle Operator 2 (host)	Safely comes to a stop behind Vehicle Operator 1 making an emergency braking maneuver.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 1, Vehicle Operator 2	Step 1) Enter a patch of heavy fog or blinding snow.
	Vehicle Operator 1	Step 2) Dramatically reduces speed due to reduced visibility. [Brakes in an emergency fashion.]
	Vehicle 1 OBU	Step 3) Broadcasts a BSM containing a data element that indicates that an emergency braking maneuver has occurred.
	Vehicle 2 OBU	Step 4) Receives the BSM, process it, and determine that a warning should be issued. [Issuance of warning is based on data contained in the BSM, as well as vehicle location and motion data obtained via GPS.]
	Vehicle Operator 2	Step 5) Receives an emergency brake light warning.
	Vehicle Operator 2	Step 6) Reduces speed in an attempt to avoid striking Vehicle Operator 1
	Vehicle Operator 2	Step 7) Avoids striking Vehicle Operator 1. [Must brake hard to stop in time.]

Use Case	Emergency Electronic Brake Light Warning	
Scenario ID and Title	*UC1-S2: Normal Operating Conditions – Low Visibility*	
Post-Conditions	• Vehicle Operator 2 comes to a safe stop and is able to avoid a crash with Vehicle Operator 1.	• The detrimental effects of a backward-propagating congestion wave are minimized
Policies and Business Rules	Columbus 2131.09 – Following too closely	ORC 4511.34 – Space between moving vehicles
Traceability	CVE-UN110-v02 – Vehicle Collision Avoidance	CVE-UN111-v02 – Emergency Braking Ahead
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: BSM from remote OBU. GNSS: Time and location data.	
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions.	

1933 *Source: City of Columbus*

1934 **Table 23: Use Case 1 – Scenario 3: Failure Condition – Diminished Communications**

Use Case	**Emergency Electronic Brake Light Warning**	
Scenario ID and Title	*UC1-S3: Failure Condition – Diminished Communications*	
Scenario Objective	• Demonstrate failure of application to provide the proper output in a safety critical situation.	
Operational Event(s)	• Two vehicles are following each other in a single file. Vehicle Operator 1: leading vehicle; Vehicle Operator 2: following vehicle; • Vehicle Operator 1 must make an emergency stop • Messages cannot be exchanged between vehicles due to diminished communications. This could be due to OBU (host or remote) power failure, limited OBU (host or remote) computing resources, or wireless communications message congestion. • Alerts and/or warnings are not issued in safety-critical situations.	
Actor(s)	Actor	Role
	Vehicle Operator 1 (remote)	Reacts to unforeseen circumstance without concern for a rear-end crash.
	Vehicle Operator 2 (host)	Safely comes to a stop behind Vehicle Operator 1 making an emergency braking maneuver.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 1	Step 1) Makes an emergency stop to avoid striking an obstacle in the road.
	General	Step 2) A BSM is not sent from the vehicle Operated by Vehicle Operator 1 to the vehicle operated by Vehicle Operator 2. [Due to diminished communication.]
	Vehicle Operator 2	Step 3) Does not receive an emergency brake light warning.
	Vehicle Operator 2	Step 4) Notices that Vehicle Operator 1 is braking and, reduces speed in an attempt to avoid striking Vehicle Operator 1. [Cues may be visible (brake lights) or audible (screeching tires) in nature.]
	Vehicle Operator 2	Step 5) Avoids striking Vehicle Operator 1. [Must brake hard to stop in time.]

Use Case	Emergency Electronic Brake Light	Warning
Scenario ID and Title	*UC1-S3: Failure Condition –*	*Diminished Communications*
Post-Conditions	• Vehicle Operator 2 must visually identify emergency braking activity ahead and react accordingly, similar to current operations, or if Vehicle Operator 2 were following a non-CV-equipped vehicle.	• Vehicle Operator 1 does not benefit from alerts or warnings that would have been issued under normal operating conditions.
Policies and Business Rules	Columbus 2131.09 – Following too closely.	ORC 4511.34 – Space between moving vehicles
Traceability	*None*	
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU alert and OBU warning set at time of configuration. Human Inputs: None. CV Data*: ~~BSM data from remote OBU~~. GNSS: Time and location data.	
Output Summary	*None*	

**Strikethrough indicates data that would normally be available where there not a diminished or failed condition.*

Source: City of Columbus

1937 **Table 24: Use Case 1 – Scenario 4: Failure Condition – Deficient OBU Data Quality**

Use Case	**Emergency Electronic Brake Light Warning**	
Scenario ID and Title	*UC1-S4: Failure Condition – Deficient OBU Data Quality*	
Scenario Objective	• Demonstrate application fails to provide proper output in a safety-critical situation.	• Demonstrate application fails to provide timely output in a safety-critical situation.

Operational Event(s)	• Three vehicles are following each other in a single file. Vehicle Operator 1: leading vehicle; Vehicle Operator 2: first following vehicle; Vehicle Operator 3: second following vehicle.
	• A vehicle operated by Vehicle Operator 4 is traveling in the opposite direction of the other three vehicle operators.
	• Vehicle Operator 1 must make an emergency stop.
	• The vehicle driven by Vehicle Operator 1 is broadcasting BSMs.
		• Alerts and/or warnings are not issued in safety-critical situations (false positive) or are issued when not warranted (false negative).
		  ○ Safety data (position, speed, acceleration) received from remote OBU is inaccurate.
		  ○ Data received from GNSS and/or motion sensors (position, speed, acceleration) is inaccurate.
		• Safety-critical alerts and/or warnings are not issued in a timely manner
		  ○ Host and remote OBUs are not synchronized.
		  ○ Host OBU exhibits delayed processing of safety-critical information due to other ongoing processes.

Actor(s)	Actor	Role
	Vehicle Operator 1 (remote)	Reacts to unforeseen circumstance by making a hard-braking maneuver without concern for a rear-end crash.
	Vehicle Operator 2 (host)	Safely come to a stop behind Vehicle Operator 1 by reacting to either a warning from onboard CV equipment, or as a result of Vehicle 1 brake lights.
	Vehicle Operator 3 (host)	Safely come to a stop behind Vehicle Operator 2 slowing down in response to the actions of Vehicle Operator 1.
	Vehicle Operator 4 (host)	Continue to proceed in the opposite direction in a safe manner.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 1	Step 1) Makes an emergency stop to avoid striking an obstacle in the road.
	Vehicle 1 OBU	Step 2) Broadcasts a BSM containing a data element that indicates that an emergency braking maneuver has occurred.

Use Case	Emergency Electronic Brake Light Warning	
Scenario ID and Title	*UC1-S4: Failure Condition – Deficient OBU Data Quality*	
	Vehicle 2 OBU	Step 3) Receives the BSM, processes it, and determines that a warning should be issued, but the warning is late. [Due to time synchronization issues or limited processing resources on either OBU on Vehicle 1 or Vehicle 2.]
	Vehicle Operator 2	Step 4) Receives an emergency brake light warning. [Later than under normal operating conditions.]
	Vehicle Operator 2	Step 5) Notices that Vehicle Operator 1 is braking and, reduces speed in an attempt to avoid striking Vehicle Operator 1. [Cues may be visible (brake lights) or audible (screeching tires) in nature. Warning may be received while performing braking maneuver.]
	Vehicle 3 OBU	Step 6) Receives the BSM, processes it, and falsely determines that a warning should not be issued. [Vehicle 3 location and motion data obtained via GPS is inaccurate.]
	Vehicle Operator 3	Step 7) Notices that Vehicle Operator 1 is braking and, reduces speed in an attempt to avoid striking Vehicle Operator 1. [Cues may be visible (brake lights) or audible (screeching tires) in nature. (false negative)]
	Vehicle 4 OBU	Step 8) Receives the BSM, processes it, and falsely determines that a warning should be issued. [Vehicle 4 location and motion data obtained via GPS is inaccurate.]
	Vehicle Operator 4	Step 9) Receives an emergency brake light warning and assesses the roadway for braking hazards. [Increases alertness of Vehicle Operator 4, but no emergency braking is noted (false positive warning).]

Use Case	Emergency Electronic Brake Light Warning
Scenario ID and Title	*UC1-S4: Failure Condition – Deficient OBU Data Quality*
Post-Conditions	• System outputs warning late, reducing vehicle operator reaction time (Vehicle Operator 2). • System does not detect alert or warning condition when condition actually exists (Vehicle Operator 3). • System detects alert or warning condition when condition does not actually exist (Vehicle Operator 4). • Corrective actions could be taken when not necessary (Vehicle Operator 4). • Vehicle operators must visually identify various conditions and react accordingly, similar to current operations. • Vehicle Operators may lose trust in the system
Policies and Business Rules	*Same as Polices and Business Rules for Normal Operating Condition scenario(s).*
Traceability	*None*
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU alert and OBU warning set at time of configuration. Human Inputs: None. CV Data: Safety data from remote OBU (inaccurate or latent). GNSS: Location and motion data (inaccurate).
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions (false positive). None (false negative).

1938 *Source: City of Columbus*

Use Case 2: Forward Collision Warning

This use case contains scenarios associated with the Forward Collision Warning Application. **Figure 9: Forward Collision Warning Diagram** provides a context diagram for all scenarios associated with this use case. Scenarios for this use case are listed below and are described in detail in tables following the context diagram. This application has a TRL-H of 7 and is considered deployment-ready.

- **Table 25: Use Case 2 – Scenario 1: Normal Operating Conditions – Approaching Rear of Queue**
- **Table 26: Use Case 2 – Scenario 2: Normal Operating Conditions – Following Distance**
- **Table 27: Use Case 2 – Scenario 3: Failure Condition – Diminished Communications**
- **Table 28: Use Case 2 – Scenario 4: Failure Condition – Deficient OBU Data Quality**

Table 25: Use Case 2 – Scenario 1: Normal Operating Conditions – Approaching Rear of Queue

Use Case	**Forward Collision Warning**	
Scenario ID and Title	*UC2-S1: Normal Operating Conditions – Approaching Rear of Queue*	
Scenario Objective	• Provide a warning to vehicle operators when too close to a preceding vehicle given the speed differential.	
Operational Event(s)	• A vehicle operator operating a vehicle on a roadway at nominal speed approaches the rear of a queue of stopped or slowly moving vehicles.	• The vehicle notifies the vehicle operator of insufficient following distance.
Actor(s)	Actor	Role
	Vehicle Operator 1 (host)	Safely come to a stop behind the vehicle operator at the end of a queue.
	Vehicle Operator 2 (remote)	Stopped or moving slowly at the back end of a queue.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 2	Step 1) Stops at the back end of a queue.
	Vehicle Operator 1	Step 2) Approaches the back of the queue at nominal speed. [Vehicle Operator 1 is at the back of the queue.]
	Vehicle 1 OBU	Step 3) Broadcasts a BSM containing data elements that indicates its position and motion.

Use Case	Forward Collision Warning	
Scenario ID and Title	*UC2-S1: Normal Operating Conditions – Approaching Rear of Queue*	
	Vehicle 2 OBU	Step 4) Receives the BSM, processes it, and determine that a warning should be issued. [Issuance of warning is based on data contained in the BSM, as well as vehicle location and motion data obtained via GPS.]
	Vehicle Operator 1	Step 5) Receives a warning that a forward collision is imminent.
	Vehicle Operator 1	Step 6) Decelerates at a normal rate and matches the speed of the back of the queue or comes to a stop at the end of the queue.
Post-Conditions	• Vehicle Operator 1 safely comes to a stop at the back of the queue.	
Policies and Business Rules	Columbus 2131.09 – Following too closely. Columbus 2131.13 – Starting and backing vehicles.	ORC 4511.34 – Space between moving vehicles
Traceability	CVE-UN110-v02 – Vehicle Collision Avoidance	CVE-UN112-v02 – Safe Following Distance
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: BSM from remote OBU. GNSS: Time and location data.	
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from OBU to vehicle operator under certain conditions.	

1951 *Source: City of Columbus*

1952 **Table 26: Use Case 2 – Scenario 2: Normal Operating Conditions – Following Distance**

Use Case	Forward Collision Warning
Scenario ID and Title	*UC2-S2: Normal Operating Conditions – Following Distance*
Scenario Objective	• Provide a warning to vehicle operators when too close to a preceding vehicle given the speed.

Use Case	**Forward Collision Warning**	
Scenario ID and Title	*UC2-S2: Normal Operating Conditions – Following Distance*	
Operational Event(s)	• A vehicle operator traveling at nominal speed closely follows another vehicle that is also operating at a nominal speed.	• The vehicle notifies the vehicle operator of insufficient following distance.
Actor(s)	Actor	Role
	Vehicle Operator 1 (host)	Maintain a safe following distance from proceeding vehicle.
	Vehicle Operator 2 (remote)	Traveling at a constant speed.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 2	Step 1) Is moving at a slow pace. [Relative to Vehicle Operator 1.]
	Vehicle Operator 1	Step 2) Approaches Vehicle Operator 2. [Comes within an insufficient following distance given the speeds of both vehicles.]
	Vehicle 1 OBU	Step 3) Broadcasts a BSM containing data elements that indicates its position and motion.
	Vehicle 2 OBU	Step 4) Receives the BSM, processes it, and determine that a warning should be issued. [Issuance of warning is based on data contained in the BSM, as well as vehicle location and motion data obtained via GPS.]
	Vehicle Operator 1	Step 5) Receives a warning that a forward collision is imminent.
	Vehicle Operator 1	Step 6) Marginally decreases speed to increase following distance.
	Vehicle Operator 1	Step 7) Resumes nominal roadway speed while maintaining increased following distance.
Post-Conditions	• Vehicle Operator 1 maintains a safe following distance.	
Policies and Business Rules	Columbus 2131.09 – Following too closely Columbus 2131.13 – Starting and backing vehicles	ORC 4511.34 – Space between moving vehicles
Traceability	CVE-UN110-v02 – Vehicle Collision Avoidance	CVE-UN112-v02 – Safe Following Distance

Use Case	Forward Collision Warning
Scenario ID and Title	*UC2-S2: Normal Operating Conditions – Following Distance*
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: BSM from remote OBU. GNSS: Time and location data.
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from OBU to vehicle operator under certain conditions.

1953 *Source: City of Columbus*

1954 **Table 27: Use Case 2 – Scenario 3: Failure Condition – Diminished Communications**

Use Case	**Forward Collision Warning**	
Scenario ID and Title	*UC2-S3: Failure Condition –*	*Diminished Communications*
Scenario Objective	• Demonstrate failure of application to provide the proper output in a safety critical situation.	
Operational Event(s)	• Messages cannot be exchanged between vehicles due to diminished communications. This could be due to OBU (host or remote) power failure, limited OBU (host or remote) computing resources, or wireless communications message congestion.	• Alerts and/or warnings are not issued in safety-critical situations.
Actor(s)	Actor	Role
	Vehicle Operator 1 (remote)	Safely come to a stop behind the vehicle operator at the end of a queue.
	Vehicle Operator 2 (host)	Stopped or moving slowly at the back end of a queue.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 2	Step 1) Stops at the back end of a queue.
	Vehicle Operator 1	Step 2) Approaches the back of the queue at nominal speed. [Vehicle Operator 1 is at the back of the queue.]
	General	Step 3) A BSM is not sent from the vehicle Operated by Vehicle Operator 2 to the vehicle operated by Vehicle Operator 1. [Due to diminished communication.]
	Vehicle Operator 1	Step 4) Does not receive an emergency brake light warning.
	Vehicle Operator 1	Step 5) Decelerates at a normal rate and matches the speed of the back of the queue or comes to a stop at the end of the queue. [Cues may be visible (brake lights).]

Use Case	Forward Collision Warning	
Scenario ID and Title	*UC2-S3: Failure Condition –*	*Diminished Communications*
Post-Conditions	• Vehicle Operator 1 must visually identify rear of queue and react accordingly, similar to current operations, or if Vehicle Operator 1 were following a non-CV-equipped vehicle.	• Vehicle Operator 2 does not benefit from alerts or warnings that would have been issued under normal operating conditions.
Policies and Business Rules	Columbus 2131.09 – Following too closely Columbus 2131.13 – Starting and backing vehicles	ORC 4511.34 – Space between moving vehicles
Traceability	CVE-UN110-v02 – Vehicle Collision Avoidance	CVE-UN112-v02 – Safe Following Distance
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: ~~BSM from remote OBU~~. GNSS: Time and location data.	
Output Summary	*None*	

1955 **Strikethrough indicates data that would normally be available where there not a diminished or failed condition.*

1956 *Source: City of Columbus*

1957 **Table 28: Use Case 2 – Scenario 4: Failure Condition – Deficient OBU Data Quality**

Use Case	Forward Collision Warning	
Scenario ID and Title	*UC2-S4: Failure Condition – Deficient*	*OBU Data Quality*
Scenario Objective	• Demonstrate application fails to provide proper output in a safety-critical situation.	• Demonstrate application fails to provide timely output in a safety-critical situation.

Use Case	Forward Collision Warning	
Scenario ID and Title	*UC2-S4: Failure Condition – Deficient OBU Data Quality*	

Operational Event(s)	• Vehicle Operator 1 is stopped or moving slowly at the back of a queue.
	• Two vehicles approach the back of the queue Vehicle Operator 2: first following vehicle; Vehicle Operator 3: second following vehicle.
	• A vehicle operated by Vehicle Operator 4 is traveling in the opposite direction of the other three vehicle operators.
	• The vehicle driven by Vehicle Operator 1 is broadcasting BSMs.
	• Alerts and/or warnings are not issued in safety-critical situations (false positive).
	• or are issued when not warranted (false negative).
	  ○ Safety data (position, speed, acceleration) received from remote OBU is inaccurate.
	  ○ Data received from GNSS and/or motion sensors (position, speed, acceleration) is inaccurate.
	• Safety-critical alerts and/or warnings are not issued in a timely manner.
	  ○ Host and remote OBUs are not synchronized.
	  ○ Host OBU exhibits delayed processing of safety-critical information due to other ongoing processes.	

Actor(s)	Actor	Role
	Vehicle Operator 1 (remote)	Stopped or moving slowly at the back end of a queue.
	Vehicle Operator 2 (host)	Safely come to a stop behind Vehicle Operator 1 by reacting to either a warning from onboard CV equipment, or as a result of Vehicle 1 brake lights.
	Vehicle Operator 3 (host)	Safely come to a stop behind Vehicle Operator 2 by reacting to either a warning from onboard CV equipment, or as a result of Vehicle 2 brake lights.
	Vehicle Operator 4 (host)	Continue to proceed in the opposite direction in a safe manner.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 1	Step 1) Stops at the back end of a queue.
	Vehicle 1 OBU	Step 2) Broadcasts a BSM containing a data element that indicates that the vehicle is stopped.
	Vehicle Operator 2	Step 3) Approaches the back of the queue at nominal speed. [Vehicle Operator 2 is at the back of the queue.]

Use Case	Forward Collision Warning	
Scenario ID and Title	*UC2-S4: Failure Condition – Deficient OBU Data Quality*	
	Vehicle 2 OBU	Step 4) Receives the BSM, processes it, and determines that a warning should be issued, but the warning is late. [Due to time synchronization issues or limited processing resources on either OBU on Vehicle 1 or Vehicle 2.]
	Vehicle Operator 2	Step 5) Receives a forward collision warning. [Later than under normal operating conditions.]
	Vehicle Operator 2	Step 6) Notices that Vehicle Operator 1 is stopped and brakes to a stop behind Vehicle Operator 1. [Cues may be visible (brake lights) in nature. Warning may be received while performing braking maneuver.]
	Vehicle 3 OBU	Step 7) Receives the BSM, processes it, and falsely determines that a warning should not be issued. [Vehicle 3 location and motion data obtained via GPS is inaccurate.]
	Vehicle Operator 3	Step 8) Notices that Vehicle Operator 1 and 2 are stopped and reduces speed in an attempt to avoid striking Vehicle Operator 2. [Cues may be visible (brake lights) in nature. (false negative).]
	Vehicle 4 OBU	Step 9) Receives the BSM, processes it, and falsely determines that a warning should be issued. [Vehicle 4 location and motion data obtained via GPS is inaccurate.]
	Vehicle Operator 4	Step 10) Receives a forward collision warning and assesses the roadway for stopped vehicles. [Increases alertness of Vehicle Operator 4, but no emergency braking is noted (false positive warning).]

Use Case	**Forward Collision Warning**
Scenario ID and Title	*UC2-S4: Failure Condition – Deficient OBU Data Quality*
Post-Conditions	• System outputs warning late, reducing vehicle operator reaction time (Vehicle Operator 2). • System does not detect alert or warning condition when condition actually exists (Vehicle Operator 3). • System detects alert or warning condition when condition does not actually exist (Vehicle Operator 4). • Corrective actions could be taken when not necessary (Vehicle Operator 4). • Vehicle operators must visually identify various conditions and react accordingly, similar to current operations. • Vehicle Operators may lose trust in the system.
Policies and Business Rules	Columbus 2131.09 – Following too closely Columbus 2131.13 – Starting and backing vehicles ORC 4511.34 – Space between moving vehicles
Traceability	*None*
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU alert and OBU warning set at time of configuration. Human Inputs: None. CV Data: Safety data from remote OBU (inaccurate or latent). GNSS: Location and motion data (inaccurate).
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host. OBU to vehicle operator under certain conditions (false positive). None (false negative).

Source: City of Columbus

Use Case 3: Intersection Movement Assist

This use case contains scenarios associated with the Intersection Movement Assist Application. **Figure 10: Intersection Movement Assist Diagram** provides a context diagram for all scenarios associated with this use case. Scenarios for this use case are listed below, and they are described in detail in the tables following the context diagram. This application has a TRL-H of 5 and is considered deployment-ready. Further research is needed to determine the feasibility of deploying this application in the CVE.

- **Table 29: Use Case 3 – Scenario 1: Normal Operating Conditions – Permitted Left Turn**
- **Table 30: Use Case 3 – Scenario 2: Normal Operating Conditions – Stop Controlled Intersection/Right Turn on Red**
- **Table 31: Use Case 3 – Scenario 3: Failure Condition – Diminished Communications**
- **Table 32: Use Case 3 – Scenario 4: Failure Condition – Deficient OBU Data Quality**

Table 29: Use Case 3 – Scenario 1: Normal Operating Conditions – Permitted Left Turn

Use Case	**Intersection Movement Assist**	
Scenario ID and Title	*UC3-S1: Normal Operating Conditions – Permitted Left Turn*	
Scenario Objective	• Notify the vehicle operator if oncoming traffic will conflict with a turning movement.	
Operational Event(s)	• A vehicle operator attempts to turn left across a stream of oncoming traffic.	
Actor(s)	Actor	Role
	Vehicle Operator 1 (host)	Safely navigate turn through an intersection.
	Vehicle Operator 2 (remote)	Approaching Vehicle 1 from the opposite direction.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 1	Step 1) Approaches a signalized intersection and intends to make a permitted left turn.
	Vehicle Operator 2	Step 2) Operates a vehicle in an oncoming through lane.
	Vehicle 2 OBU	Step 3) Broadcasts a BSM containing data elements that indicates its position and motion.

Use Case	**Intersection Movement Assist**	
Scenario ID and Title	*UC3-S1: Normal Operating Conditions – Permitted Left Turn*	
	Vehicle 1 OBU	Step 4) Receives the BSM, processes it, and determine that a warning should be issued. [Issuance of warning is based on data contained in the BSM, as well as vehicle location and motion data obtained via GPS.]
	Vehicle Operator 1	Step 5a) Receives a warning that there is not sufficient distance to turn in front of Vehicle Operator 2.
	Vehicle Operator 1	Step 6a) Turns after Vehicle Operator 2 passes thru intersection and safely completes the turn.
	Vehicle Operator 1	Step 5b) Does not receive a warning. [Implying it will be able to turn before Vehicle Operator 2 reaches the intersection.]
	Vehicle Operator 1	Step 6b) Safely completes the turn in front of Vehicle Operator 2.
Post-Conditions	• Vehicle Operator 1 properly reacts to the warning and safely completes the left turn through the intersection.	
Policies and Business Rules	Columbus 2113.01 – Obedience to traffic control devices. Columbus 2113.03 – Traffic control signal terms and lights. Columbus 2113.04 – Signal to control lane direction of travel. Columbus 2131.10 – Turning at intersections. Columbus 2131.11 – Turning into private driveway, alley, or building. Columbus 2131.14 – Signals before changing course, turning, or stopping. Columbus 2131.16 – Right-of-way at intersections. Columbus 2131.17 – Right-of-way when turning left. Columbus 2131.18 – Right-of-way at through streets; stop and yield right-of-way signs; merging into laned traffic.	Columbus 2131.22 – Right-of-way at private driveway, alley, or building. Columbus 2131.23 – Emerging from private driveway, alley, or building. ORC 4511.12 – Obedience to traffic control devices. ORC 4511.13 – Highway traffic signal indications; section not applicable of railroad crossings. ORC 4511.36 – Rules for turns at intersections. ORC 4511.41 – Right-of-way rule at intersections. ORC 4511.42 – Right-of-way rule when turning left. ORC 4511.43 – Right-of-way rule at through highways, stop signs, yield signs. ORC 4511.44 – Right-of-Way at highway from any place other than another roadway.
Traceability	CVE-UN110-v02 – Vehicle Collision Avoidance	CVE-UN113-v02 – Monitor Vehicle Trajectories at Intersection

Use Case	Intersection Movement Assist
Scenario ID and Title	*UC3-S1: Normal Operating Conditions – Permitted Left Turn*
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: BSM from remote OBU. GNSS: Time and location data
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions.

Source: City of Columbus

Table 30: Use Case 3 – Scenario 2: Normal Operating Conditions – Stop Controlled Intersection/Right Turn on Red

Use Case	Intersection Movement Assist	
Scenario ID and Title	*UC3-S2: Normal Operating Conditions – Stop Controlled Intersection/Right Turn on Red*	
Scenario Objective	• Notify the operator of a vehicle making a right turn from a stop sign if there is insufficient distance to turn in front of oncoming traffic.	
Operational Event(s)	• A vehicle operator attempts to turn right into a stream of approaching traffic.	
Actor(s)	Actor	Role
	Vehicle Operator 1 (host)	Safely navigate turn through an intersection.
	Vehicle Operator 2 (remote)	Approaching Vehicle 1 in the merging through lane.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 1	Step 1) Approaches a stop-controlled intersection and intends to make a right turn on red.
	Vehicle Operator 2	Step 2) Operates a vehicle in a merging through lane.

Use Case	**Intersection Movement Assist**	
Scenario ID and Title	*UC3-S2: Normal Operating Conditions*	*– Stop Controlled Intersection/Right Turn on Red*
	Vehicle 2 OBU	Step 3) Broadcasts a BSM containing data elements that indicates its position and motion.
	Vehicle 1 OBU	Step 4) Receives the BSM, processes it, and determine that a warning should be issued. [Issuance of warning is based on data contained in the BSM, as well as vehicle location and motion data obtained via GPS.]
	Vehicle Operator 1	Step 5a) Receives a warning that Vehicle Operator 2 is approaching the receiving lane, and there is not sufficient distance to complete the right turn.
	Vehicle Operator 1	Step 6a) Turns after Vehicle Operator 2 passes thru intersection and safely completes the turn.
	Vehicle Operator 1	Step 5b) Does not receive a warning.
	Vehicle Operator 1	Step 6b) Safely completes the turn in front of Vehicle Operator 2.
Post-Conditions	• Vehicle Operator 1 properly reacts to the warning and safely completes the right turn through the intersection.	
Policies and Business Rules	Columbus 2113.01 – Obedience to traffic control devices. Columbus 2113.03 – Traffic control signal terms and lights. Columbus 2113.04 – Signal to control lane direction of travel. Columbus 2131.10 – Turning at intersections. Columbus 2131.11 – Turning into private driveway, alley, or building. Columbus 2131.14 – Signals before changing course, turning, or stopping. Columbus 2131.16 – Right-of-way at intersections. Columbus 2131.17 – Right-of-way when turning left. Columbus 2131.18 – Right-of-way at through streets; stop and yield right-of-way signs; merging into laned traffic.	Columbus 2131.22 – Right-of-way at private driveway, alley, or building. Columbus 2131.23 – Emerging from private driveway, alley, or building. ORC 4511.36 – Rules for turns at intersections. ORC 4511.41 – Right-of-way rule at intersections. ORC 4511.42 – Right-of-way rule when turning left. ORC 4511.43 – Right-of-way rule at through highways, stop signs, yield signs. ORC 4511.44 – Right-of-Way at highway from any place other than another roadway.

Use Case	Intersection Movement Assist	
Scenario ID and Title	*UC3-S2: Normal Operating Conditions*	*– Stop Controlled Intersection/Right Turn on Red*
Traceability	CVE-UN110-v02 – Vehicle Collision Avoidance	CVE-UN113-v02 – Monitor Vehicle Trajectories at Intersection
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: BSM from remote OBU. GNSS: Time and location data.	
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions.	

1975 *Source: City of Columbus*

1976 **Table 31: Use Case 3 – Scenario 3: Failure Condition – Diminished Communications**

Use Case	Intersection Movement Assist	
Scenario ID and Title	*UC3-S3: Failure Condition –*	*Diminished Communications*
Scenario Objective	• Demonstrate failure of application to provide the proper output in a safety critical situation.	
Operational Event(s)	• Vehicles cannot exchange messages due to diminished communications. This could be due to OBU (host or remote) power failure, limited OBU (host or remote) computing resources, or wireless communications message congestion.	• Alerts and/or warnings are not issued in safety-critical situations.
Actor(s)	Actor	Role
	Vehicle Operator 1 (host)	Safely navigate turn through an intersection.
	Vehicle Operator 2 (remote)	Approaching Vehicle 1 from the opposite direction.
	Source	Key Action [Comments]

Use Case	**Intersection Movement Assist**	
Scenario ID and Title	*UC3-S3: Failure Condition – Diminished Communications*	
Key Actions and Flow of Events	Vehicle Operator 1	Step 1) Approaches a signalized intersection and intends to make a permitted left turn.
	Vehicle Operator 2	Step 2) Operates a vehicle in an oncoming through lane.
	General	Step 3) A BSM is not sent from the vehicle Operated by Vehicle Operator 2 to the vehicle operated by Vehicle Operator 1. [Due to diminished communication.]
	Vehicle Operator 1	Step 4) Does not receive an intersection movement assist warning.
	Vehicle Operator 1	Step 5) Notices that Vehicle Operator 2 is approaching. [Must judge speed based on visually observing Vehicle Operator 2 as they approach the intersection.]
	Vehicle Operator 1	Step 6) Proceeds though intersection. [Once an acceptable gap is available.]
Post-Conditions	• Vehicle Operator 1 must visually identify gaps in conflicting traffic streams and proceed though the intersection accordingly, similar to current operations, or if vehicles in the opposing traffic streams are non-CV-equipped.	• Vehicle Operator 2 does not benefit from alerts or warnings that would have been issued under normal operating conditions.

Use Case	Intersection Movement Assist
Scenario ID and Title	*UC3-S3: Failure Condition – Diminished Communications*
Policies and Business Rules	Columbus 2113.01 – Obedience to traffic control devices. Columbus 2113.03 – Traffic control signal terms and lights. Columbus 2113.04 – Signal to control lane direction of travel. Columbus 2131.10 – Turning at intersections. Columbus 2131.11 – Turning into private driveway, alley, or building. Columbus 2131.14 – Signals before changing course, turning, or stopping. Columbus 2131.16 – Right-of-way at intersections. Columbus 2131.17 – Right-of-way when turning left. Columbus 2131.18 – Right-of-way at through streets; stop and yield right-of-way signs; merging into laned traffic. Columbus 2131.22 – Right-of-way at private driveway, alley, or building. Columbus 2131.23 – Emerging from private driveway, alley, or building. ORC 4511.12 – Obedience to traffic control devices. ORC 4511.13 – Highway traffic signal indications; section not applicable of railroad crossings. ORC 4511.36 – Rules for turns at intersections. ORC 4511.41 – Right-of-way rule at intersections. ORC 4511.42 – Right-of-way rule when turning left. ORC 4511.43 – Right-of-way rule at through highways, stop signs, yield signs. ORC 4511.44 – Right-of-Way at highway from any place other than another roadway.
Traceability	None
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: BSM from remote OBU. GNSS: Time and location data.
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions.

Source: City of Columbus

Table 32: Use Case 3 – Scenario 4: Failure Condition – Deficient OBU Data Quality

Use Case	Intersection Movement Assist
Scenario ID and Title	*UC3-S4: Failure Condition – Deficient OBU Data Quality*
Scenario Objective	• Demonstrate application fails to provide proper output in a safety-critical situation. • Demonstrate application fails to provide timely output in a safety-critical situation.

<table>
<tr><td>Use Case</td><td colspan="2">Intersection Movement Assist</td></tr>
<tr><td>Scenario ID and Title</td><td colspan="2">UC3-S4: Failure Condition – Deficient OBU Data Quality</td></tr>
<tr><td>Operational Event(s)</td><td colspan="2">

Vehicle Operator 1 is approaching a two-way stop-controlled intersection on a non-stop-controlled approach.
Vehicle Operator 2 is stopped on one of the stop-controlled approach and is turning right onto the same roadway and same direction as Vehicle Operator 1. (i.e. must turn into and yield to Vehicle Operator 1 to make right turn).
Vehicle Operator 3 is waiting to turn left from a left-turn lane on the opposite non-stop-controlled approach (i.e. must turn across and yield to Vehicle Operator 1 to make left turn).
Vehicle Operator 4: is turning right on the opposite non-stop-controlled approach (i.e. does not yield to Vehicle Operator 1).
The vehicle driven by Vehicle Operator 1 is broadcasting BSMs.
Alerts and/or warnings are not issued in safety-critical situations (false positive) or are issued when not warranted (false negative).

Safety data (position, speed, acceleration) received from remote OBU is inaccurate.
Data received from GNSS and/or motion sensors (position, speed, acceleration) is inaccurate.

Safety-critical alerts and/or warnings are not issued in a timely manner.

Host and remote OBUs are not synchronized.
Host OBU exhibits delayed processing of safety-critical information due to other ongoing processes.

</td></tr>
<tr><td rowspan="5">Actor(s)</td><td>Actor</td><td>Role</td></tr>
<tr><td>Vehicle Operator 1 (remote)</td><td>Safely navigate through movement through an intersection.</td></tr>
<tr><td>Vehicle Operator 2 (host)</td><td>Safely navigate turn through an intersection.</td></tr>
<tr><td>Vehicle Operator 3 (host)</td><td>Safely navigate turn through an intersection.</td></tr>
<tr><td>Vehicle Operator 4 (host)</td><td>Safely navigate turn through an intersection.</td></tr>
<tr><td rowspan="4">Key Actions and Flow of Events</td><td>Source</td><td>Key Action [Comments]</td></tr>
<tr><td>Vehicle Operator 1</td><td>Step 1) Approaches an intersection operating a vehicle in an oncoming through lane.</td></tr>
<tr><td>Vehicle 1 OBU</td><td>Step 2) Broadcasts a BSM containing a data element that indicates location and motion.</td></tr>
<tr><td>Vehicle Operator 2</td><td>Step 3) Approaches the intersection and intends to make a permitted left turn.</td></tr>
</table>

Use Case	**Intersection Movement Assist**	
Scenario ID and Title	*UC3-S4: Failure Condition – Deficient OBU Data Quality*	
	Vehicle 2 OBU	Step 4) Receives the BSM, processes it, and determines that a warning should be issued, but the warning is late. [Due to time synchronization issues or limited processing resources on either OBU on Vehicle 1 or Vehicle 2.]
	Vehicle Operator 2	Step 5) Receives an intersection movement assist warning. [Later than under normal operating conditions.]
	Vehicle Operator 2	Step 6a) Notices that Vehicle Operator 1 is approaching and waits for Vehicle Operator 1 to pass before turning. [Cues may be visible (approaching vehicle) in nature. Warning may be received while waiting.]
	Vehicle Operator 2	Step 6b) Turns in front of Vehicle Operator 1. [Causing Vehicle Operator 1 to decrease speed as Vehicle Operator 2 accelerates.]
	Vehicle Operator 3	Step 7) Approaches the intersection and intends to make a permitted left turn.
	Vehicle 3 OBU	Step 8) Receives the BSM, processes it, and falsely determines that a warning should not be issued. [Vehicle 3 location and motion data obtained via GPS is inaccurate.]
	Vehicle Operator 3	Step 9a) Notices that Vehicle Operator 1 is approaching and waits for Vehicle Operator 1 to pass before turning. [Cues may be visible (approaching vehicle) in nature. Warning may be received while waiting.]
	Vehicle Operator 3	Step 9b) Notices that Vehicle Operator 1 is braking and reduces speed in an attempt to avoid striking Vehicle Operator 1. [Cues may be visible (brake lights) or audible (screeching tires) in nature. (false negative).]
	Vehicle Operator 3	Step 10b) Turns in front of Vehicle Operator 1. [Causing Vehicle Operator 1 to decrease speed as Vehicle Operator 3 crosses their path.]
	Vehicle Operator 4	Step 11) Approaches the intersection and intends to make a permitted left turn.

Use Case	**Intersection Movement Assist**	
Scenario ID and Title	*UC3-S4: Failure Condition – Deficient*	*OBU Data Quality*
	Vehicle 4 OBU	Step 12) Receives the BSM, processes it, and falsely determines that a warning should be issued. [Vehicle 3 location and motion data obtained via GPS is inaccurate.]
	Vehicle Operator 4	Step 13) Receives an intersection movement warning and assesses the roadway for other vehicles that may be cutting into their path. [Increases alertness of Vehicle Operator 4, but no other vehicles are noted (false positive warning).]
Post-Conditions	• System outputs warning late, reducing vehicle operator reaction time (Vehicle Operator 2). • System does not detect alert or warning condition when condition actually exists (Vehicle Operator 3). • System detects alert or warning condition when condition does not actually exist (Vehicle Operator 4).	• Corrective actions could be taken when not necessary (Vehicle Operator 4). • Vehicle operators must visually identify various conditions and react accordingly, similar to current operations. • Vehicle Operators may lose trust in the system.
Policies and Business Rules	Columbus 2113.01 – Obedience to traffic control devices. Columbus 2113.03 – Traffic control signal terms and lights. Columbus 2113.04 – Signal to control lane direction of travel. Columbus 2131.10 – Turning at intersections. Columbus 2131.11 – Turning into private driveway, alley, or building. Columbus 2131.14 – Signals before changing course, turning, or stopping. Columbus 2131.16 – Right-of-way at intersections. Columbus 2131.17 – Right-of-way when turning left. Columbus 2131.18 – Right-of-way at through streets; stop and yield right-of-way signs; merging into laned traffic. Columbus 2131.22 – Right-of-way at private driveway, alley, or building.	Columbus 2131.23 – Emerging from private driveway, alley, or building. ORC 4511.12 – Obedience to traffic control devices. ORC 4511.13 – Highway traffic signal indications; section not applicable of railroad crossings. ORC 4511.36 – Rules for turns at intersections. ORC 4511.41 – Right-of-way rule at intersections. ORC 4511.42 – Right-of-way rule when turning left. ORC 4511.43 – Right-of-way rule at through highways, stop signs, yield signs. ORC 4511.44 – Right-of-Way at highway from any place other than another roadway.
Traceability	*None*	

Use Case	Intersection Movement Assist
Scenario ID and Title	*UC3-S4: Failure Condition – Deficient OBU Data Quality*
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU alert and OBU warning set at time of configuration. Human Inputs: None. CV Data: Safety data from remote OBU (inaccurate or latent). GNSS: Location and motion data (inaccurate).
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions (false positive). None (false negative).

Source: City of Columbus

Use Case 4: Lane Change Warning/Blind Spot Warning

This use case contains scenarios associated with the Lane Change Warning/Blind Spot Warning Application. **Figure 11: Lane Change Warning/Blind Spot Warning Diagram** provides a context diagram for all scenarios associated with this use case. Scenarios for this use case are listed below, and they are described in detail in tables following the context diagram. This application has a TRL-H of 7 and is considered deployment-ready

- **Table 33: Use Case 4 – Scenario 1: Normal Operating Conditions – Vehicle in Blind Spot**
- **Table 34: Use Case 4 – Scenario 2: Normal Operating Conditions – Lane Change Collision Avoidance**
- **Table 35: Use Case 4 – Scenario 3: Failure Condition – Diminished Communications**
- **Table 36: Use Case 4 – Scenario 4: Failure Condition – Deficient OBU Data Quality**

Table 33: Use Case 4 – Scenario 1: Normal Operating Conditions – Vehicle in Blind Spot

Use Case	Lane Change Warning/Blind Spot Warning
Scenario ID and Title	*UC4-S1: Normal Operating Conditions – Vehicle in Blind Spot*
Scenario Objective	• Notify vehicle operators when another vehicle is located in their blind spot.

Use Case	**Lane Change Warning/Blind Spot Warning**	
Scenario ID and Title	*UC4-S1: Normal Operating Conditions – Vehicle in Blind Spot*	
Operational Event(s)	• A vehicle operator overtakes a second vehicle operator on a multi-lane roadway, prompting a blind spot warning.	
Actor(s)	Actor	Role
	Vehicle Operator 1 (host)	Maintain safe operation of vehicle while on a multi-lane roadway.
	Vehicle Operator 2 (remote)	Maintain safe operation of vehicle while on a multi-lane roadway.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 1	Step 1) Is driving at a constant speed in the right-most lane.
	Vehicle Operator 2	Step 2) Is driving at a constant, faster speed in the second right-most lane.
	Vehicle Operator 2	Step 3) Begins to overtake Vehicle Operator 1.
	Vehicle 2 OBU	Step 4) Broadcasts a BSM containing data elements that indicates its position and motion.
	Vehicle 1 OBU	Step 5) Receives the BSM, processes it, and determine that a warning should be issued. [Issuance of warning is based on data contained in the BSM, as well as vehicle location and motion data obtained via GPS.]
	Vehicle Operator 1	Step 6) Receives a warning that there is a vehicle in the blind spot of Vehicle Operator 1.
	Vehicle Operator 1	Step 7) Needs to make a left turn ahead, prepares to move to the left side of the roadway.
	Vehicle Operator 1	Step 8) Maintains the position of the vehicle in the right-most lane and allows Vehicle Operator 2 to pass.
	Vehicle Operator 1	Step 9) Moves to the lane to the left.
Post-Conditions	• Vehicle Operator 1 has increased awareness of surrounding vehicles in blind spot.	• Vehicle Operator 1 properly reacts to the warning and safely completes the lane change.

Use Case	Lane Change Warning/Blind Spot Warning	
Scenario ID and Title	*UC4-S1: Normal Operating Conditions – Vehicle in Blind Spot*	
Policies and Business Rules	Columbus 2131.08 – Driving within lanes or continuous lines of traffic. Columbus 2131.14 – Signals before changing course, turning, or stopping.	ORC – 4511.27 – Overtaking and passing of vehicles proceeding in the same direction. ORC – 4511.27 – Turn and stop signals.
Traceability	CVE-UN110-v02 – Vehicle Collision Avoidance CVE-UN114-v02 – Lane Change Collision Warning	CVE-UN120-v02 – Vehicle in Blind Spot
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: BSM from remote OBU. GNSS: Time and location data.	
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions.	

Source: City of Columbus

Table 34: Use Case 4 – Scenario 2: Normal Operating Conditions – Lane Change Collision Avoidance

Use Case	Lane Change Warning/Blind Spot Warning	
Scenario ID and Title	*UC4-S2: Normal Operating Conditions – Lane Change Collision Avoidance*	
Scenario Objective	• Warn vehicle operators when a lane change is expected to result in near-miss or crash.	
Operational Event(s)	• A vehicle operator attempts to change lanes with insufficient distance in front of another vehicle operator prompting a lane change warning.	
Actor(s)	Actor	Role
	Vehicle Operator 1 (host)	Maintain safe operation of vehicle while on a multi-lane roadway.
	Vehicle Operator 2 (remote)	Maintain safe operation of vehicle while on a multi-lane roadway.

Use Case	Lane Change Warning/Blind Spot Warning	
Scenario ID and Title	*UC4-S2: Normal Operating Conditions – Lane Change Collision Avoidance*	
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 1	Step 1) Is driving at a constant speed in the right-most lane.
	Vehicle Operator 2	Step 2) Is driving at a constant, faster speed in the second right-most lane.
	Vehicle Operator 2	Step 3) Begins to overtake Vehicle Operator 1.
	Vehicle 2 OBU	Step 4) Broadcasts a BSM containing data elements that indicates its position and motion.
	Vehicle 1 OBU	Step 5) Receives the BSM, processes it, and determine that a warning should be issued. [Issuance of warning is based on data contained in the BSM, as well as vehicle location and motion data obtained via GPS.]
	Vehicle Operator 1	Step 6) Receives an alert that there is a vehicle in the blind spot of Vehicle Operator 1.
	Vehicle Operator 1	Step 7) Does not notice the alert and begins to make the lane change.
	Vehicle Operator 1	Step 8) Receives a potential conflict warning.
	Vehicle Operator 1	Step 9) Maintains the position of the vehicle in the right-most lane and allows Vehicle Operator 2 to pass. [In response to the warning.]
	Vehicle Operator 1	Step 10) Moves to the lane to the left.
Post-Conditions	• Vehicle Operator 1 is provided a more urgent warning in response to a potential conflict.	• Vehicle Operator 1 properly reacts to the warning and safely completes the lane change.
Policies and Business Rules	Columbus 2131.08 – Driving within lanes or continuous lines of traffic. Columbus 2131.14 – Signals before changing course, turning, or stopping.	ORC – 4511.27 – Overtaking and passing of vehicles proceeding in the same direction. ORC – 4511.27 – Turn and stop signals.
Traceability	CVE-UN110-v02 – Vehicle Collision Avoidance CVE-UN114-v02 – Lane Change Collision Warning	CVE-UN120-v02 – Vehicle in Blind Spot

Use Case	**Lane Change Warning/Blind Spot Warning**
Scenario ID and Title	*UC4-S2: Normal Operating Conditions – Lane Change Collision Avoidance*
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU alerts and OBU warning set at time of configuration. Human Inputs: None. CV Data: BSM from remote OBU. GNSS: Time and location data.
Output Summary	**Host Vehicle OBU:** Alert audio/visual output from host OBU to vehicle operator under certain conditions. Warning audio/visual output from host OBU to vehicle operator under certain conditions.

1995 *Source: City of Columbus*

1996 **Table 35: Use Case 4 – Scenario 3: Failure Condition – Diminished Communications**

Use Case	**Lane Change Warning/Blind Spot Warning**	
Scenario ID and Title	*UC4-S3: Failure Condition – Diminished Communications*	
Scenario Objective	• Demonstrate failure of application to provide the proper output in a safety critical situation.	
Operational Event(s)	• Messages cannot be exchanged between vehicles due to diminished communications. This could be due to OBU (host or remote) power failure, limited OBU (host or remote) computing resources, or wireless communications message congestion.	• Alerts and/or warnings are not issued in safety-critical situations.
Actor(s)	Actor	Role
	Vehicle Operator 1 (host)	Maintain safe operation of vehicle while on a multi-lane roadway.
	Vehicle Operator 2 (remote)	Maintain safe operation of vehicle while on a multi-lane roadway.
	Source	Key Action [Comments]

Use Case	**Lane Change Warning/Blind Spot Warning**	
Scenario ID and Title	*UC4-S3: Failure Condition – Diminished Communications*	
Key Actions and Flow of Events	Vehicle Operator 1	Step 1) Is driving at a constant speed in the right-most lane.
	Vehicle Operator 2	Step 2) Is driving at a constant, faster speed in the second right-most lane.
	Vehicle Operator 2	Step 3) Begins to overtake Vehicle Operator 1.
	General	Step 4) A BSM is not sent from the vehicle Operated by Vehicle Operator 1 to the vehicle operated by Vehicle Operator 2. [Due to diminished communication.]
	Vehicle Operator 2	Step 5) Does not receive an emergency brake light warning.
	Vehicle Operator 1	Step 6) Needs to make a left turn ahead, prepares to move to the left side of the roadway.
	Vehicle Operator 1	Step 7) Notices that Vehicle Operator 2 is in the blind spot. [Based on checking mirrors, or by looking over left shoulder.]
	Vehicle Operator 1	Step 8) Maintains the position of the vehicle in the right-most lane and allows Vehicle Operator 2 to pass.
	Vehicle Operator 1	Step 9) Moves to the lane to the left.
Post-Conditions	• Vehicle Operator 1 must visually identify vehicle in blind spot and react accordingly, similar to current operations, or if Vehicle Operator 2 had a non-CV-equipped vehicle in its blind spot.	• Vehicle Operator 2 does not benefit from alerts or warnings that would have been issued under normal operating conditions.
Policies and Business Rules	Columbus 2131.08 – Driving within lanes or continuous lines of traffic. Columbus 2131.14 – Signals before changing course, turning, or stopping.	ORC – 4511.27 – Overtaking and passing of vehicles proceeding in the same direction. ORC – 4511.27 – Turn and stop signals.
Traceability	None	
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: BSM from remote OBU. GNSS: Time and location data.	

Use Case	Lane Change Warning/Blind Spot Warning
Scenario ID and Title	*UC4-S3: Failure Condition – Diminished Communications*
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions.

1997 *Source: City of Columbus*

1998 **Table 36: Use Case 4 – Scenario 4: Failure Condition – Deficient OBU Data Quality**

Use Case	Lane Change Warning/Blind Spot Warning	
Scenario ID and Title	*UC4-S4: Failure Condition – Deficient OBU Data Quality*	
Scenario Objective	• Demonstrate application fails to provide proper output in a safety-critical situation.	• Demonstrate application fails to provide timely output in a safety-critical situation.

Operational Event(s)	• Two vehicles are following each other in a single file in the left lane on a two-lane roadway. Vehicle Operator 1: leading vehicle; Vehicle Operator 4: first following vehicle;
	• Two vehicles are following each other in a single file in the right lane on a two-lane roadway. Vehicle Operator 2: leading vehicle; Vehicle Operator 3: first following vehicle;
	• The vehicle driven by Vehicle Operator 1 is broadcasting BSMs.
		• Alerts and/or warnings are not issued in safety-critical situations (false positive) or are issued when not warranted (false negative).
		  ○ Safety data (position, speed, acceleration) received from remote OBU is inaccurate.
		  ○ Data received from GNSS and/or motion sensors (position, speed, acceleration) is inaccurate.
		• Safety-critical alerts and/or warnings are not issued in a timely manner.
		  ○ Host and remote OBUs are not synchronized.
		  ○ Host OBU exhibits delayed processing of safety-critical information due to other ongoing processes.

Actor(s)	Actor	Role
	Vehicle Operator 1 (remote)	Maintain safe operation of vehicle while on a multi-lane roadway.
	Vehicle Operator 2 (host)	Safely merge into the left lane.
	Vehicle Operator 3 (host)	Safely merge into the left lane.
	Vehicle Operator 4 (host)	Maintain safe operation of vehicle while on a multi-lane roadway.

Use Case	**Lane Change Warning/Blind Spot Warning**	
Scenario ID and Title	*UC4-S4: Failure Condition – Deficient OBU Data Quality*	
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 2	Step 1) Is driving at a constant speed in the right-most lane.
	Vehicle Operator 1	Step 2) Is driving at a constant, faster speed in the second right-most lane.
	Vehicle Operator 1	Step 3) Begins to overtake Vehicle Operator 2.
	Vehicle 1 OBU	Step 4) Broadcasts a BSM containing a data element that indicates the location and direction of Vehicle 1.
	Vehicle 2 OBU	Step 5) Receives the BSM, processes it, and determines that a warning should be issued, but the warning is late. [Due to time synchronization issues or limited processing resources on either OBU on Vehicle 1 or Vehicle 2.]
	Vehicle Operator 2	Step 6) Receives a Blind Spot warning. [Later than under normal operating conditions.]
	Vehicle Operator 2	Step 7) Notices that Vehicle Operator 1 is in the blind spot and allows Vehicle Operator 1 to pass before changing lanes. [Warning may be received after Vehicle 1 has passed through the blind spot of Vehicle Operator 2.]
	Vehicle Operator 1	Step 8) Begins to overtake Vehicle Operator 3.
	General	Step 9) The vehicle operated by Vehicle Operator 3 receives the BSM, processes it, and falsely determines that a warning should not be issued. [Vehicle 3 location and motion data obtained via GPS is inaccurate.]
	Vehicle Operator 3	Step 10) Notices that Vehicle Operator 1 is in the blind spot and allows Vehicle Operator 1 to pass before changing lanes. [(false negative).]

Use Case	**Lane Change Warning/Blind Spot Warning**	
Scenario ID and Title	*UC4-S4: Failure Condition – Deficient OBU Data Quality*	
	General	Step 11) The vehicle operated by Vehicle Operator 4 receives the BSM, processes it, and falsely determines that a warning should be issued. [Vehicle 3 location and motion data obtained via GPS is inaccurate. It improperly positions Vehicle 4 in the blind spot of Vehicle 1.]
	Vehicle Operator 4	Step 12) Receives a blind spot warning and assesses their blind spot. [Increases alertness of Vehicle Operator 4, but no in the blind spot are noted (false positive warning).]
Post-Conditions	• System outputs warning late, reducing vehicle operator reaction time (Vehicle Operator 2). • System does not detect alert or warning condition when condition actually exists (Vehicle Operator 3). • System detects alert or warning condition when condition does not actually exist (Vehicle Operator 4).	• Corrective actions could be taken when not necessary (Vehicle Operator 4). • Vehicle operators must visually identify various conditions and react accordingly, similar to current operations. • Vehicle Operators may lose trust in the system.
Policies and Business Rules	Columbus 2131.08 – Driving within lanes or continuous lines of traffic. Columbus 2131.14 – Signals before changing course, turning, or stopping.	ORC – 4511.27 – Overtaking and passing of vehicles proceeding in the same direction. ORC – 4511.27 – Turn and stop signals.
Traceability	*None*	
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU alert and OBU warning set at time of configuration. Human Inputs: None. CV Data: Safety data from remote OBU (inaccurate or latent). GNSS: Location and motion data (inaccurate).	
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions (false positive). None (false negative).	

1999 *Source: City of Columbus*

Use Case 5: Traffic Signal Priority/Preemption

This use case contains scenarios associated with the Traffic Signal Priority/Preemption Application. **Figure 12: Traffic Signal Priority/Preemption Diagram** provides a context diagram for all scenarios associated with this use case. Scenarios for this use case are listed below and are described in detail in tables following the context diagram. Transit Signal Priority, Emergency Vehicle Preemption, and Freight Vehicle Priority have a TRL-H of 6 and are expected to be ready for deployment. Intent to Platoon Priority has a TRL-H of 4, and further research is needed to determine the feasibility of deploying this application in the CVE**. Appendix G, Roadside Equipment Locations** indicates which priority/preempt requests will be accommodated at each intersection.

- **Table 37: Use Case 5 – Scenario 1: Normal Operating Conditions – Emergency Vehicle Preempt**
- **Table 38: Use Case 5 – Scenario 2: Normal Operating Conditions – Freight Signal Priority/Intent to Platoon Priority**
- **Table 39: Use Case 5 – Scenario 3: Normal Operating Conditions – Transit Signal Priority**
- **Table 40: Use Case 5 – Scenario 4: Normal Operating Conditions – Multiple Priority/Preemption Requests**
- **Table 41: Use Case 5 – Scenario 5: Degraded Condition – Platoon Dissolution at Signal**
- **Table 42: Use Case 5 – Scenario 6: Degraded Condition – Diminished Communications**

Table 37: Use Case 5 – Scenario 1: Normal Operating Conditions – Emergency Vehicle Preempt

Use Case	**Traffic Signal Priority/Preemption**	
Scenario ID and Title	*UC5-S1: Normal Operating Conditions – Emergency Vehicle Preempt*	
Scenario Objective	• Provide safe and efficient movement through intersections for emergency vehicles actively responding to an emergency situation.	
Operational Event(s)	• Emergency vehicle operator activates lights and siren, and the emergency vehicle sends signal priority requests to approaching intersections.	
Actor(s)	Actor	Role
	Emergency Vehicle Operator	Quickly and safely traverse an intersection to improve mobility while responding to an emergency.
	Source	Key Action [Comments]

Use Case	**Traffic Signal Priority/Preemption**	
Scenario ID and Title	*UC5-S1: Normal Operating Conditions – Emergency Vehicle Preempt*	
Key Actions and Flow of Events	Emergency Vehicle Operator	Step 1) Approaches an intersection. [Lights and sirens activated.]
	Emergency Vehicle OBU	Step 2) Broadcasts a SRM containing data elements that indicate the requested approach.
	RSU	Step 3) Receives the SRM and processes it.
	Message Handler/ Processor	Step 4) Determines if signal priority request can be accommodated. [May forward priority request to TMC, which would provide a response if the priority request should be granted.]
	RSU	Step 5) Broadcasts SSM containing data elements that indicate if the request was accepted and the priority order. [Indicates that the signal priority request has been accepted.]
	Emergency Vehicle OBU	Step 6) Receives the SSM and processes it.
	TSC	Step 7) Services the approach taken by the emergency vehicle.
	General	Step 8) Queue at intersection dissipates. [On the emergency vehicle approach.]
	Emergency Vehicle Operator	Step 9) Proceeds through intersection. [On green indication.]
	TSC	Step 10) Resumes normal intersection operations.
Post-Conditions	• Emergency Vehicle Operator experiences improved mobility at the intersection.	• Emergency Vehicle Operator is able to provide improved emergency response service.
Policies and Business Rules	Columbus 2131.20 – Emergency or public safety vehicles at stop signals or signs. ORC 4511.041 – Exceptions to traffic rules for emergency or public safety vehicle responding to emergency call.	System will necessitate first come/first serve for preemption, as no driver interface is expected to provide indications of preempt status.
Traceability	CVE-UN220-v02 – Emergency Vehicle Intersection Priority	

Use Case	Traffic Signal Priority/Preemption	
Scenario ID and Title	*UC5-S1: Normal Operating Conditions*	*– Emergency Vehicle Preempt*
Inputs Summary	**Emergency Vehicle OBU:** System Initialization Input: Emergency vehicle OBU signal status notification, and priority level assessment algorithm set at time of configuration. Human Inputs: Emergency vehicle operator activates lights/siren. CV Data: SPAT and MAP data from roadside, signal status message. GNSS: Time and location data.	**TSC:** System Initialization Input: Signal timing adjustment algorithm set at time of configuration or remote updated by TMC. **RSU:** CV Data: Signal Priority request from emergency vehicle OBU.
Output Summary	**Emergency Vehicle OBU:** CV Data: Signal Priority Request message.	**RSU:** CV Data: SPAT, MAP, signal status message.

Source: City of Columbus

Table 38: Use Case 5 – Scenario 2: Normal Operating Conditions – Freight Signal Priority/Intent to Platoon Priority

Use Case	Traffic Signal Priority/Preemption	
Scenario ID and Title	*UC5-S2: Normal Operating Conditions*	*– Freight Signal Priority/Intent to Platoon Priority*
Scenario Objective	• Provide safe and efficient movement through intersections for freight vehicles.	• Allow freight vehicle platoons to remain contiguous through an intersection.
Operational Event(s)	• The freight vehicle(s) sends signal priority requests to approaching intersections. • System determines if normal freight signal priority request or if there is an intent to platoon. • A Freight Vehicle Operator is immediately followed by another freight vehicle (that it will platoon with at a downstream location) and is approaching a signalized intersection.	• The system provides the capability to lengthen the green cycle so that two trucks following each other on an arterial route can stay together through a signalized intersection so that they may form a platoon at a downstream location.
	Actor	Role

Use Case	**Traffic Signal Priority/Preemption**	
Scenario ID and Title	*UC5-S2: Normal Operating Conditions*	*– Freight Signal Priority/Intent to Platoon Priority*
Actor(s)	Freight Vehicle Operator	Quickly and safely traverse an intersection to improve mobility, allow proceeding freight vehicle to maintain following distance through intersection (to later form platoon with that freight vehicle, if applicable).
Key Actions and Flow of Events	Source	Key Action [Comments]
	Freight Vehicle Operator	Step 1) Approaches an intersection. [Could be intending to platoon through intersection.]
	Freight Vehicle OBU	Step 2) Determines if it will be forming a platoon with the preceding freight vehicle, and platoon characteristics. [Data obtained though interface with in-vehicle platooning system deployed as part of DATP project.]
	Freight Vehicle OBU	Step 3) Broadcasts a SRM containing data elements that indicate the requested approach. [Request signal priority. If platooning is intended, priority is requested over a longer duration (based on location, speed, and acceleration profile of all vehicles that intend to platoon).]
	RSU	Step 4) Receives the SRM and processes it.
	Message Handler/ Processor	Step 5) Determines if signal priority request can be accommodated. [May forward priority request to TMC, which would provide a response if the priority request should be granted.]
	RSU	Step 6) Broadcasts SSM containing data elements that indicate if the request was accepted and the priority order. [Indicates that the signal priority request has been accepted.]
	Freight Vehicle OBU	Step 7) Receives the SSM and processes it.
	TSC	Step 8a) Green phase on approach is called early. [On the freight vehicle approach.]
	TSC	Step 8b) Green phase on approach is extended. [On the freight vehicle approach.]
	Freight Vehicle Operator	Step 9) Proceeds through intersection. [On green indication.]

Use Case	Traffic Signal Priority/Preemption	
Scenario ID and Title	*UC5-S2: Normal Operating Conditions*	*– Freight Signal Priority/Intent to Platoon Priority*
	Freight Vehicle Operator	Step 10) Clears intersection. [Single freight vehicle, or multiple freight vehicles if intending to platoon.]
	TSC	Step 11) Resumes normal intersection operations.
Post-Conditions	• Freight Vehicle Operator experiences improved mobility at the intersection.	• Multiple fright vehicles are able to maintain contiguity (to later form a platoon, if applicable).
Policies and Business Rules	Columbus 2113.01 – Obedience to traffic control devices. Columbus 2113.03 – Traffic control signal terms and lights. Columbus 2113.04 – Signal to control lane direction of travel.	ORC 4511.12 – Obedience to traffic control devices. ORC 4511.13 – Highway traffic signal indications; section not applicable of railroad crossings.
Traceability	CVE-UN310-v02 – Heavy-Duty Vehicle Intersection Priority	CVE-UN320-v02 – Freight Signal Priority with Platoon Intent
Inputs Summary	**Heavy-Duty Vehicle OBU:** System Initialization Input: Heavy-duty vehicle OBU signal status notification and priority level assessment algorithm set at time of configuration. Human Inputs: None. CV Data: SPAT and MAP data from RSU, signal status message. GNSS: Time and location data.	**TSC:** System Initialization Input: Signal timing adjustment algorithm set at time of configuration or remote updated by TMC. **RSU:** CV Data: Signal Priority request from heavy-duty vehicle OBU. ITS Data: Signal state data.
Output Summary	**Heavy-Duty Vehicle OBU:** CV Data: Signal Priority Request message.	**RSU:** CV Data: SPAT, MAP, Signal Status Message.

Source: City of Columbus

Table 39: Use Case 5 – Scenario 3: Normal Operating Conditions – Transit Signal Priority

Use Case	Traffic Signal Priority/Preemption	
Scenario ID and Title	*UC5-S3: Normal Operating Conditions*	*– Transit Signal Priority*
Scenario Objective	• Provide safe and efficient movement through intersections for transit vehicles that may be falling behind schedule.	

Use Case	Traffic Signal Priority/Preemption	
Scenario ID and Title	*UC5-S3: Normal Operating Conditions – Transit Signal Priority*	
Operational Event(s)	• The transit vehicle sends signal priority requests to approaching intersections.	
Actor(s)	Actor	Role
	Transit Vehicle Operator	Quickly and safely traverse an intersection to improve mobility.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Transit Vehicle Operator	Step 1) Approaches an intersection.
	Transit Vehicle OBU	Step 2) Broadcasts a SRM containing data elements that indicate the requested approach.
	RSU	Step 3) Receives the SRM and processes it.
	Message Handler/ Processor	Step 4) Determines if signal priority request can be accommodated. [May forward priority request to TMC or be determined at the TSC which would provide a response if the priority request should be granted. Priority will be granted based on agreement between COTA and DPS.]
	RSU	Step 5) Broadcasts SSM containing data elements that indicate if the request was accepted and the priority order. [Indicates that the signal priority request has been accepted.]
	Transit Vehicle OBU	Step 6) Receives the SSM and processes it.
	TSC	Step 7a) Green phase on approach is called early. [On the transit vehicle approach.]
	TSC	Step 7b) Green phase on approach is extended. [On the transit vehicle approach.]
	Transit Vehicle Operator	Step 8) Proceeds through intersection. [On green indication.]
	TSC	Step 9) Resumes normal intersection operations.
Post-Conditions	• Transit Vehicle Operator experiences improved mobility at the intersection.	• Transit Vehicle Operator gets route back on schedule.

Use Case	Traffic Signal Priority/Preemption	
Scenario ID and Title	*UC5-S3: Normal Operating Conditions*	*– Transit Signal Priority*
Policies and Business Rules	Columbus 2113.01 – Obedience to traffic control devices. Columbus 2113.03 – Traffic control signal terms and lights. Columbus 2113.04 – Signal to control lane direction of travel.	ORC 4511.12 – Obedience to traffic control devices. ORC 4511.13 – Highway traffic signal indications; section not applicable of railroad crossings.
Traceability	CVE-UN510-v02 – Service Management	CVE-UN520-v02 – On-Schedule Status
Inputs Summary	**Transit Vehicle OBU:** System Initialization Input: Transit Vehicle OBU signal status notification and priority level assessment algorithm set at time of configuration. Human Inputs: None. CV Data: SPAT and MAP data from RSU, signal status message. GNSSL Time and location data. Existing Transit Vehicle System: On-Time status.	**TSC:** System Initialization Input: Signal timing adjustment algorithm set at time of configuration or remote updated by TMC. **RSU:** CV Data: Signal Priority Request from Transit Vehicle OBU. ITS Data: Signal state data.
Output Summary	**Transit Vehicle OBU:** CV Data: Signal Priority Request message.	**RSU:** CV Data: SPAT, MAP, Signal Status Message.

Source: City of Columbus

Table 40: Use Case 5 – Scenario 4: Normal Operating Conditions – Multiple Priority/Preemption Requests

Use Case	Traffic Signal Priority/Preemption	
Scenario ID and Title	*UC5-S4: Normal Operating Conditions*	*– Multiple Priority/Preemption Requests*
Scenario Objective	• Intersection is able to arbitrate and service multiple priority requests.	
Operational Event(s)	• Multiple signal priority requests are received from conflicting approaches. • The TSC arbitrates between priority messages.	• Priority requests are served in priority order as determined by arbitration. • This scenario focuses on an emergency vehicle and a transit vehicle, but it could happen between any two vehicles requesting signal priority.
	Actor	Role

Use Case	**Traffic Signal Priority/Preemption**	
Scenario ID and Title	*UC5-S4: Normal Operating Conditions – Multiple Priority/Preemption Requests*	
Actor(s)	Emergency Vehicle Operator	Quickly and safely traverse an intersection to improve mobility while responding to an emergency.
	Transit Vehicle Operator	Quickly and safely traverse an intersection to improve mobility.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Emergency Vehicle Operator	Step 1) Approaches an intersection.
	Emergency Vehicle OBU	Step 2) Broadcasts a SRM containing data elements that indicate the requested approach. [Request signal preemption.]
	RSU	Step 3) Receives the SRM and processes it.
	Transit Vehicle Operator	Step 4) Approaches an intersection.
	Transit Vehicle OBU	Step 5) Broadcasts a SRM containing data elements that indicate the requested approach. [Request signal priority.]
	RSU	Step 6) Receives the SRM and processes it.
	Message Handler/ Processor	Step 7) Prioritizes the requests and assigns levels of priority. [May forward priority requests to TMC or processed at the TSC, which would provide a response if the priority request should be granted. Determines emergency vehicle has highest priority.]
	Message Handler/ Processor	Step 8) Determines if signal priority requests can be accommodated.
	RSU	Step 9) Broadcasts SSM containing data elements that indicate if the request was accepted and the priority order. [Indicates that the signal priority request has been accepted for the emergency vehicle, and that the signal priority request has been accepted but delayed for the transit vehicle.]
	Emergency Vehicle OBU	Step 10) Receives the SSM and processes it.
	Transit Vehicle OBU	Step 11) Receives the SSM and processes it.
	TSC	Step 12) Services the approach taken by the Emergency Vehicle Operator.

Use Case	**Traffic Signal Priority/Preemption**	
Scenario ID and Title	*UC5-S4: Normal Operating Conditions – Multiple Priority/Preemption Requests*	
	General	Step 13) Queue at intersection dissipates. [On the emergency vehicle approach.]
	Emergency Vehicle Operator	Step 14) Proceeds through intersection. [On green indication.]
	TSC	Step 15) Resumes intersection operations.
	TSC	Step 16) Cycles through phases to service transit vehicle approach as quickly as possible.
	Transit Vehicle Operator	Step 17) Proceeds through intersection. [On green indication.]
	TSC	Step 18) Resumes normal intersection operations.
Post-Conditions	• TSC properly arbitrates between competing signal priority requests.	• All users experience improved mobility compared to current operations.
Policies and Business Rules	Columbus 2113.01 – Obedience to traffic control devices. Columbus 2113.03 – Traffic control signal terms and lights. Columbus 2113.04 – Signal to control lane direction of travel. Columbus 2131.20 – Emergency or public safety vehicles at stop signals or signs.	ORC 4511.041 – Exceptions to traffic rules for emergency or public safety vehicle responding to emergency call. ORC 4511.12 – Obedience to traffic control devices. ORC 4511.13 – Highway traffic signal indications; section not applicable of railroad crossings.
Traceability	CVE-UN220-v02 – Emergency Vehicle Intersection Priority CVE-UN310-v02 – Heavy-Duty Vehicle Intersection Priority	CVE-UN320-v02 – Freight Signal Priority with Platoon Intent CVE-UN510-v02 – Service Management CVE-UN520-v02 – On-Schedule Status
Inputs Summary	**Emergency, Heavy-Duty, Transit Vehicle OBU:** System Initialization Input: Vehicle OBU signal status notification and priority level assessment algorithm set at time of configuration. Human Inputs: Emergency vehicle operator activates lights/siren. CV Data: SPAT and MAP data from RSU, signal status message. GNSS: Time and location data.	**TSC:** System Initialization Input: Signal timing adjustment algorithm set at time of configuration or remote updated by TMC. **RSU:** CV Data: Signal Priority Request from vehicle OBU. ITS Data: Signal state data.

Use Case	Traffic Signal Priority/Preemption	
Scenario ID and Title	*UC5-S4: Normal Operating Conditions – Multiple Priority/Preemption Requests*	
Output Summary	**Emergency, Heavy-Duty, Transit Vehicle OBU:** CV Data: Signal Priority Request message.	**RSU:** CV Data: SPAT, MAP, Signal Status Message.

2029 *Source: City of Columbus*

2030 **Table 41: Use Case 5 – Scenario 5: Degraded Condition – Platoon Dissolution at Signal**

Use Case	Traffic Signal Priority/Preemption	
Scenario ID and Title	*UC5-S5: Degraded Condition – Platoon Dissolution at Signal*	
Scenario Objective	• Provide safe and efficient movement through intersections for freight vehicles.	• Allow freight vehicle platoons to remain contiguous through an intersection.
Operational Event(s)	• The freight vehicle sends signal priority requests to approaching intersections. • System determines if normal freight signal priority request or if there is an intent to platoon.	• Freight Vehicle Operator 1 is immediately followed by Freight Vehicle Operator 2 (that it will platoon with at a downstream location) and is approaching a signalized intersection. • The system is not able to accommodate priority and the two Freight Vehicle Operators are temporarily separated.
Actor(s)	Actor	Role
	Freight Vehicle Operator 1	Quickly and safely traverse an intersection to improve mobility, allow proceeding freight vehicle to maintain following distance through intersection (to later form platoon with that freight vehicle
	Freight Vehicle Operator 2	Continue to follow preceding freight vehicle through intersection (to later form platoon with Freight Vehicle 1).
Key Actions and Flow of Events	Source	Key Action [Comments]
	Freight Vehicle Operator	Step 1) Approaches an intersection. [Could be intending to platoon.]
	Freight Vehicle 1 OBU	Step 2) Determines if it will be forming a platoon with the preceding freight vehicle, and platoon characteristics. [Data obtained though interface with in-vehicle platooning system deployed as part of DATP project.]

Use Case	**Traffic Signal Priority/Preemption**	
Scenario ID and Title	*UC5-S5: Degraded Condition –*	*Platoon Dissolution at Signal*
	Freight Vehicle 1 OBU	Step 3) Broadcasts a SRM containing data elements that indicate the requested approach. [Requests priority over a longer duration to accommodate platoon (based on platoon location, speed, and acceleration profile).]
	RSU	Step 4) Receives the SRM and processes it.
	Message Handler/ Processor	Step 5) Determines if signal priority request can be accommodated. [May forward priority request to TMC, which would provide a response if the priority request should be granted.]
	RSU	Step 6) Broadcasts SSM containing data elements that indicate if the request was accepted and the priority order. [Indicates that the signal priority request has been denied.]
	Freight Vehicle 1 OBU	Step 7) Receives the SSM and processes it.
	Freight Vehicle Operator 1	Step 8a) Preemptively slows down and comes to a stop at the intersection to maintain the platoon. [On green indication.]
	Freight Vehicle Operator 1	Step 8b) Is not able to stop in a safe manner, and proceeds through intersection. [On yellow indication.]
	Freight Vehicle Operator 2	Step 9) Cannot continue toward the intersection without risking running a red light, begins to decrease speed. [Freight Vehicle 1 and Freight Vehicle 2 become separated.]
	TSC	Step 10) Turns from yellow to red. [On the freight vehicle approach.]
	Freight Vehicle Operator 2	Step 11) Comes to a stop at the intersection. [On red indication.]
	Freight Vehicle Operator 1	Step 12a) May stop/pull over to wait for following vehicles to clear the intersection. [In a receiving lane to re-form a platoon once following vehicles have cleared intersection.]
	Freight Vehicle Operator 1	Step 12b) Continues along route. [With no intention of re-forming the platoon.]

Use Case	**Traffic Signal Priority/Preemption**	
Scenario ID and Title	*UC5-S5: Degraded Condition –*	*Platoon Dissolution at Signal*
	Freight Vehicle Operator 2	Step 13) Proceeds through intersection. [When the signal turns green again.]
	Freight Vehicle Operator 2	Step 14) Attempts to reform the platoon with the previous platoon leader. [If follower is able to catch up to previous platoon leader, platoon re-forms according to scenario outlined in DATP Trade Study.]
Post-Conditions	• Freight Vehicle Platoon does not experience improved mobility at the intersection.	• Contiguity of the platoon is not maintained and must be re-formed once all platooning vehicles have traversed the intersection.
Policies and Business Rules	Columbus 2113.01 – Obedience to traffic control devices. Columbus 2113.03 – Traffic control signal terms and lights. Columbus 2113.04 – Signal to control lane direction of travel.	ORC 4511.12 – Obedience to traffic control devices. ORC 4511.13 – Highway traffic signal indications; section not applicable of railroad crossings.
Traceability	CVE-UN310-v02 – Heavy-Duty Vehicle Intersection Priority	CVE-UN320-v02 – Freight Signal Priority with Platoon Intent
Inputs Summary	**Heavy-Duty Vehicle OBU:** System Initialization Input: Heavy-duty vehicle OBU signal status notification and priority level assessment algorithm set at time of configuration. Human Inputs: None. CV Data: SPAT and MAP data from RSU, signal status message. GNSS: Time and location data.	**TSC:** System Initialization Input: Signal timing adjustment algorithm set at time of configuration or remote updated by TMC. **RSU:** CV Data: Signal Priority Request from heavy-duty vehicle OBU. ITS Data: Signal state data.
Output Summary	**Heavy-Duty Vehicle OBU:** CV Data: Signal Priority Request message. Signal Status Notification audio/visual output from heavy-duty OBU to freight vehicle operator.	**RSU:** CV Data: SPAT, MAP, Signal Status Message.

Source: City of Columbus

Table 42: Use Case 5 – Scenario 6: Degraded Condition – Diminished Communications

Use Case	**Traffic Signal Priority/Preemption**	
Scenario ID and Title	*UC5-S6: Degraded Condition – Diminished Communications*	
Scenario Objective	• Provide safe and efficient movement through intersections for emergency vehicles actively responding to an emergency situation.	
Operational Event(s)	• Emergency vehicle operator activates lights and siren, and the emergency vehicle sends signal priority requests to approaching intersections. • Intersection does not receive signal priority request because of RSU malfunction.	• This scenario focuses on an emergency vehicle, but it could apply to any vehicle requesting signal priority.
Actor(s)	Actor	Role
	Emergency Vehicle Operator	Quickly and safely traverse an intersection to improve mobility while responding to an emergency.
	Network Manager	Diagnose and repair connectivity issue
Key Actions and Flow of Events	Source	Key Action [Comments]
	Emergency Vehicle Operator	Step 1) Approaches an intersection.
	Emergency Vehicle OBU	Step 2) Broadcasts a SRM containing data elements that indicate the requested approach.
	RSU	Step 3) Is not able to receive messages. [Does not respond with message indicating priority status accepted or denied.]
	Emergency Vehicle Operator	Step 4) Navigates through queued vehicles. [Queued vehicles pull over or pull into intersection to make room for the emergency vehicle to proceed. The emergency vehicle may also use the opposing lanes to pass queued vehicles, if safe.]
	Emergency Vehicle Operator	Step 5) Proceeds through intersection. [Proceeds normally if approaching on a green indication. Proceeds after making sure all opposing traffic has stopped on if approaching on a red indication.]
	TSC	Step 6) Continues normal intersection operations

Use Case	**Traffic Signal Priority/Preemption**	
Scenario ID and Title	*UC5-S6: Degraded Condition –*	*Diminished Communications*
	Network Manager	Step 7) Receives notification regarding connectivity issue. [If infrastructure connectivity is the source of the diminished communications.]
	Network Manager	Step 8) Diagnoses and repairs connectivity issue
Post-Conditions	• Emergency Vehicle Operator navigates through intersection traffic, and negotiates safe passage through the intersection, similar to current conditions.	
Policies and Business Rules		
Traceability	CVE-UN220-v02 – Emergency Vehicle Intersection Priority CVE-UN310-v02 – Heavy-Duty Vehicle Intersection Priority CVE-UN320-v02 – Freight Signal Priority with Platoon Intent	CVE-UN510-v02 – Service Management CVE-UN520-v02 – On-Schedule Status CVE-UN710-v02 – Maintain Connectivity
Inputs Summary	**Emergency Vehicle OBU:** System Initialization Input: Emergency vehicle OBU signal status notification and priority level assessment algorithm set at time of configuration. Human Inputs: Emergency vehicle operator activates lights/siren. CV Data*: ~~SPAT and MAP data from RSU, signal status message.~~ GNSS: Time and location data.	**TSC:** System Initialization Input: Signal timing adjustment algorithm set at time of configuration or remote updated by TMC. **RSU:** CV Data*: ~~Signal Priority Request from Emergency Vehicle OBU~~ ITS Data: Signal state data.
Output Summary	**Emergency Vehicle OBU:** CV Data*: ~~Signal Priority Request Message.~~ ~~Signal Status Notification audio/visual output from host OBU to Emergency vehicle operator.~~	**RSU:** CV Data*: ~~SPAT, MAP, Signal Status Message~~

**Strikethrough indicates data that would normally be available where there not a diminished or failed condition.*

Source: City of Columbus

Use Case 6: Vehicle Data for Traffic Operations

This use case contains scenarios associated with the Vehicle Data for Traffic Operations Application. **Figure 13: Vehicle Data for Traffic Operations Diagram** provides a context diagram for all scenarios associated with this use case. Scenarios for this use case are listed below and are described in detail in tables following the context diagram.

- **Table 43: Use Case 6 – Scenario 1: Normal Operating Conditions – Collect and Store Operations Data**
- **Table 44: Use Case 6 – Scenario 2: Degraded Condition – Diminished Communications**

Table 43: Use Case 6 – Scenario 1: Normal Operating Conditions – Collect and Store Operations Data

Use Case	**Vehicle Data for Traffic Operations**	
Scenario ID and Title	*UC6-S1: Normal Operating Conditions – Collect and Store Operations Data*	
Scenario Objective	• Archive operations data on the Operating System.	
Operational Event(s)	• Data received by the RSU and data captured from roadside ITS devices (TSC) are made available to the TMC via the Operating System.	• Removal of PII from data. • Archiving data in the Operating System.
Actor(s)	Actor	Role
	Traffic Manager	Use operations data to manage transportation network and status data to maintain equipment when necessary.
Key Actions and Flow of Events	Source	Key Action [Comments]
	OBU	Step 1) Broadcasts a message containing the vehicle's situation (location, speed, acceleration, axles, etc.) at a pre-defined interval.
	RSU	Step 2) Receives the vehicle's situation messages when the vehicle comes within range of a DSRC receiver.
	Message Handler/ Processor	Step 3) Forwards messages received to the Operating System. [Via Backhaul]
	Message Handler/ Processor	Step 4) Sends all data generated by roadside equipment (such as the TSC) to the Operating System. [Via Backhaul, also includes uptime status data.]

Use Case	**Vehicle Data for Traffic Operations**	
Scenario ID and Title	*UC6-S1: Normal Operating Conditions – Collect and Store Operations Data*	
	Operating System	Step 5) Aggregates and or filters situation messages received on roadside equipment. [To remove PII, if desired. This could also be performed by the Handler/Processor.]
	Traffic Manager	Step 6) Queries Operating System data to perform a number of transportation network management functions. [Could include adjusting traffic signal timing, crash detection, identifying malfunctioning equipment, etc.]
Post-Conditions	• Operations and status data are available on the Operating System for traffic management and system maintenance purposes.	
Policies and Business Rules	*Protecting PII (see Chapter 5: Concept for the New System, Protecting PII)*	*Privacy and Data Security (see Chapter 5: Concept for the New System, Privacy and Data Security)*
Traceability	CVE-UN410-v02 – Monitor Performance CVE-UN430-v02 – Configure and Monitor Roadside Devices	CVE-UN440-v02 – Data Archive Configuration
Inputs Summary	**RSU:** CV Data: BSM, Signal Priority Request message, from vehicle OBUs. **TSC:** ITS Data: signal state data from TSC. Status Data: TSC status data.	**Operating System:** Filtered CV and ITS data
Output Summary	**OBU:** CV Data: BSM, Signal Priority Request message.	**Handler/Processor:** All CV, ITS data, and status data (to TMC).

Source: City of Columbus

2047 **Table 44: Use Case 6 – Scenario 2: Degraded Condition – Diminished Communications**

Use Case	**Vehicle Data for Traffic Operations**	
Scenario ID and Title	*UC6-S2: Degraded Condition – Diminished Communications*	
Scenario Objective	• Demonstrate that operations data can be archived on Operating System despite diminished communications between the equipment on the roadside and Operating System.	
Operational Event(s)	• Temporary archiving of data on Handler/Processor and transmission of data once connectivity is established.	• This scenario replaces steps 2-3 in the Use Case 6 – Scenario 1.
Actor(s)	Actor	Role
	Traffic Manager	Use operations data to manage transportation network and status data to maintain equipment when necessary.
	Network Manager	Diagnose and repair connectivity issue
Key Actions and Flow of Events	Source	Key Action [Comments]
	Message Handler/ Processor	Step 1) Unsuccessfully attempts to report various operations and data to the Operating System at predefined (e.g. 5-min) intervals. [Operations data could be periodically pushed or pulled from the Handler/Processor to the Operating System.]
	Message Handler/ Processor	Step 2) Archives operations and data. [While data cannot be transferred from Handler/Processor to the Operating System.]
	Traffic Manager	Step 3) Executes an application that tests and archives Operating System-Roadside connectivity at predefined (e.g. 5-min) intervals.
	Application	Step 4) Alerts traffic manager and archives records of roadside equipment that cannot be accessed.
	Traffic Manager	Step 5a) Dispatches maintenance technician to restore connectivity.
	Network Manager	Step 5b) Remotely diagnoses and repairs Operating System-Roadside connectivity.

Use Case	Vehicle Data for Traffic Operations	
Scenario ID and Title	*UC6-S2: Degraded Condition –*	*Diminished Communications*
	General	Step 6) Operating System-Roadside connectivity is restored.
	Message Handler/ Processor	Step 7) Reports archived operations data to the Operating System.
	General	Step 8) Normal operating conditions resume.
Post-Conditions	• CVE status data and operations data is not available on the Operating System during times when there is no connectivity between Handler/Processer (roadside equipment) and the Operating System.	• CVE status data and operations data (temporarily archived by Handler/Processor during the loss of connectivity) becomes available on the Operating System shortly after connectivity has been reestablished.
Policies and Business Rules	*None.*	
Traceability	CVE-UN410-v02 – Monitor Performance CVE-UN430-v02 – Configure and Monitor Roadside Devices	CVE-UN440-v02 – Data Archive Configuration CVE-UN710-v02 – Maintain Connectivity
Inputs Summary	**RSU:** CV Data: BSM, Signal Priority Request message, from vehicle OBUs. **TSC:** ITS Data: signal state data from TSC. Status Data: TSC status data.	**Operating System:** Filtered CV and ITS data.
Output Summary	**OBU:** CV Data: BSM, Signal Priority Request message	**Handler/Processor:** All CV, ITS data, and status data (to TMC).

Source: City of Columbus

Use Case 7: Transit Vehicle Interaction Event Recording

This use case contains scenarios associated with the Transit Vehicle Interaction Capture Application. **Figure 14: Transit Vehicle Interaction Event Capture Diagram** provides a context diagram for all scenarios associated with this use case. Scenarios for this use case are listed below, and they are described in detail in tables following the context diagram. This application has a TRL-H of 7 and is considered deployment-ready.

- **Table 45: Use Case 7 – Scenario 1: Normal Operating Conditions**
- **Table 46: Use Case 7 – Scenario 2: Degraded Conditions – Diminished Communications**

Table 45: Use Case 7 – Scenario 1: Normal Operating Conditions

Use Case	**Transit Vehicle Interaction Event**	**Recording**
Scenario ID and Title	*UC7-S1: Normal Operating Conditions*	
Scenario Objective	• Make transit vehicle interaction data available to the Transit Manager via the Operating System.	
Operational Event(s)	• Data captured on the transit vehicle OBU are sent to the Transit Management Center.	• Removal of PII from data. • Archiving data in the Operating System.
Actor(s)	Actor	Role
	Transit Manager	Use transit vehicle interaction data to assess transit operations and manage transit system.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Other Vehicle OBU	Step 1) Broadcasts a message containing the vehicle's situation (location, speed, acceleration, axles, etc.) at a pre-defined interval.
	Transit Vehicle OBU	Step 2) Receives the vehicle's situation messages when the vehicle comes within range of the Other Vehicle OBU.
	Transit Vehicle OBU	Step 3) OBU-internal functions determine if an alert or warning would have been raised.
	Transit Vehicle OBU	Step 4) If indicated, forwards event log to the Operating System. [May leverage existing communications media available to the transit vehicle to send.]
	Operating System	Step 5) Captures data received from the Transit Vehicle OBU. [To remove PII, if desired. This could also be performed by the Handler/Processor.]
	Transit Manager	Step 6) Queries Operating System data to perform a number of transit management functions.
Post-Conditions	• Operations and status data are available on the Operating System for transit management purposes.	
Policies and Business Rules	*none*	
Traceability	CVE-UN530-v02 – Monitor Transit Vehicle Interactions	CVE-UN540-v02 – Transit Vehicle Operator CVE Output

Use Case	Transit Vehicle Interaction Event Recording	
Scenario ID and Title	*UC7-S1: Normal Operating Conditions*	
Inputs Summary	**Transit Vehicle OBU:** CV Data: SPaT, MAP, TIM, from RSUs; BSM from other vehicle OBUs. CV Data: GNSS: Time and location data.	**Operating System:** Transit Vehicle Telematics, BSM, SPaT, MAP, TIM, and Alert/Warning data.
Output Summary	**RSU:** CV Data: SPAT, MAP, TIM.	**OBU:** Transit Vehicle Telematics, BSM, SPaT, MAP, TIM, and Alert/Warning data.

Source: City of Columbus

Table 46: Use Case 7 – Scenario 2: Degraded Conditions – Diminished Communications

Use Case	Transit Vehicle Interaction Event Recording	
Scenario ID and Title	*UC7-S2: Degraded Operating Conditions – Diminished Communications*	
Scenario Objective	• Demonstrate that operations data can be archived on Operating System despite diminished communications between the Transit Vehicle OBU and the Operating System.	
Operational Event(s)	• Temporary retention of data on Transit Vehicle OBU and transmission of data after connectivity is established.	• This scenario replaces steps 3-4 in the Use Case 7 – Scenario 1.
Actor(s)	Actor	Role
	Transit Manager	Use transit vehicle interaction data to assess transit operations and manage transit system
	Network Manager	Diagnose and repair connectivity issue
	Source	Key Action [Comments]
	Transit Vehicle OBU	Step 1) Unsuccessful to report various event data to the Operating System. [Data could be periodically exchanged from the Transit Vehicle OBU to the Operating System.]

Use Case	Transit Vehicle Interaction Event	Recording
Scenario ID and Title	*UC7-S2: Degraded Operating*	*Conditions – Diminished Communications*
Key Actions and Flow of Events	Transit Vehicle OBU	Step 2) Retains operations and data. [While data cannot be transferred from Handler/Processor to the Operating System.]
	Transit Vehicle OBU	Step 3) Executes an application that retries Operating System-Transit Vehicle OBU connectivity at pre-defined (e.g. 5-min) intervals.
	Transit Vehicle OBU	Step 4) Alerts transit manager and archives records of roadside equipment that cannot be accessed.
Post-Conditions	• Operations and status data are not available on the Operating System during times when there is no connectivity between the Transit Vehicle OBU and the Operating System.	• Operations and status data (temporarily archived by the Transit Vehicle OBU during the loss of connectivity) becomes available on the Operating System shortly after connectivity has been reestablished.
Policies and Business Rules	*none*	
Traceability	CVE-UN530-v02 – Monitor Transit Vehicle Interactions CVE-UN540-v02 – Transit Vehicle Operator CVE Output	CVE-UN710-v02 – Maintain Connectivity
Inputs Summary	**Transit Vehicle OBU:** CV Data: SPaT, MAP, TIM, from RSUs; BSM from other vehicle OBUs. CV Data: GNSS: Time and location data.	**Operating System:** Transit Vehicle Telematics, BSM, SPaT, MAP, TIM, and Alert/Warning data.
Output Summary	**RSU:** CV Data: SPAT, MAP, TIM.	**OBU:** Transit Vehicle Telematics, BSM, SPaT, MAP, TIM, and Alert/Warning data.

Source: City of Columbus

Use Case 8: Red Light Violation Warning

This use case contains scenarios associated with the Red Light Violation Warning Application. **Figure 15: Red Light Violation Warning Diagram** provides a context diagram for all scenarios associated with this use case. Scenarios for this use case are listed below, and they are described in detail in tables following the context diagram. This application has a TRL-H of 7 and is considered deployment-ready.

- **Table 47: Use Case 8 – Scenario 1: Normal Operating Conditions – Approaching Yellow/Red Signal**
- **Table 48: Use Case 8 – Scenario 2: Failure Condition – Diminished Communications**
- **Table 49: Use Case 8 – Scenario 3: Failure Condition – Deficient OBU Data Quality**

Table 47: Use Case 8 – Scenario 1: Normal Operating Conditions – Approaching Yellow/Red Signal

Use Case	**Red Light Violation Warning**	
Scenario ID and Title	*UC8-S1: Normal Operating Conditions – Approaching Yellow/Red Signal*	
Scenario Objective	• Provide the vehicle operator with a warning when they must prepare to stop prior to a traffic signal.	
Operational Event(s)	• Intersection broadcasts SPAT and MAP data that are received by the vehicle.	• The vehicle receives the SPAT and MAP data, and – along with its location, position, and motion data – determines if a red-light running event is imminent.
Actor(s)	Actor	Role
	Vehicle Operator (host)	Safely come to a stop at a red signal indication. Proceed through intersection without running red light.
Key Actions and Flow of Events	Source	Key Action [Comments]
	General	Step 1) A vehicle approaches an intersection with a green signal indication.
	RSU	Step 2) Broadcasts SPaT and MAP message containing data elements that indicates intersection geometry and signal state information.
	Vehicle OBU	Step 3) Receives the SPaT and MAP messages, processes them, and determine that a warning should be issued. [Issuance of warning is based on data contained in the SPaT and MAP messages, as well as vehicle location and motion data obtained via GPS.]
	Vehicle Operator	Step 4) Receives a warning indicating the signal indication will turn yellow. [Prior to entering the dilemma zone.]
	Vehicle Operator	Step 5) Reacts to the warning by decelerating.
	General	Step 6) The signal indication turns yellow.
	General	Step 7) The signal indication turns red.

Use Case	Red Light Violation Warning	
Scenario ID and Title	*UC8-S1: Normal Operating Conditions*	*– Approaching Yellow/Red Signal*
	Vehicle Operator	Step 8) Comes to a stop at the stop bar. [At a normal rate of deceleration.]
Post-Conditions	• Vehicle Operator is more aware of signal state while approaching intersection.	• Vehicle Operator properly reacts to an in-vehicle warning.
Policies and Business Rules	Columbus 2113.01 – Obedience to traffic control devices. Columbus 2113.03 – Traffic control signal terms and lights. Columbus 2113.04 – Signal to control lane direction of travel.	ORC 4511.12 – Obedience to traffic control devices. ORC 4511.13 – Highway traffic signal indications; section not applicable of railroad crossings.
Traceability	CVE-UN130-v02 – Stop on Red Signal	
Inputs Summary	**OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: SPAT from RSU, MAP from RSU. GNSS: Time and location data.	
Output Summary	**RSU:** CV Data: SPAT, MAP.	**OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions.

2072 *Source: City of Columbus*

2073 **Table 48: Use Case 8 – Scenario 2: Failure Condition – Diminished Communications**

Use Case	Red Light Violation Warning	
Scenario ID and Title	*UC8-S2: Failure Conditions –*	*Diminished Communications*
Scenario Objective	• Demonstrate failure of application to provide a warning when the vehicle operator is in the dilemma zone.	
Operational Event(s)	• Warnings are not issued to prevent a dilemma zone issue.	• Vehicle operator does not take corrective actions resulting from the warnings.
	Actor	Role

Use Case	**Red Light Violation Warning**	
Scenario ID and Title	*UC8-S2: Failure Conditions –*	*Diminished Communications*
Actor(s)	Vehicle Operator (host)	Safely come to a stop at a red signal indication. Proceed through intersection without running red light.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator	Step 1) A vehicle approaches an intersection with a green signal indication.
	RSU	Step 2) Broadcasts SPaT and MAP message containing data element that indicates intersection geometry and signal state information
	Vehicle OBU	Step 3) Is not able to receive messages.
	Vehicle Operator	Step 4) Does not receive a warning indicating the signal will turn yellow. [Prior to entering the dilemma zone.]
	General	Step 5) The signal indication turns yellow. [In the dilemma zone.]
	General	Step 6) The signal indication turns red.
	Vehicle Operator	Step 7a) Comes to a stop at the stop bar. [At a hastened rate of deceleration.]
	Vehicle Operator	Step 7b) Decides to continue through the intersection with a red light indication.
Post-Conditions	• Vehicle Operator must identify safety-critical situation and react accordingly, similar to current operations. • Vehicle Operator may not make correct decision in dilemma zone, similar to current operations.	• Vehicle Operator does not benefit from alerts or warnings that would have been issued under normal operating conditions.
Policies and Business Rules	Columbus 2113.01 – Obedience to traffic control devices. Columbus 2113.03 – Traffic control signal terms and lights. Columbus 2113.04 – Signal to control lane direction of travel.	ORC 4511.12 – Obedience to traffic control devices. ORC 4511.13 – Highway traffic signal indications; section not applicable of railroad crossings.
Traceability	*None*	

Use Case	Red Light Violation Warning	
Scenario ID and Title	*UC8-S2: Failure Conditions –*	*Diminished Communications*
Inputs Summary	**OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data*: ~~SPAT from RSU, MAP from RSU,~~ GNSS: Time and location data.	
Output Summary	**RSU:** CV Data*: ~~SPAT~~, ~~MAP~~.	**OBU:** ~~Notification audio/visual output from host OBU to vehicle operator under certain conditions~~.*

**Strikethrough indicates data that would normally be available where there not a diminished or failed condition.*

Source: City of Columbus

Table 49: Use Case 8 – Scenario 3: Failure Condition – Deficient OBU Data Quality

Use Case	Red Light Violation Warning	
Scenario ID and Title	*UC8-S3: Failure Condition – Deficient*	*OBU Data Quality*
Scenario Objective	• Demonstrate application fails to provide proper output in a safety-critical situation.	• Demonstrate application fails to provide timely output in a safety-critical situation.

Use Case	**Red Light Violation Warning**	
Scenario ID and Title	*UC8-S3: Failure Condition – Deficient OBU Data Quality*	

Operational Event(s)	• Intersection broadcasts SPAT and MAP data.
	• Vehicle Operator 1 and Vehicle Operator 2 are approaching the intersection, side-by-side on a two-lane roadway. They are more than three seconds from passing through the intersection.
	• Vehicle Operator 3 is ahead of Vehicle Operators 1 and 2 and is less than three seconds from passing through the intersection.
	• The vehicles receives the SPAT and MAP data, and – along with location, position, and motion data and determines if a red-light running event is imminent.
	• Alerts and/or warnings are not issued in safety-critical situations (false positive).
		• Alerts and/or warnings are issued when not warranted (false negative).
		  o Safety data (position, speed, acceleration) received from remote OBU is inaccurate.
		  o Data received from GNSS and/or motion sensors (position, speed, acceleration) is inaccurate.
		• Safety-critical alerts and/or warnings are not issued in a timely manner.
		  o Host and remote OBUs are not synchronized.
		  o Host OBU exhibits delayed processing of safety-critical information due to other ongoing processes.

Actor(s)	Actor	Role
	Vehicle Operator 1 (host)	Safely come to a stop at a red signal indication. Proceed through intersection without running red light.
	Vehicle Operator 2 (host)	Safely come to a stop at a red signal indication. Proceed through intersection without running red light.
	Vehicle Operator 3 (host)	Safely come to a stop at a red signal indication. Proceed through intersection without running red light.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 1, Vehicle Operator 2, Vehicle Operator 3	Step 1) Approach an intersection with a green signal indication.
	RSU	Step 2) Broadcasts SPaT and MAP data containing data element that indicates intersection geometry and signal state information. [That indicates that the light will turn yellow and subsequently red in 3 seconds.]

Use Case	Red Light Violation Warning	
Scenario ID and Title	*UC8-S3: Failure Condition – Deficient OBU Data Quality*	
	Vehicle OBU	Step 3) Receives the SPaT and MAP data, processes it, and determines that a warning should be issued, but the warning is late. [Due to time synchronization issues or limited processing resources on either roadside equipment or the OBU on Vehicle 1.]
	Vehicle Operator 1	Step 4) Receives a Red Light Violation warning. [Later than under normal operating conditions.]
	Vehicle Operator 1	Step 5) Notices that light turns yellow and decelerates to stop before reaching the stop bar. [Cues may be visible (traffic signal) in nature. Warning may be received while performing braking maneuver.]
	General	Step 6) The vehicle operated by Vehicle Operator 2 receives the SPaT and MAP data, processes it, and falsely determines that a warning should not be issued. [Vehicle 2 location data obtained via GPS is indicates the vehicle is further ahead of its actual position.]
	Vehicle Operator 2	Step 7) Notices that light turns yellow and decelerates to stop before reaching the stop bar. [Cues may be visible (traffic signal) in nature. (false negative)]
	General	Step 8) The vehicle operated by Vehicle Operator 3 receives the SPaT and MAP data, processes it, and falsely determines that a warning should be issued. [Vehicle 3 location data obtained via GPS is indicates the vehicle is further behind of its actual position.]
	Vehicle Operator 3	Step 9a) Receives a Red Light Violation warning and must brake rapidly to stop before the stop bar. [May brake when braking is not necessary. This could have negative consequences for following vehicles. (false positive warning).]
	Vehicle Operator 3	Step 9b) Receives a Red Light Violation warning but continues at full speed through the intersection. [If Vehicle Operator 3 is close enough to the intersection while the signal is green.]

Use Case	Red Light Violation Warning
Scenario ID and Title	*UC8-S3: Failure Condition – Deficient OBU Data Quality*
Post-Conditions	• System outputs warning late, reducing vehicle operator reaction time (Vehicle Operator 1). • System does not detect alert or warning condition when condition actually exists (Vehicle Operator 2). • System detects alert or warning condition when condition does not actually exist (Vehicle Operator 3). • Corrective actions could be taken when not necessary (Vehicle Operator 3). • Vehicle operators must visually identify various conditions and react accordingly, similar to current operations. • Vehicle Operators may lose trust in the system.
Policies and Business Rules	Columbus 2113.01 – Obedience to traffic control devices. Columbus 2113.03 – Traffic control signal terms and lights. Columbus 2113.04 – Signal to control lane direction of travel. ORC 4511.12 – Obedience to traffic control devices. ORC 4511.13 – Highway traffic signal indications; section not applicable of railroad crossings.
Traceability	*None*
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU alert and OBU warning set at time of configuration. Human Inputs: None. CV Data: Safety data from remote OBU (inaccurate or latent). GNSS: Location and motion data (inaccurate).
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions (false positive). None (false negative).

Source: City of Columbus

Use Case 9: Reduced Speed School Zone

This use case contains scenarios associated with the Reduced Speed School Zone Light Application. **Figure 16: Reduced Speed School Zone Diagram** provides a context diagram for all scenarios associated with this use case. Scenarios for this use case are listed below and are described in detail in tables following the context diagram. This application has a TRL-H of 7 and is considered deployment-ready.

- **Table 50: Use Case 9 – Scenario 1: Normal Operating Conditions – During School Hours**

- **Table 51: Use Case 9 – Scenario 2: Normal Operating Conditions – Non-School Hours**
- **Table 52: Use Case 9 – Scenario 3: Degraded Condition – Diminished Communications**
- **Table 53: Use Case 9 – Scenario 4: Failure Condition – Deficient OBU Data Quality**

Table 50: Use Case 9 – Scenario 1: Normal Operating Conditions – During School Hours

Use Case	**Reduced Speed School Zone**	
Scenario ID and Title	*UC9-S1: Normal Operating Conditions – During School Hours*	
Scenario Objective	• Provide alert to vehicle operator when in excess of speed limit when approaching school zone.	
Operational Event(s)	• School zone broadcasts TIM data.	• The vehicle receives the TIM data, and – along with its location, position, and motion data – determines if the vehicle operator needs to decrease speed prior to entering or while in school zone.
Actor(s)	Actor	Role
	Vehicle Operator (host)	Safe and compliant operation of vehicle in school zone.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator	Step 1) Approaches a school zone during a time when the school zone is active.
	RSU	Step 2) Broadcasts TIM message containing data elements that indicates intersection geometry and signal state information.
	Vehicle OBU	Step 3) Receives the TIM, processes it, and determines that a warning should be issued. [Issuance of warning is based on data contained in the TIM message, as well as vehicle location and motion data obtained via GPS.]
	Vehicle Operator	Step 4) Receives an in-vehicle message that they are about to enter a school zone and the speed limit.
	Vehicle Operator	Step 5) Reduces the speed of the vehicle while the in-vehicle message continues to be displayed.
	Vehicle Operator	Step 6) Leaves the school zone. The original in-vehicle message ceases, and a message indicating the school zone has ended is displayed.

Use Case	**Reduced Speed School Zone**	
Scenario ID and Title	*UC9-S1: Normal Operating Conditions*	*– During School Hours*
	Vehicle Operator	Step 7) Continues at the nominal roadway speed.
Post-Conditions	• Vehicle Operator is more aware of speed while approaching school zone. • Vehicle Operator is more aware of speed while within school zone.	• Vehicle Operator properly reacts to an in-vehicle alert. • Vehicle Operator safely traverses school zone during active school zone hours.
Policies and Business Rules	Columbus 2133.03 – Maximum speed limits—Assured clear distance ahead—Reasonable for conditions—Per se violation.	ORC 4511.21 – Speed Limits – assured clear distance
Traceability	CVE-UN140-v02 – School Zone/Decrease Speed CVE-UN420-v02 – Update Static Messages	CVE-UN610-v02 – School Zone Pedestrian Safety
Inputs Summary	**Handler/Processor:** System Initialization Input: Active School Zone configuration set at time of configuration or remote updated by TMC.	**OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: TIM from RSU. GNSS: Time and location data.
Output Summary	**RSU:** CV Data: TIM.	**OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions.

Source: City of Columbus

Table 51: Use Case 9 – Scenario 2: Normal Operating Conditions – Non-School Hours

Use Case	**Reduced Speed School Zone**	
Scenario ID and Title	*UC9-S2: Normal Operating Conditions*	*– Non-School Hours*
Scenario Objective	• Provide alert to vehicle operator when in excess of speed limit when approaching school zone.	

Use Case	Reduced Speed School Zone	
Scenario ID and Title	*UC9-S2: Normal Operating Conditions – Non-School Hours*	
Operational Event(s)	• School zone broadcasts TIM data received.	• The vehicle receives the TIM data, and – along with its location, position, and motion data – determines if the vehicle operator needs to decrease speed prior to entering school zone or while in school zone.
Actor(s)	Actor	Role
	Vehicle Operator (host)	Safe and compliant operation of vehicle in school zone.
Key Actions and Flow of Events	Source	Key Action
	Vehicle Operator	Step 1) Approaches a school zone during non-school hours.
	RSU	Step 2) Does not broadcasts TIM message.
	Vehicle Operator	Step 3) Does not receive an in-vehicle message, as the school zone is not active.
	Vehicle Operator	Step 4) Continues at the nominal roadway speed.
Post-Conditions	• Vehicle operator safely traverses school zone during non-school zone hours.	
Policies and Business Rules	Columbus 2133.03 – Maximum speed limits—Assured clear distance ahead—Reasonable for conditions—Per se violation.	ORC 4511.21 – Speed Limits – assured clear distance
Traceability	CVE-UN140-v02 – School Zone/Decrease Speed CVE-UN420-v02 – Update Static Messages	CVE-UN610-v02 – School Zone Pedestrian Safety
Inputs Summary	**Handler/Processor:** System Initialization Input: Active School Zone configuration set at time of configuration or remote updated by TMC.	**OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: TIM from RSU. GNSS: Time and location data.
Output Summary	**RSU:** CV Data: TIM.	**OBU:** None.

Source: City of Columbus

Table 52: Use Case 9 – Scenario 3: Degraded Condition – Diminished Communications

Use Case	**Reduced Speed School Zone**	
Scenario ID and Title	*UC9-S3: Degraded Condition – Diminished Communications*	
Scenario Objective	• Provide alert to vehicle operator when in excess of speed limit when approaching school zone in absence of communication between school zone RSU and OBU.	
Operational Event(s)	• Vehicle operator approaches school zone during active school zone hours. • Roadside equipment is not able to broadcast school zone information. • Vehicle retains TIM from the previous instance of passing through the school zone.	• This scenario effectively represents a failure condition if the school zones operations (school zone speed, school zone active times, or school zone location) have changed since the last time the vehicle operator passed the school zone.
Actor(s)	Actor	Role
	Vehicle Operator (host)	Safe and compliant operation of vehicle in school zone.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator	Step 1) Approaches a school zone during a time when the school zone is active.
	RSU	Step 2) Broadcasts TIM message containing data elements that indicates intersection geometry and signal state information.
	Vehicle OBU	Step 3) Is not able to receive messages.
	Vehicle OBU	Step 4) Receives the TIM, processes it, and determines that a warning should be issued
	Vehicle Operator	Step 5) Receives an in-vehicle message that they are about to enter a school zone and the speed limit. [Issuance of warning is based on data contained in a TIM message that was previously received for the school zone, as well as vehicle location and motion data obtained via GPS.]
	Vehicle Operator	Step 6) Reduces the speed of the vehicle while the in-vehicle message continues to be displayed.

Use Case	**Reduced Speed School Zone**	
Scenario ID and Title	*UC9-S3: Degraded Condition –*	*Diminished Communications*
	Vehicle Operator	Step 7) Leaves the school zone. The original in-vehicle message ceases, and a message indicating the school zone has ended is displayed.
	Vehicle Operator	Step 8) Continues at the nominal roadway speed.
Post-Conditions	• Vehicle Operator is more aware of speed while approaching school zone. • Vehicle Operator is more aware of speed while within school zone.	• Vehicle Operator properly reacts to an in-vehicle alert. • Vehicle Operator safely traverses school zone during active school zone hours.
Policies and Business Rules	Columbus 2133.03 – Maximum speed limits—Assured clear distance ahead—Reasonable for conditions—Per se violation.	ORC 4511.21 – Speed Limits – assured clear distance
Traceability	CVE-UN140-v02 – School Zone/Decrease Speed CVE-UN420-v02 – Update Static Messages	CVE-UN610-v02 – School Zone Pedestrian Safety
Inputs Summary	**Handler/Processor:** System Initialization Input: Active School Zone configuration set at time of configuration or remote updated by TMC.	**OBU:** System Initialization Input: OBU warning set at time of configuration. Human Inputs: None. CV Data: TIM from RSU (from previous trip through work zone). GNSS: Time and location data.
Output Summary	**RSU:** CV Data*: ~~TIM~~	**OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions.

**Strikethrough indicates data that would normally be available where there not a diminished or failed condition.*

Source: City of Columbus

Table 53: Use Case 9 – Scenario 4: Failure Condition – Deficient OBU Data Quality

Use Case	**Reduced Speed School Zone**	
Scenario ID and Title	*UC9-S4: Failure Condition – Deficient OBU Data Quality*	
Scenario Objective	• Demonstrate application fails to provide proper output in a safety-critical situation.	
Operational Event(s)	• Two vehicles are following each other in a single file into a school zone. Vehicle Operator 1: leading vehicle traveling above the school zone speed limit and; Vehicle Operator 2: first following vehicle traveling at the school zone speed limit. • Roadside equipment in the vicinity of the school zone broadcasts TIM messages.	• Alerts and/or warnings are not issued in safety-critical situations (false positive). • Alerts and/or warnings are issued when not warranted (false negative). • Data received from GNSS and/or motion sensors (position, speed, acceleration) is inaccurate.
Actor(s)	Actor	Role
	Vehicle Operator 1 (host)	Safe and compliant operation of vehicle in school zone.
	Vehicle Operator 2 (host)	Safe and compliant operation of vehicle in school zone.
Key Actions and Flow of Events	Source	Key Action [Comments]
	Vehicle Operator 1, Vehicle Operator 2	Step 1) Approaches a school zone during a time when the school zone is active.
	RSU	Step 2) Broadcasts a TIM containing the location of the school zone and the school zone speed limit.
	Vehicle 1 OBU	Step 3) Receives the TIM, processes it, and falsely determines that a warning should not be issued. [Vehicle 1 speed data obtained via GPS is inaccurate. GPS speed is lower than actual vehicle speed.]
	Vehicle Operator 1	Step 4) Notices the flashing school signal and reduces speed in school zone. [Cues may be visible (flashing school signal, or presence of pedestrians) (false negative).]
	Vehicle 2 OBU	Step 5) Receives the TIM, processes it, and falsely determines that a warning should be issued. [Vehicle 2 speed data obtained via GPS is inaccurate. GPS speed is higher than actual vehicle speed.]

Use Case	Reduced Speed School Zone	
Scenario ID and Title	*UC9-S4: Failure Condition – Deficient OBU Data Quality*	
	Vehicle Operator 2	Step 6) Receives a school zone speed warning and further decreases speed. [Increases alertness of Vehicle Operator 2 (false positive warning).]
Post-Conditions	• System does not detect alert or warning condition when condition actually exists (Vehicle Operator 1). • System detects alert or warning condition when condition does not actually exist (Vehicle Operator 2). • Corrective actions could be taken when not necessary (Vehicle Operator 2).	• Vehicle operators must visually identify various conditions and react accordingly, similar to current operations. • Vehicle Operators may lose trust in the system.
Policies and Business Rules	Columbus 2133.03 – Maximum speed limits—Assured clear distance ahead—Reasonable for conditions—Per se violation.	ORC 4511.21 – Speed Limits – assured clear distance
Traceability	*None*	
Inputs Summary	**Host Vehicle OBU:** System Initialization Input: OBU alert and OBU warning set at time of configuration. Human Inputs: None. CV Data: Safety data from remote OBU (inaccurate or latent). GNSS: Location and motion data (inaccurate).	
Output Summary	**Host Vehicle OBU:** Warning audio/visual output from host OBU to vehicle operator under certain conditions (false positive). None (false negative).	

2096 *Source: City of Columbus*

User Needs to Scenarios Summary

Table 54: User Needs to Scenarios Summary provides the traceability between the user needs and the Normal Operating Condition scenarios presented previously in this section. Note that general system needs (CVE-SN8.XX) do not have corresponding scenarios, as these needs are considered foundational in nature for the system to properly operate.

Table 54: User Needs to Scenarios Summary

User Need Identification	User Need Title	Applicable Scenarios (Normal Operating Conditions scenarios only)
CVE-UN110-v02	Vehicle Collision Avoidance	UC1-S1; UC1-S2; UC2-S1 UC2-S2; UC3-S1; UC3-S2 UC4-S2
CVE-UN111-v02	Emergency Braking Ahead	UC1-S1; UC1-S2
CVE-UN112-v02	Safe Following Distance	UC2-S1; UC2-S2
CVE-UN113-v02	Monitor Vehicle Trajectories at Intersection	UC3-S1; UC3-S2
CVE-UN114-v02	Lane Change Collision Warning	UC4-S2
CVE-UN120-v02	Vehicle in Blind Spot	UC4-S1; UC4-S2
CVE-UN130-v02	Stop on Red Signal	UC8-S1
CVE-UN140-v02	School Zone/Decrease Speed	UC9-S1; UC9-S2
CVE-UN220-v02	Emergency Vehicle Intersection Priority	UC5-S1; UC5-S4
CVE-UN310-v02	Heavy-Duty Vehicle Intersection Priority	UC5-S2; UC5-S4
CVE-UN320-v02	Freight Signal Priority with Platoon Intent	UC5-S2; UC5-S4
CVE-UN410-v02	Monitor Performance	UC6-S1
CVE-UN420-v02	Update Static Messages	UC9-S1; UC9-S2
CVE-UN430-v02	Configure and Monitor Roadside Devices	UC6-S1
CVE-UN440-v02	Data Archive Configuration	UC6-S1
CVE-UN510-v02	Service Management	UC5-S3; UC5-S4
CVE-UN520-v02	On-Schedule Status	UC5-S3; UC5-S4
CVE-UN530-v02	Monitor Transit Vehicle Interactions	UC7-S1
CVE-UN540-v02	Transit Vehicle Operator CVE Output	UC7-S1
CVE-UN610-v02	School Zone Pedestrian Safety	UC9-S1; UC9-S2
CVE-UN710-v02	Maintain Connectivity	UC5-S6; UC6-S2; UC7-S2
CVE-SN810-v02	Smart Columbus Operating System Connectivity	General System Needs are ubiquitous amongst all Normal Operating Condition scenarios, and thus are not specified for specific scenarios.
CVE-SN820-v02	Wireless Communications Security	
CVE-SN830-v02	In-Vehicle Positioning	
CVE-SN840-v02	In-Vehicle Time Synchronization	
CVE-SN850-v02	Roadside Time Synchronization	
CVE-SN860-v02	Position Correction	
CVE-SN870-v02	In-Vehicle Device Wireless Communications Security	

Source: City of Columbus

Chapter 7. Summary of Impacts

This section provides a summary of the expected operational and organizational impacts of the proposed system on stakeholders and other supporting entities. This includes a section on temporary impacts that are expected to occur while the new system is being developed, installed, or tested. **Table 55: Stakeholder Impacts by Proposed Application** shows a list of stakeholder impacts organized by application.

Table 55: Stakeholder Impacts by Proposed Application

CV Application	Expected Impact
Emergency Electronic Brake Light Warning	• Reduced likelihood of collisions due to emergency braking.
Forward Collision Warning	• Increased vehicle operator awareness of traffic conditions. • Increased amount of time a vehicle operator has to perceive and react to a situation. • Reduced likelihood of collisions caused by speed differentials between leading and following vehicles.
Intersection Movement Assist	• A decrease in intersection intrusions and red light running. • Reduced likelihood of intersection crashes. • Improved vehicle operator awareness of conflicting movements through an intersection.
Lane Change Warning/Blind Spot Warning	• Reduced potential for sideswipe crashes.
Traffic Signal Priority/ Preemption (**Appendix G, Roadside Equipment Locations** indicates which priority/preempt requests will be accommodated at each intersection)	• Safe and efficient movement of emergency vehicles through intersections. • Improved travel/response time for emergency vehicles. • Safety through reducing human decision for heavy-duty vehicle operators in dilemma zones. • Enhanced pavement life. • Reduced vehicle emissions. • Dilemma zone protection for vehicles in the back of the platoon. • Reduced amount of time between sending of TSP request and the time the request reaches the traffic signal controller.

CV Application	Expected Impact
Vehicle Data for Traffic Operations	• More intelligent priority strategies that implement trade-offs between traffic and transit delay at intersections in a network. • Comprehensive vehicle data coverage. • Increased vehicle data accuracy. • Improved traffic flow on select managed corridors. • A system-optimal solution for reducing travel time and delay.
Red Light Violation Warning	• Eliminated dilemma zone. • Reduced number of vehicles that enter the intersection while the signal indicates red. • Monitoring of intersection operations and assessment of where signal violations occur to decide how to modify signal operations (e.g. adjust clearance and all-red times) and placement of traffic control features (e.g. signal head and stop bar location) to increase intersection safety.
Reduced Speed School Zone	• Reduced amount of effort required by vehicle operator to interpret when a school zone is active. • Increased flexibility and customization of school zone active hours (e.g. A school zone does not need to be active on a holiday). • Processing of archived data by enforcement officials to determine if there is a speeding problem during school zone active hours (to determine if enforcement is needed, not to identify previous violators).

Source: City of Columbus

Operational Impacts

Changes expected from the CVE include the issuance of safety alerts and warnings to vehicle operators, improved mobility for vehicles using signal preempt and signal prioritization applications, and increased amounts of operations data received at the TMC. Safety warnings and alerts are expected to decrease the number of crashes among vehicle operators with in-vehicle CV technology installed. However, actual safety improvements are expected to be either minimal or difficult to quantify due to the limited number of vehicles with CV technology (resulting in a limited number of interactions between two CV-equipped vehicles). Emergency vehicles responding to an active emergency call are expected to experience lower delays at intersections equipped with CV technology than at non-CV-equipped intersections. A similar (though less pronounced) effect may be noticed by transit and platooned vehicles at intersections equipped with CV technology. The primary impact for platooned vehicles is maintaining the platoon through signalized intersections; the secondary impact is to improve fuel efficiency and reduce emissions. Providing priority and preemption for certain classes of vehicles has the potential to negatively affect the mobility of other vehicles arriving to the intersection when priority or preemption is being given.

The system will increase the amount and quality of traffic operations data received at the TMC that can be used to optimize traffic signal timing in real-time to provide optimal signal timing along CV-equipped corridors. It is expected that these corridors will exhibit a lower total delay (including side streets) than the current system given similar system demands. Finally, traffic operations data can be archived (according to a Data Management Plan) to provide support and substantiate long-term transportation plans that will further improve the transportation system.

Organizational Impacts

The addition of the CVE is expected to result in organizational impacts for agencies that own and maintain CV equipment and manage the data that is gathered by the system. The City of Columbus Department of Public Service will manage O&M of the system when it is operational. This includes the execution of a fiber maintenance contract to support the additional responsibilities of the fiber-optic network that the CVE relies on. Traffic engineers and technicians will need to monitor various aspects of the CVE, perform necessary troubleshooting and repairs, and analyze system performance metrics. Furthermore, city staff will need to be available to monitor and provide O&M relating to the fiber network. Currently, DoT has staff on-hand to accommodate the added responsibilities of the network expansion and has the flexibility to hire additional staff if additional support is needed.

Other organizational impacts are expected for logistics companies, the regional transit agency, and emergency vehicle dispatchers. Logistics companies will need to coordinate the installation of any in-vehicle equipment, train operators how to use the new technologies, and adapt their fleet operations to enable the best utilization of their new capabilities. For example, they may coordinate delivery times so that vehicles will be traveling together and can benefit from forming a platoon, and train drivers on use of the signal priority system to maintain platoons. COTA will also need to coordinate installation of CV equipment on its transit vehicles, as well as determine the appropriate policies and procedures on how to respond when a bus is behind schedule. Issues to be addressed may include what level of schedule deviation will trigger intervention and how to prioritize between the demands of different vehicles on different routes, among others. Emergency dispatchers will need to adapt to their new capabilities, which are likely to enable better response times and more efficient operations and may reduce staffing and other organizational demands. These organizations will also all need to develop contingency plans to mitigate the risks associated with the deployment of and connectivity to the CVE, as well as to maintain operations during scheduled and unexpected system maintenance and downtime.

Impacts During Development

Impacts during development primarily include continued stakeholder involvement and acquiring the proper permits for deploying CV technology. The City of Columbus must continually reach out to stakeholder agencies to maintain agreement on features that will be included on the various in-vehicle systems, and to ensure a continued commitment by these agencies to allow CV equipment to be installed on (a portion of) their fleets. Furthermore, public outreach must be performed to enlist private vehicle owners who are willing to install CV equipment on their vehicle(s). Also, companies that can install the equipment must be identified, certified, and trained.

As discussed in **Chapter 5, Concept for the New System**, testing permits from the State of Ohio or from the City of Columbus may be required before any CV hardware is deployed. Such testing is important to consider because of the amount of time it could take to complete. More research is needed to determine State and City requirements for deploying CV equipment.

Prior to the system functioning, an FCC license must be obtained for every OBU and RSU. It will take time to complete, file, and process FCC license applications, especially for 1,800 OBUs and 113 RSUs. Each intersection will require its own FCC application (FCC applications are location-specific and vary depending on message types that will be broadcast).

Prior to building the system, it will be important to understand what version of the Security and SCMS will be used and how hardware in the CVE is expected to interact with the SCMS. It is expected that the updated version of SCMS will be functional for the CVE in Columbus

Chapter 8. Analysis of the Connected Vehicle Environment

This section provides an analysis and summary of the benefits, limitations, advantages, disadvantages, and alternatives and tradeoffs considered for the proposed system.

Summary of Improvements

The CV infrastructure deployment will occur in seven major corridors/areas. The deployment of in-vehicle devices will be targeted toward populations and VRUs who are located near the infrastructure deployment. Improvements associated with the CVE include:

- Installation of 113 RSUs along with other CV-compatible equipment such as TSC in the project area
- Installation of 1,800 OBUs on participating private, emergency, transit, and freight vehicles
- Development and installation of V2V Safety, V2I Safety, and V2I Mobility applications
- CV data capture and storage for traffic management activities

The CVE is expected to enhance safety and mobility for vehicle operators and improve the safety of pedestrians in school zones by deploying CV infrastructure on the roadside and CV equipment in vehicles. The CVE will also provide sources of high quality data for traffic management purposes.

To gauge whether the CVE achieves the improvements listed above, performance measures were developed in line with the intended purpose of each CVE application. Some performance measures require data collection before implementation to compare before and after conditions. Other performance measures compare areas with connected vehicle technology and to those that do not. A similar comparison could be drawn between the safety and operations of equipped vehicles and non-equipped vehicles on the same road network at the same time. The decision of which type of performance measure to use depends on a variety of factors, including data availability. The benefit of before and after comparisons is that they can measure changes directly in the areas that are improved, from a baseline of current conditions. Additionally, the benefit of with and without comparisons is that they can be done at the same time, mitigating the impact of external forces such as car ownership rates and technological innovations unrelated to the CVE.

Other more complex analyses may be designed depending on the availability and complexity of the data that is gathered from the CVE. Data collection is an integral part of the Smart Columbus project, and the information gathered will be used to evaluate performance measures. Existing data sources, such as a record of the on-time performance of COTA vehicles, can also be used to support this analysis. However, data that can be automatically collected by the new infrastructure and in-vehicle systems will provide an even larger amount of information to support the assessment of the CVE. Data that will be used to evaluate performance metrics will come from the events archived on the Operating System. Such events are expected to include (but are not limited to) signal priority requests, and alerts and warnings issued from applications. Furthermore, information captured from the Vehicle Data for Traffic Operations application can be used to assess the operations of CV vehicles along CV corridors – near roadside equipment locations. Assessing these operations will play a critical role in understanding the operating characteristics of the CVE.

It is also important to address confounding factors not associated with the CVE that may also affect performance measures. Controlling for confounding factors will improve the ability to isolate changes in the performance of the system that can be attributed to the CVE. For instance, if roadwork is being performed on a parallel route and a CV corridor experiences increased demand due to detouring traffic, this may negatively impact operations on the CV corridor. Thus, it will be important to isolate the impact of the detour so that a proper assessment of performance metrics can be performed.

Disadvantages and Limitations

As discussed in **Limitations of the Connected Vehicle Environment Within the Operational Environment**, limitations regarding the operation of the CVE exist with the context of the current operational system. Given that not all vehicles and intersections will be equipped with CV technology, the ability of the system to work under all conditions is limited. V2V applications only work when both vehicles are CV-equipped and V2I applications only work when a CV-equipped vehicle approaches a CV-equipped intersection.

Furthermore, DSRC attenuation and/or DSRC channel congestion may impact the ability of CV equipment to communicate and allow the proposed applications to function as intended. The likelihood of attenuation can be mitigated by strategically locating roadside CV equipment (to allow for maximum line-of-sight) and removing obstructions between CV-equipped devices in the roadway environment when possible. Though it is difficult to estimate the impact of channel congestion until the system is deployed, the scale of the deployment suggests that channel congestion should not be a prominent issue – this is more likely to be an issue under an expansion upon the currently proposed system. The more CV-equipped devices (roadside equipment, vehicles, personal communications equipment) in the network, the more likely channel congestion will be an issue. Steps should be taken to mitigate channel congestion for the proposed system and as the system expands.

Alternatives and Trade-Offs Considered

Other non-CV solutions could satisfy the user needs for certain applications. As discussed in **Chapter 4, Introduction**, transit and emergency vehicle priority applications along with pedestrian school zone safety applications could be satisfied by alternative solutions. Opticom provides a proprietary product that uses Wi-Fi to allow transit and emergency vehicles to communicate with traffic signals to enable emergency vehicle preemption and transit priority at signalized intersections. Signal priority for transit vehicles would be deployed alongside the Opticom system, as COTA has already dedicated resources to the deployment of the Opticom system in COTA buses. Since the CV-based transit signal priority will be running alongside the Opticom system, test data from the two systems can be used to assess the effectiveness of the two systems.

Chapter 9. Notes

No notes are applicable for this document.

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Appendix A. Acronyms and Definitions

The **Table 56: Acronym List** contains project specific acronyms used throughout this document.

Table 56: Acronym List

Acronym/Abbreviation	Definition
3PL	Third-Party Logistics
ABS	Antilock Braking System
ADA	Americans with Disabilities Act
AMT	Automated Manual Transmission
API	Application Programming Interface
ASD	Aftermarket Safety Device
AV	Autonomous Vehicle
BRT	Bus Rapid Transit
BSM	Basic Safety Message
BSW	Blind Spot Warning
CAMP	Crash Avoidance Metrics Partnership
CDP	Columbus Division of Police
CEAV	Connected Electric Automated Vehicle (Smart Columbus Project #8)
CFR	Code of Federal Regulations
CMAX	Brand for COTA Cleveland Avenue Bus Rapid Transit
CMS	Collision Mitigation System
COTA	Central Ohio Transit Authority
ConOps	Concept of Operations
CPS	Common Payment System (Smart Columbus Project #3)
CSCC	Columbus State Community College
CTSS	Columbus Traffic Signal System
CV	Connected Vehicle
CV Environment	Connected Vehicle Environment (Smart Columbus Project #2)
CVRIA	Connected Vehicle Reference Implementation Architecture

Acronym/Abbreviation	Definition
DoT	City of Columbus Department of Technology
DMS	Data Management System (used in context of Operating System)
DMS	Dynamic Message Signs (used in context of CVE and ITS solutions)
DPS	City of Columbus Department of Public Service
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface
EAV	Electric Autonomous Vehicle
EEBL	Emergency Electronic Brake Light
EMS	Emergency Medical Service
EPM	Event Parking Management (Smart Columbus Project #7)
ETA	Estimated Time of Arrival
ETSI	European Telecommunications Standards Institute
EV	Electric Vehicle
EVP	Emergency Vehicle Preempt
FCCFA	Franklin County Convention Facilities Authority
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FMLM	First Mile / Last Mile
FSP	Freight Signal Priority
GHz	Gigahertz
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GTFS	General Transit Feed Specification
GTFS-RT	General Transit Feed Specification – Real-Time
HDV	Heavy-Duty Vehicle
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
IMA	Intersection Movement Assist
INCOSE	International Council on Systems Engineering
IP	Internet Protocol address
IRB	Institutional Review Board
ISO	International Organization for Standardization

Acronym/Abbreviation	Definition
ISP	Internet Service Provider
IT	Information Technology
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
JIT	Just-in-Time
LBRS	Location Based Response System
LCW	Lane Change Warning
LDV	Light-duty Vehicle
LED	Light-Emitting Diode
LTE	Long-Term Evolution
MAASTO	Mid America Association of State Transportation Officials
MAP	Map Message
MAPCD	Mobility Assistance for People with Cognitive Disabilities (Smart Columbus Project #5)
MMITSS	Multi-Modal Intelligent Traffic Signal System
MMTPA	Multi-Modal Trip Planning Application (Smart Columbus Project #3)
MOE	Measure of Effectiveness
MORPC	Mid-Ohio Regional Planning Commission
NB	Northbound
NEMA	National Electrical Manufacturers Association
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
NOC	Network Operations Center
NOFO	Notice of Funding Opportunity
O&M	Operations and Maintenance
OBE	Onboard Equipment (many or all onboard devices)
OBU	Onboard Unit (one onboard device)
ODOT	Ohio Department of Transportation
OEM	Original Equipment Manufacturer
OSADP	Open-Source Application Data Portal
OSU	Ohio State University
PEO	Parking Enforcement Officer

Acronym/Abbreviation	Definition
PII	Personally Identifiable Information
RSE	(generic) Roadside Equipment
RDE	Research Data Exchange
RFID	Radio Frequency Identification
RFQ	Request for Quote
RLVW	Red Light Violation Warning
ROI	Return on Investment
RSSZ	Reduced Speed School Zone
RSU	(DSRC) Roadside Unit
RTCM	Radio Technical Commission for Maritime
SAE	Society of Automotive Engineers
SB	Southbound
SBS	System Breakdown Structure
SC	Smart Columbus
SCC	Smart City Challenge
SCMS	Security and Credentials Management System
SDD	System Design Document
SE	Systems Engineering
SEMP	Systems Engineering Management Plan
SEMS	Systems Engineering Master Schedule
SEP	Systems Engineering Process
SET-IT	Systems Engineering Tool for Intelligent Transportation
SMH	Smart Mobility Hubs (Smart Columbus Project #4)
SPAT	Signal Phase and Timing
SRM	Signal Request Message
SSM	Signal Status Message
STEM	Science Technology Engineering and Math
SyRS	System Requirements Specification
TIMS	Transportation Information Mapping System
TIM	Traveler Information Message
TNC	Transportation Network Company
TP	Truck Platooning (Smart Columbus Project #9)

Acronym/Abbreviation	Definition
TRB	Transportation Research Board
TRL	Technology Readiness Level
TSC	Traffic Signal Controller
TSP	Transit Signal Priority
TWLTL	Two-Way Left-Turn Lanes
UI	User Interface
USDOE	United States Department of Energy
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VAD	Vehicle Awareness Device
VDTO	Vehicle Data for Traffic Operations
VRU	Vulnerable Road User

Source: City of Columbus

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Appendix B. Glossary

The **Table 57: Glossary of Terms** contains project specific terms used throughout this document.

Table 57: Glossary of Terms

Term	Definition
311 Columbus Call Center	The City of Columbus Service Center which is the single point of contact for requesting all non-emergency City services and is available to residents, City businesses, and visitors
Agile	A method of project management that is characterized by the division of tasks into short phases of work and frequent reassessment and adaptation of plans
Alert	Indication to vehicle operator of potential situation for which they should take action. Less critical than a warning.
App	Software application
Application solution providers	Private companies that design, test, integrate, operate, and maintain one or more aspects of the Common Payment System
Application users (end users)	The drivers (residents and visitors) in Columbus who will be interacting with the EPM system to view, plan, reserve, and navigate to desired parking
Automated vehicle	A vehicle that can sense its environment and navigate without human input
Central Fare Management System	System implemented through a recently executed contract with SPX Genfare and will accept various forms of payment including cash, magnetic cards, smart cards and mobile tickets
Commercial-off-the-shelf system (COTS)	Software or hardware product that are ready-made and available for sale to the public
Connection Protection (CP) system	A system which will hold a bus for someone that has reserved a trip
Connected vehicle	A vehicle capable of communicating with other vehicles, infrastructure, and smartphones
CV Technology	Technology that lays the foundation for a fully interoperable, open, wireless environment for enhancing safety and mobility for vehicles and pedestrians in school zones
CV Message Suppression	Application that allows the vehicle operator to cease the broadcasting of CV messages from their vehicle
Dynamic Message Sign (DMS)	An ITS device used to convey information to drivers about travel time, roadway conditions and other information for which they should be aware.

Term	Definition
Data Management System (DMS)	A secure, Software-as-a-Service web-based application that allows management of an entire parking meter network
Data privacy	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
Data retention	The continued storage of data for compliance or business reasons
Data security	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 without authorization, as well as the corrective actions taken when data breaches are suspected or have been identified.
Data sharing policies	Adopted plan around the practice of making data available to others
Dedicated Short Range Communications (DSRC)	A two-way short- to medium-range wireless communications capability that permits very high data transmission critical in communications-based active safety applications
Dependency	When one project, agency, or entity requires data or functionality provided by another project, agency, or entity to meet its objectives
Diminished operations	When pre-determined signal timing plans are not implemented at the proper time, or when traffic detection does not function properly
Emergency Electronic Break Light Warning (EEBL)	Application that enables a vehicle to broadcast a self-generated emergency break event to surrounding vehicles
Enabling Technologies	An innovation that alone or paired with an existing solution produces a better end user solution at a rapid rate
Experience Columbus	An organization whose mission is to market and promote Columbus services, attractions, and facilities to visitors, meeting planners, convention delegates, and residents
Failure operations	When a complete failure of the intersection occurs, primarily due to loss of power or other malfunctions
Fare collection system	A system, either automated or manual, that collects fares for Transportation Service Providers
Forward Collision Warning (FCW)	Application that is intended to warn the vehicle operator of the vehicle in case of an impending rear-end collision with another vehicle ahead in traffic in the same and direction of travel
Global Navigation Satellite System	Standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. GPS, GLONASS, Galileo and Beidou are examples.
Global Positioning System	US Standard implementation of GNSS
Host vehicle	The vehicle that issues the alert or warning to the vehicle operator in a safety-critical situation
Integrated traceable fare collection method	Multiple forms of payment and various media issuance such as smart cards, online payments, and standard magnetic cards

Term	Definition
Intersection Movement Assist (IMA) (V2V Safety)	Application that warns the vehicle operator of a vehicle when it is not safe to enter an intersection due to high collision probability with other vehicles at stop sign-controlled and uncontrolled intersections
Lane Change Warning/Blind Spot Warning (V2V Safety)	Application that is intended to warn the vehicle operator of the vehicle during a lane change attempt of the blind spot zone into which the vehicle intends to switch is, or will soon be, occupied by another vehicle traveling in the same direction
Multimodal transportation	Travel that is performed with more than one mode of transportation
Normal operations	When a signalized intersection is cycling through its pre-planned phases correctly, servicing all approaches, including pedestrian phases
Notification	General term used for message, alert or warning issued to vehicle operator.
Onboard equipment	All equipment that is located in the vehicle, including any or all of the following items: GNSS receiver, vehicle data bus, a DSRC radio, a processing unit, and a display
Open-data	Information that is freely available for anyone to use and republish as they wish
Open-source concepts	The notion of open collaboration and voluntary contribution for software development by writing and exchanging programming code
Payment settlement	The process by which funds are sent by an issuing bank to the CPS for processing and dispersal to the Transportation Network Companies
Performance metric	A measurement used to determine how a project is performing
Personally Identifiable Information (PII)	Information used in security and privacy laws that can be used to identify an individual, such as vehicle, driver, and payment information
Parking facility	Land or a structure used for light-duty vehicle parking
Parking management system	A system intended to aggregate location, availability, payment information, and reservation capabilities across all public and private parking options
Platoon	Several vehicles using onboard and infrastructure-based technology to maintain close spacing between vehicles to improve safety, fuel mileage, and efficiency
Procurement	The act of obtaining or acquiring goods, services or works, from a competitive bidding process
Push notifications	Alert users to relevant information pertaining to a route or selected mode of transportation, such as the approach of a transfer location, congestion or other impediment to travel, or pricing change
Quick Response barcode	Commonly referred to as a QR Code. A barcode that stores information that can be used for marketing or sharing information and can be read using a digital device such as a cell phone
Real-time data	Information that is delivered immediately after collection

Term	Definition
Red Light Violation Warning (RLVW)	Application that enables a connected vehicle approaching an instrumented signalized intersection to receive information from the infrastructure about the signal timing and geometry of the intersection
Reduced Speed School Zone (RSSZ)	Application that provides connected vehicles that are approaching a school zone with information on the zone's posted speed limit
Roadside equipment	All equipment located on the roadside, including any or all of the following items: traffic signal controllers, GNSS receiver, a DSRC radio, and a processing unit
Operating System user	Administrators interested in gathering performance and usage information from the Common Payment System
Sidewalk Labs	A Google company and a national partner in the USDOT Smart City Challenge
Signal preemption	An interruption of the current intersection state to provide service to a specified phase, typically used for emergency first responders
Signal priority	The ability to provide either an early green or extended green for a specific phase
Operating System	A dynamic governed platform that integrates data and data services for the Smart Columbus program
Smart parking meter	A parking meter equipped with technology to collect data and make interactions easier for the end user
Smart sensors	A device that takes input from the physical environment and uses built-in technology to perform functions upon detection of specific input and then process data before passing it on
System analytics or data analytics	The analysis of data, procedures, or business practices to locate information that can be used to create more efficient solutions
System integration user	A firm that specializes in bringing together component subsystems into a whole and ensuring that those subsystems function together
Systems Engineering (waterfall) approach	A linear and sequential product or software development model that includes Conception, Initiation, Analysis, Design, Construction, Testing, Production/Implementation, and Maintenance phases
Third-party	Organizations not affiliated with the Smart Columbus program
Token access function	The ability to use a token that holds security data for the user to allow access into a system
Traffic Signal Priority/Preemption (V2I Mobility)	Application that provides improved mobility for emergency vehicle operators, heavy-duty vehicle operators, and transit vehicle operators
TransitApp	A free trip planning application available to users of iPhone or Android devices
Transportation Network Companies (TNCs)	Private businesses, non-profits, and quasi-governmental agencies that offer one or more types of transportation for use in exchange for payment

Term	Definition
Two-Way Left-Turn Lanes	A roadway design comprised of a shared, center 'turn' lane to be used by vehicles from either direction.
Unbanked users	Application users who do not participate in the formal banking sector by maintaining traditional checking accounts or credit card amounts
Unified parking availability and reservation system	A system that would allow parking availability information and reservations for parking lots and garages without concern for lot or garage ownership
User Interface	Visual, audible, or haptic interface between a human and a machine, likely a computer of some form. Used to both convey and collect information.
Vehicle Data for Traffic Operations (VDTO)	Application that uses probe data obtained from vehicles in the network to support traffic operations, including incident detection and the implementation of localized operational strategies
Vulnerable road users	Pedestrian, cyclist, or motorist who has a higher risk in traffic
Warning	Indication to vehicle operator of imminent situation for which they should take immediate action. Highest level of criticality.

2262 *Source: City of Columbus*

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Appendix C. End-User/Stakeholder Engagement Summary

The following is a summary of end-user and stakeholder engagement activities to assess the current environment and challenges of Columbus residents in relation to motorist, bicycles, and pedestrian safety.

End-users and stakeholders involved in the engagement process included:

- Expecting Mothers
- Older Adults
- Linden Residents
- People who work in Linden
- Bicyclists
- Pedestrians
- Traffic Manager
- Transit Vehicle Operator
- Transit Manager
- Heavy-Duty Vehicle Operator
- Emergency Vehicle Operator

End-user Engagement Events Summary

1. Event 1: Smart Columbus Connects Linden
    a. When: February 10-11, 2017
    b. Where: St. Stephens Community House, Linden
    c. Who participated: 160 community members volunteered to attend
    d. Why: Linden residents are the target population group for recruiting participants willing to install CV equipment on private vehicles
    e. Key takeaways
        i. Safety is a primary concern for Linden residents. Those expressing safety concerns included single mothers with children and older adults riding COTA and walking home from a bus stop. In addition, residents expressed physical safety concerns about being afraid to ride a bicycle on congested city streets.
        ii. Linden residents have privacy concerns with CV technology, specifically with the connected vehicle device itself as well as personal information provided at kiosks.
        iii. There is concern over cost for installation and/or purchase of the CV device; participants were excited to learn that for the demonstration project the devices would be free

2. Event 2: Online Survey
    a. When: April 2017

   b. Where: Promoted online and distributed to contacts who expressed interest
   c. Who participated: 34 community members volunteered to participate
   d. Why: Given the volume of interest in the Smart Columbus Connects Linden event, an online survey was conducted to gain participation from those unable to attend that event
   e. Key takeaways:
      i. Participants felt installing equipment on cars to enhance safety was a very good idea
      ii. Participants most frequently take a vehicle (their own or via a ride from someone else). Walking is the mode second-most common followed closely by the bus and lastly, a bike.

3. Event 3: Linden Older Adults Focus Group
   a. When: June 21, 2017
   b. Where: Northern Lights Library, Linden
   c. Who participated: Four community members volunteered to attend
   d. Why: Focus group of community volunteers to gain additional, more directed insight on specific user needs
   e. Key takeaways:
      i. Safety when riding a bicycle or walking to a bus stop is a prevalent concern
      ii. The group preferred to have the flexibility to choose indicator preference because sometimes audible indicators are preferred and at other times visible indicators are preferred.

4. Event 4: Linden Moms2Be Focus Group
   a. When: June 21, 2017
   b. Where: Grace Baptist Church, Linden
   c. Who participated: 11 female community members (expecting and new mothers) volunteered to attend
   d. Why: Focus group of community volunteers to gain additional, more directed insight on specific user needs
   e. Key takeaways:
      i. When traveling with children, it is often too cumbersome to take the bus, which is why cab service, Uber and rides with others are so prevalent
      ii. Participants expressed interest and excitement in participating in the connected vehicle project due to its aim to help with alleviating safety concerns in their day-to-day lives
      iii. Different participants had different preferences between an audible voice, a beep, vibration, or light to serve as the warning indicator; as a whole, the group preferred to have the flexibility to choose indicator preference.

City of Columbus Internal Stakeholder Engagements

Following are a list of dates, times, and participants for City-led engagements with internal stakeholders.

July 29, 2016 – Discussed additional support required for the CVE from Traffic Management perspective and potential staffing during Smart Columbus RFQ Selection Committee meeting. – (Smart Columbus) Ryan Bollo and (Administrator of Traffic Management) Reynaldo Stargell

September 2, 2016 – Discussed Additional technical skills and additional staffing required for the CVE from the Divisions of Traffic Management and Design and Construction perspectives during Smart City Consultant Proposed Budgets meeting. – (Smart Columbus) Ryan Bollo and (Director of Department of Public Service) Jennifer Gallagher.

December 22, 2016 – (Smart Columbus) Ryan Bollo updated (Director of Department of Public Service) Jennifer Gallagher on the timeframes of the projects to plan additional authorized strength in the Department of Public Service.

February 15, 2017 – (Smart Columbus) Ryan Bollo meeting with the (Traffic Engineering Section Manager) Ryan Lowe about potential technical skill sets required for CVE and increased staffing levels and skills required to maintain it after the Smart Columbus | USDOT ConOps Training session.

July 12, 2017 –During the CVE Bi-weekly Coordination Call discussed additional required staffing for the CVE from Traffic Management perspective and potential staffing during Smart Columbus RFQ Selection Committee meeting. – (Smart Columbus) Ryan Bollo and (Administrator of Traffic Management) Reynaldo Stargell.

January 18, 2018 – After the Data Technical Working Group (TWG) (Smart Columbus) Ryan Bollo meeting with the (Traffic Engineering Section Manager) Ryan Lowe about technical skill sets required for CVE and increased staffing levels and skills required to maintain it after the Smart Columbus | USDOT ConOps Training session.

March 12, 2018 – During the draft revised ConOps review discussed additional required staffing for the CVE from Traffic Management perspective and potential staffing during Smart Columbus RFQ Selection Committee meeting. – (Smart Columbus) Ryan Bollo and (Administrator of Traffic Management) Reynaldo Stargell. Confirmed that he is requesting the authorized strength once the System Requirements are drafted.

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Appendix D. Survey Results

Surveys were distributed at the Smart Columbus Connects Linden event and 71 were returned. It should be noted that some participants gave more than one response to a question, and not every participant answered each question. All percentages are calculated with a denominator of 71 participants, regardless of the number of individual responses received for that question. Therefore, percentages may not sum to 100 percent.

Survey Question 1: Consider an option to install a safety device in your car that would help the car avoid crashes with other vehicles, bicyclists and pedestrians. The device does not transmit any of your personal information. Would you be interested in having one installed in your car?"

Table 58: Survey Question 1 Responses

Response	Number of Responses	Percentage
Yes	30	42%
No	11	16%
Did not answer	30	42%

Source: City of Columbus

Of those who responded "Yes," 13 (18%) saw this option as improving safety, while 11 (16%) did not give a reason. Others mentioned that it would be beneficial or a good idea, though some did not own a vehicle. For those who responded "No" to this option, most did not give a response or no major theme was discovered. However, several expressed concerns about privacy. A few other comments of interest included

- There needs to be more attention to road and intersection safety.
- Need more information on how devices work before deciding.
- How can Smart Columbus leverage sustainable change on issues like tire disposal, better sidewalks, and guarded bike lanes?

Survey Question 2: When you travel, do you have safety concerns; and if so, what are they?

Table 59: Survey Question 2 Responses

Potential Travel Services	Number of Responses	Percentage
Reckless drivers	10	18%
Lack of pedestrian crossings	9	16%
Bicyclists	7	12%
Yes, but unspecified concerns	5	9%
Lack of signals	4	7%

Potential Travel Services	Number of Responses	Percentage
Theft/crime	3	6%
Lighting	2	4%
COTA	2	4%
Potholes/road conditions	2	4%
Drunk drivers	1	1%
Weather	1	1%
Did not answer	10	18%

Source: City of Columbus

Survey Question 3: Do you ever worry about crashing into cars, buses, bicyclists or pedestrians; and if so, why?

Table 60: Survey Question 3 Responses

Response	Number of Responses	Percentage
Yes	25	35%
No response	10	14%
Yes, delayed travel concerns	4	6%
No	3	4%
Would stick to sidewalks	2	3%
Did not answer	27	38%

Source: City of Columbus

Residents were also asked “how does that (worry of crashing) affect how you travel?” Of the 16 individual responses collected, seven said their trip would be delayed, four would have added stress, three would be concerned about the cost of damage, and two residents said this would limit their transportation choices.

Survey Question 4: Would you be interested in having a device like this installed on your vehicle to improve your safety and that of others?

Table 61: Survey Question 4 Responses

Response	Number of Responses	Percentage
Yes	25	35%
No	2	3%
Might be distracting	1	1%
Did not answer	43	61%

Source: City of Columbus

This question was based on the viewing of the USDOT CV video and the ability for participants to see firsthand example of a connected vehicle onboard unit (OBU).

Survey Question 5: Why might you want this device [CV OBU] installed?

Table 62: Survey Question 5 Responses

Response	Number of Responses	Percentage
Safety	4	6%
Technology	3	4%
Cost	3	4%
Did not answer	61	86%

Source: City of Columbus

Survey Question 6: What is your preferred transportation mode for trips?

Table 63: Survey Question 6 Responses

Response	Number of Responses	Percentage
Automobile	24	34%
Bus	10	14%
Carpooling	5	7%
Combination of transportation modes	8	11%
Did not answer	24	34%

Source: City of Columbus

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Appendix E. Working Group Attending Members

- **CVE Technical Working Group**
  - Ryan Bollo, City of Columbus
  - Sonja Summer, City of Columbus
  - Tom Timcho, WSP
  - Chris Toth, WSP
  - Katie Zehnder, HNTB
  - Greg Zink, Battelle
  - Micheal Carroll, COTA
  - Russel Rayburn, City of Columbus
  - Reynaldo Stargell, City of Columbus
  - Cornell Robertson, Franklin County
  - Mindy Justis, Murphy Epson
  - Yohannan Terrell, Warhol & Wall St.
  - Bud Braughton, City of Columbus
  - Jeff Ortega, City of Columbus
  - Nick Hegemier, Ohio Department of Transportation
  - Frank Perry, HNTB
  - Dave Holstein, Ohio Department of Transportation
  - Ed Fok, USDOT
  - Cathy Collins, City of Columbus
  - JD Schneeberger, Noblis
  - Drennan Hicks, Noblis
  - Levent Guvenc, Ohio State University
  - Ryan Lowe, City of Columbus
  - Andy Volenik, City of Columbus
  - Shane Warner, COTA
  - Jamie Fink, Ohio Department of Transportation
  - Drew Janek, Ohio Department of Transportation
  - Erica Toussant, WSP
  - Treea Sekla, USDOT (Ohio)

  - Jason Spilak, USDOT (Ohio)
  - Kate Hartman, USDOT
  - Dominik Karbowski, Argonne National Lab
- **CEAV Technical Working Group**
  - Andrew Wolpert, City of Columbus
  - Ryan Bollo, City of Columbus
  - Katie McLaughlin, WSP
  - Tim Rosenberger, WSP
  - Tom Timcho, WSP
  - Christopher Toth, WSP
  - Katie Zehnder, HNTB
  - Bilin Akson Guvenc, Ohio State University
  - Levant Guvenc, Ohio State University
  - Carla Bailo, Ohio State University
  - Sherry Kish, City of Columbus
  - Mindy Justis, Murphy Epson
  - Jeff Ortega, City of Columbus
  - Andrew Bremer, Ohio Department of Transportation
  - Adam Sheets, HNTB
  - Sandy Doyle-Ahern, EMHT
  - Yohannan Terrell, Warhol & Wall St.
  - Stan Young, DOE – NREL
  - Beau Arnason, Steiner & Associates
  - Jen Peterson, Steiner & Associates
  - Kristin Randall, Steiner & Associates
  - Reynaldo Stargell, City of Columbus
  - Kevin Dopart, USDOT
  - Micheal Carrol, COTA
  - Mike Bradley, COTA
  - Cornell Robertson, Franklin County
  - Cathy Collins, City of Columbus
  - Lindsay Miller, Ice Miller
  - Ginny Barry, COTA
  - Jordan Davis, Columbus Partnership
  - Jim Barbaresso, HNTB

  - Eric Rask, ANC
- **DATP Technical Working Group**
  - Andy Wolbert, City of Columbus
  - Aparna Dial, City of Columbus
  - Randy Butler, CDM Smith
  - Roger Schiller, CDM Smith
  - Laurie McGill, CDM Smith
  - Marwau Modi, CDM Smith
  - Doug Pape, Battelle
  - Travis Bonnett, Ohio Turnpike
  - Mark Rogers, Siemens
  - James Young, City of Columbus
  - Katie Zehnder, HNTB
  - Richard Jones, HNTB
  - Dina Lopez, MORPC
  - Tom Bauzer, Ohio Trucking Association
  - Robert Stewart, City of Columbus
  - Andrew Bremer, ODOT
  - James Schimmer, Franklin County
  - Joe VonVille, City of Columbus
  - Alisha Womack, City of Columbus
  - Erica Toussant, WSP
  - Tom Timcho, WSP
  - Frank Perry, HNTB
  - Arda Kurt, Ohio State University
  - Carla Bailo, Ohio State University
  - Shane Warner, COTA
  - Mike Lammert, DOE – NREL
  - Tony Yacobucci, Ohio Turnpike
  - Ben Ritchie, CDM Smith
  - Stan Young, DOE – NREL
  - Dave Miller, Siemens
  - Wendy Tao, Siemens
  - JD Schneeberger, Noblis
  - Kate Hartman, USDOT

- **COTA Meeting**
  - Ryan Bollo, City of Columbus
  - Chris Toth, WSP
  - Diane Newton, HNTB
  - Bob James, HNTB
  - Micheal Carroll, COTA
  - Michael Bradley, COTA
  - Shane Warner, COTA
  - Jeff Vosler, COTA
  - Laura Koprowski, COTA
  - Matthew Allison, COTA

Appendix F. Proposed Application Technology Readiness Level Assessment

The Smart Columbus program is an opportunity to deploy CV technology in an operational environment, therefore, it was determined by program leadership that the development of new applications would not comprise a significant activity for the CVE. In order to evaluate the originally proposed applications versus this deployment approach, a nine-level evaluation framework called the Technology Readiness Level for Highway Research (TRL-H) was implemented. This framework is shown in **Table 64: Technology Readiness Level for Highway Research (TRL-H) Scale** below. The framework describes the criteria that must be met for an application to achieve each level. A "Yes" answer to each criteria question indicates that a particular application has achieved the given level.[37]

Table 64: Technology Readiness Level for Highway Research (TRL-H) Scale

.	TRL	Description	Criteria ("Yes" required for all questions)
Basic Research	1	Basic Principles and Research	Do basic scientific principles support the concept? Has the technology development methodology or approach been developed?
	2	Application Formulated	Are potential system applications identified? Are system components and the user interface at least partly described? Do preliminary analyses or experiments confirm that the application might meet the user need?
	3	Proof of Concept	Are system performance metrics established? Is system feasibility fully established? Do experiments or modeling and simulation validate performance predictions of system capability? Does the technology address a need or introduce an innovation in the field of transportation?
Research	4	Components Validated in Laboratory Environment	Are end user requirements documented? Does a plausible draft integration plan exist and is component compatibility demonstrated? Were individual components successfully tested in a laboratory environment (a fully controlled test environment where a limited number of critical functions are tested)?

[37] Transportation Research Board – Technology Readiness Level Assessments for Research Program Managers and Customers Webinar. 4/28/2016. http://onlinepubs.trb.org/Onlinepubs/webinars/160428.pdf

.	TRL	Description	Criteria ("Yes" required for all questions)
Applied	5	Integrated Components Demonstrated in a Laboratory Environment	Are external and internal system interfaces documented? Are target and minimum operational requirements developed? Is component integration demonstrated in a laboratory environment (i.e. fully controlled setting)?
Development	6	Prototype Demonstrated in Relevant Environment	Is the operational environment fully known (i.e. user community, physical environment, and input data characteristics as appropriate)? Was the prototype tested in a realistic environment outside the laboratory (i.e. relevant environment)? Does the prototype satisfy all operational requirements when confronted with realistic problems?
	7	Prototype Demonstrated in Operational Environment	Are available components representative of production components? Is the fully integrated prototype demonstrated in an operational environment (i.e. real-world conditions, including the user community)? Are all interfaces tested individually under stressed and anomalous conditions?
	8	Technology Proven in Operational Environment	Are all system components form, fit, and function compatible with each other and with the operational environment? Is the technology proven in an operational environment (i.e. meet target performance measures)? Was a rigorous test and evaluation process completed successfully? Does the technology meet its stated purpose and functionality as designed?
Implementation	9	Technology Refined and Adopted	Is the technology deployed in its intended operational environment? Is information about the technology disseminated to the user community? Is the technology adopted by the user community?

Source: TRB

With this framework, each of the proposed applications was assessed for deployment readiness. This deployment readiness assessment was performed by a collective of working group members with a background in CV systems development. **Table 65: Connected Vehicle Environment Proposed Application Technology Readiness Levels** identifies the TRL-H (at the time this ConOps was produced) for each application including a justification for why the TRL-H was chosen. Applications with lower TRL-H values were considered but not included as part of the initial deployment. With additional development and testing, the TRL-H values for applications could increase though it is not the intent of the CVE project to significantly advance the deployment-readiness of these applications. It is important to note that application development that occurs outside of this project may result in TRL-H advancement. Thus, the proposed applications may be re-assessed at the time of CVE deployment to determine the final set of applications that can be included.

TRL-H of 1 or 2 indicates that the application has not been significantly researched, or it has been assessed for technical feasibility but not developed or tested in any manner. A TRL-H of 3 or 4 indicates that the application has been assessed from a theoretical standpoint, and passes all functional tests, but has not been tested in a controlled test environment or operational environment. A TRL-H of 5 or 6 indicates that the application has passed all functional tests in a controlled test environment and may require minor to moderate modifications to operate as intended in the deployment area. A TRL-H of 7 or 8 indicates that the application has passed functional tests in an operational environment and is generally accepted as being deployment-ready. No applications have a TRL-H of 9, as no applications have been deployed en masse over an extended period that would be considered a full deployment.

2561 **Table 65: Connected Vehicle Environment Proposed Application Technology Readiness Levels**

Class	Application	Source	TRL-H	Justification
V2V Safety	Emergency Electronic Brake Light Warning	Safety Pilot	7	Developed and passed functional tests as part of the Safety Pilot Model Deployment. This application is deployment-ready.
	Forward Collision Warning	Safety Pilot	7	Developed and passed functional tests as part of the Safety Pilot Model Deployment. This application is deployment-ready.
	Intersection Movement Assist	Safety Pilot	5	A concept for this application has been created and there are standardized messages (BSM) that support the implementation of this application. However, there has been very little work done researching and testing this application. Though several vendors have indicated that this application is available, further research is needed to determine the feasibility of deploying this application in the CVE.
	Lane Change Warning/Blind Spot Warning	Safety Pilot	7	Developed and passed functional tests as part of the Safety Pilot Model Deployment. This application is deployment-ready.
V2I Mobility	Transit Signal Priority	MMITSS	6	This application was developed and tested under the MMITSS project. It is unknown if how this application may behave when confronted with realistic problems. Through future research, it is expected that this application will be ready for deployment.
	Intent to Platoon Priority	MMITSS	4	Considered a new application, Intent to Platoon Priority would require a minor modification of the Freight Signal Priority Application developed and tested under the MMITSS project. Further research is needed to determine the feasibility of deploying this application in the CVE.
	Freight Signal Priority	MMITSS	6	*See description for Transit Signal Priority.*
	Emergency Vehicle Preemption	MMITSS	6	*See description for Transit Signal Priority.*
	Vehicle Data for Traffic Operations	USDOT	8	Though not a standard application, there have been many instances in other tests/pilot projects where roadside units have been networked to a data server and messages

Class	Application	Source	TRL-H	Justification
				have been successfully transmitted from the RSU to the server – where management center staff will be able to access it to assist in management activities.
V2I Safety	Red Light Violation Warning	Safety Pilot	7	This application was developed and tested under the Crash Avoidance Metrics Partnership project. Extensive testing and algorithm development has occurred for this application. Minimal modification to the application may be needed for deployment.
	Reduced Speed School Zone	Safety Pilot	7	This application would be a modification of the Reduced Speed Work Zone application that was developed and tested under the Crash Avoidance Metrics Partnership project. Extensive testing and algorithm development has occurred for this application. Modification to the application may be needed for deployment.

Source: City of Columbus

A number of other CV applications were considered to be deployed a part of the CVE. However, many were removed from consideration because they are not considered to be deployment-ready. One application that was deployment-ready (Warnings About Upcoming Work Zone) was removed due to the anticipated operational challenges. **Table 66: Connected Vehicle Environment Applications Considered but not Included Technology Readiness Levels** below provides the justification behind why each application is not considered to be deployment-ready

Table 66: Connected Vehicle Environment Applications Considered but not Included Technology Readiness Levels

Class	Application	Source	TRL-H	Justification
V2V Safety	Bicycle Approaching Indication/Bicycle Passing Distance Warning	New	1	Adapted from an existing application concept (Motorcycle Approaching Warning). This application may require non-standardized messaging to differentiate between vehicle and VRU remote units. Without significant development, this application will likely **not** be deployed.
	Emergency Vehicle Alert	New	3	A concept for this application has been created and there are standardized messages (Emergency Vehicle Approaching Message) that support the implementation of this application. However, there has been very little work done researching and testing this application. Further research is needed to determine the feasibility of deploying this application in an operational environment.

Class	Application	Source	TRL-H	Justification
	Transit Vehicle at Station/Stop Warning	New	4	This application has passed functional tests and has been demonstrated in a controlled test environment as part of the Transit Bus Stop Pedestrian Warning Application. Further refinement of the application algorithm and testing in an operational environment is needed before it is ready to be deployed in an operational environment.
	Vehicle Turning Right in Front of a Transit Vehicle	Battelle	6	This application has passed functional tests and has been demonstrated in a controlled test environment as part of the Enhanced Transit Safety Retrofit Project. Further refinement of the application algorithm and testing in an operational environment is needed before it is ready to be deployed in an operational environment.
V2I Safety	Pedestrian in Signalized Crosswalk Warning	Battelle	6	This application has passed functional tests and has been demonstrated in a controlled test environment as part of the Enhanced Transit Safety Retrofit Project. Further refinement of the application algorithm and testing in an operational environment is needed before it is ready to be deployed in an operational environment.
	Transit Pedestrian Indication	Battelle	5	This application has passed functional tests and has been demonstrated in a controlled test environment as part of the Transit Bus Stop Pedestrian Warning Application. Further refinement of the application algorithm and testing in an operational environment is needed before it is ready to be deployed in an operational environment.
	Warnings about Upcoming Work Zone	Safety Pilot	7	This application would be a modification of the Reduced Speed Work Zone application that was developed and tested under the Crash Avoidance Metrics Partnership project. Extensive testing and algorithm development has occurred for this application. Modification to this existing application will be needed for deployment. However, it was decided that this application would be deployed due to operations challenges associated with maintaining this application.

2568 *Source: City of Columbus*

Appendix G. Roadside Equipment Locations

Table 67: Roadside Equipment Locations lists proposed locations where Roadside Equipment will be installed.

Table 67: Roadside Equipment Locations

Primary Road	Cross Street	Operating Agency	Special Notes
High Street	Fifth Avenue	City of Columbus	EVP
High Street	King Avenue/Seventh Avenue	City of Columbus	EVP
High Street	Ninth Avenue	City of Columbus	EVP
High Street	Tenth Avenue	City of Columbus	EVP
High Street	Eleventh Avenue	City of Columbus	EVP
High Street	Chittenden Avenue	City of Columbus	EVP
High Street	Twelfth Avenue	City of Columbus	EVP
High Street	Thirteenth Avenue	City of Columbus	Pedestrian Signal, EVP
High Street	Fifteenth Avenue	City of Columbus	EVP
High Street	Woodruff Avenue	City of Columbus	EVP
High Street	Lane Avenue	City of Columbus	EVP
High Street	Northwood Avenue	City of Columbus	EVP
High Street	Patterson Avenue	City of Columbus	EVP
High Street	Hudson Street	City of Columbus	EVP
High Street	Dodridge Street	City of Columbus	EVP
High Street	Arcadia Avenue	City of Columbus	EVP
High Street	Olentangy Street	City of Columbus	EVP
High Street	Kelso Road	City of Columbus	EVP
High Street	Weber Road	City of Columbus	EVP
High Street	Pacemont Road	City of Columbus	EVP
High Street	Como Avenue	City of Columbus	EVP
High Street	North Broadway	City of Columbus	EVP
High Street	Oakland Park	City of Columbus	EVP

Primary Road	Cross Street	Operating Agency	Special Notes
High Street	Torrence Road	City of Columbus	EVP
High Street	Erie Road	City of Columbus	EVP
High Street	Acton Road	City of Columbus	EVP
High Street	Glenmont Avenue	City of Columbus	EVP
High Street	Cooke Road	City of Columbus	EVP
High Street	Henderson Road	City of Columbus	EVP
High Street	Dominion Boulevard	City of Columbus	EVP
High Street	Weisheimer Road	City of Columbus	EVP
High Street	Garden Road	City of Columbus	EVP
High Street	Morse Road	City of Columbus	EVP
Morse Road	Sharon Avenue	City of Columbus	Flashing yellow/red
Morse Road	Indianola Avenue	City of Columbus	EVP
Morse Road	Sinclair Road/I-71 SB	City of Columbus	EVP
Morse Road	I-71 NB	City of Columbus	EVP
Morse Road	Evanswood Drive	City of Columbus	EVP
Morse Road	Sandy Lane Road	City of Columbus	EVP
Morse Road	Maize Road	City of Columbus	EVP
Morse Road	McFadden Road	City of Columbus	EVP
Morse Road	Karl Road	City of Columbus	EVP
Morse Road	Northland Ridge Boulevard	City of Columbus	EVP
Morse Road	Tamarack Boulevard	City of Columbus	EVP
Morse Road	Heaton Road	City of Columbus	EVP
Morse Road	Walford Street/Northtowne Boulevard	City of Columbus	EVP
Morse Road	Malin Street	City of Columbus	EVP
Morse Road	Cleveland Avenue	City of Columbus	EVP
Morse Road	Chesford Road	City of Columbus	EVP
Morse Road	Westerville Road	City of Columbus	EVP
Morse Road	Sunbury Road	City of Columbus	EVP
Morse Road	Morse Crossing	City of Columbus	EVP, TSP
Morse Road	Easton Loop	City of Columbus	EVP, TSP
Morse Road	Stelzer Road	City of Columbus	EVP

Primary Road	Cross Street	Operating Agency	Special Notes
Morse Road	I-270 SB	City of Columbus	EVP, FSP
Morse Road	I-270 NB	City of Columbus	EVP, FSP
Morse Road	Appian Way	City of Columbus	EVP, FSP
Morse Road	L Brands Driveway	City of Columbus	EVP, FSP
Morse Road	Stygler Road	City of Columbus	EVP, FSP
Morse Crossing	Seton Street	City of Columbus	EVP, TSP
Morse Crossing	Grammercy Street	City of Columbus	EVP, TSP
Morse Crossing	Easton Market/Gramercy Street	City of Columbus	EVP, TSP
Morse Crossing	Easton Way	City of Columbus	EVP, TSP
Stelzer Road	Worth Avenue	City of Columbus	EVP
Stelzer Road	Alston Street	City of Columbus	EVP
Stelzer Road	Colliery Avenue	City of Columbus	EVP
Stelzer Road	Easton Way	City of Columbus	EVP
Easton Loop East	Grammercy Street	City of Columbus	EVP
Easton Loop West	Grammercy Street	City of Columbus	EVP
Easton Way	Easton Loop W	City of Columbus	EVP
Easton Way	Easton Square Pl	City of Columbus	EVP
Easton Way	Easton Loop E	City of Columbus	EVP
Cleveland Avenue	Second Avenue	City of Columbus	EVP, TSP
Cleveland Avenue	Fifth Avenue	City of Columbus	EVP, TSP
Cleveland Avenue	Eleventh Avenue	City of Columbus	EVP, TSP
Cleveland Avenue	Windsor Avenue	City of Columbus	EVP, TSP
Cleveland Avenue	Seventeenth Avenue	City of Columbus	EVP, TSP
Cleveland Avenue	Twentieth Avenue	City of Columbus	EVP, TSP
Cleveland Avenue	Twenty-fourth Avenue	City of Columbus	EVP, TSP
Cleveland Avenue	Duxberry Avenue	City of Columbus	EVP, TSP
Cleveland Avenue	Hudson Street	City of Columbus	EVP, TSP
Cleveland Avenue	Myrtle Avenue	City of Columbus	EVP, TSP
Cleveland Avenue	Genessee Avenue	City of Columbus	EVP, TSP
Cleveland Avenue	Westerville Road	City of Columbus	EVP, TSP
Cleveland Avenue	Weber Road	City of Columbus	EVP, TSP
Cleveland Avenue	Oakland Park Avenue	City of Columbus	EVP, TSP

Primary Road	Cross Street	Operating Agency	Special Notes
Cleveland Avenue	Huy Road	Franklin County	EVP, TSP
Cleveland Avenue	Innis Road	Franklin County	EVP, TSP
Cleveland Avenue	Elmore Avenue	Franklin County	EVP, TSP
Cleveland Avenue	Ormond Avenue	Franklin County	EVP, TSP (fire signal)
Cleveland Avenue	Cooke Road	Franklin County	EVP, TSP
Cleveland Avenue	Ferris Road	City of Columbus	EVP, TSP
Cleveland Avenue	Plaza Entrance	City of Columbus	EVP, TSP
SR-317	Port Road	ODOT	FSP
Alum Creek Drive	SR-317 London-Groveport Road	ODOT	FSP
Alum Creek Drive	Spiegel Drive	Franklin County	FSP
Alum Creek Drive	Rohr Road	Franklin County	FSP
Alum Creek Drive	*unnamed road*	Franklin County	FSP
Alum Creek Drive	Creekside Parkway/Toy Road	Franklin County	FSP
Alum Creek Drive	Groveport Road	Village of Obetz	FSP
Alum Creek Drive	I-270 EB/NB	City of Columbus	FSP
Alum Creek Drive	I-270 SB/EB	City of Columbus	FSP
Wilson Road	I-70 EB	City of Columbus	FSP, PITP
Wilson Road	I-70 WB / Interchange Road	City of Columbus	FSP, PITP
Wilson Road	Twin Creeks Drive	City of Columbus	FSP, PITP
Wilson Road	Trabue Road	City of Columbus	FSP, PITP
Trabue Road	Westbelt Drive	Franklin County	FSP, PITP
SR-209 Southgate Road	I-70 WB	ODOT	FSP
SR-209 Southgate Road	I-70 EB	ODOT	FSP
SR-209 Southgate Road	*unnamed road*	ODOT	FSP
SR-209 Southgate Road	*unnamed road*	ODOT	FSP
SR-209 Southgate Road	SR-660 Brick Church Road	ODOT	FSP
SR-209 Southgate Road	CR-345 Country Club Road	ODOT	FSP

2574 *Source: City of Columbus*

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