Minnesota Department of Transportation

Connected Corridor System

Concept of Operations

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In conjunction with:

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1 Introduction

This Concept of Operations (ConOps) serves as the first in a series of systems engineering documents for the MnDOT Connected Corridor System (CC System). The purpose of this ConOps is to clearly convey a high-level view of the CC 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 generally technology independent, focusing on the functionality of the proposed system, and forming the basis of the project. The ConOps also serves to communicate the user's needs and expectations for the proposed system. Finally, this document gives stakeholders the opportunity to provide 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 document is organized into the following sections:

- **Section 1** introduces the project and provides a document overview.
- **Section 2** describes the current and supporting systems and problem(s) to be addressed, and stakeholder feedback elicited in developing this document
- **Section 3** provides a high-level description of the proposed system resulting from the features described in Section 4.
- **Section 4** presents scenarios that illustrate how the project is envisioned to operate from various perspectives.

1.1 SPaT Challenge

The American Association of State Highway Transportation Officials (AASHTO), the Institute of Traffic Engineers (ITE), and ITS America (ITSA) working together through the Vehicle to Infrastructure Deployment Coalition (V2I DC) have challenged state and local public sector transportation infrastructure owners and operators (IOOs) to work together to achieve deployment of roadside Dedicated Short Range Communications (DSRC) 5.9 GHz broadcast radio infrastructure to broadcast signal phase and timing (SPaT) in real-time at signalized intersections on at least one road corridor or street network (approximately 20 signalized intersections) in each of the 50 states by January 2020. This is commonly called the SPaT Challenge. The SPaT Challenge does not specify that Connected Vehicle (CV) technology must be deployed in vehicles. Rather, vehicles with the equipment necessary to receive data sent from the roadside are expected to already exist or eventually be introduced and will be capable of receiving data transmitted from the roadside. These radios are expected to be able to receive agency transmitted data, such as SPaT, with the intent to support safer, more efficient operations. The Connected Corridor concept is in part MnDOT's response to this call to action; fulfilling the SPaT Challenge is a foundational motivation for the development of this system.

MnDOT also recognizes that additional benefits can be derived from expanding on the scope of the SPaT Challenge. Additional functions such as the transmission of intersection geometry data, position correction data, and traveler information data can be enabled using the same roadside hardware that is used to respond to the SPaT Challenge. The addition of ITS devices can further enhance system capabilities. For instance, pedestrian detection equipment allows crosswalk status information to be specified in the SPaT message. Finally, the deployment of CV technology in vehicles allow those vehicles to receive data transmitted from the roadside to provide day-one safety and mobility benefits. Vehicles outfitted with CV technology can also transmit vehicle location and motion information, which can be used by other vehicles to improve safety, and captured by equipment on the roadside to improve the quality of system operations data. By expanding on the scope of the SPaT Challenge, MnDOT intends to address the needs of users that cannot be satisfied through the broadcasting of SPaT data alone.

1.2 CC System Scope

The Connected Corridor will consist of the deployment of CV technology on the roadside and in select vehicles, as well as the use of and interface to existing infrastructure and devices to improve information dissemination. The Connected Corridor system boundary encompasses all devices that are deployed as part of the project, as well as the communications between them, and interfaces between the deployed devices and existing systems and users. Figure 1 shows the system boundary and illustrates the relationship of the CC System, System Users (Pedestrian, Work Zone Worker, Snow Plow Operator, General Equipped Vehicle Operator, Traffic Operations Manager, Self-Equipped Driver, Unequipped Driver), existing supporting systems in the scope of the CC System (Traffic Signal Controller, MnCORS, ATMS (IRIS), and Travel Information Providers), and existing systems outside of the scope of the CC System (DMS and On-Board/Nomadic Devices). A summary of this system is provided in Figure 1 below and is described in detail in Section 3.1.

Together, equipment deployed on the roadside and in vehicles, the transmission of messages, and the deployment of applications supports the needs of users. While not detailed specifically in this concept, roadside equipment is expected to consist of communications equipment, data processing/handling equipment, and other ITS hardware such as pedestrian detection equipment. Communications equipment enables the secure communication of SPaT data, along with other associated message types to vehicles.

Equipment deployed in select vehicles will receive messages from roadside equipment to support Vehicle-Pedestrian Intersection Conflict Warning, Snow Plow Signal Priority, and the Mobile Work Zone Warning System. In-Vehicle Equipment also broadcasts data (such as Basic Safety Message and Signal Request Messages) that can be captured by other in-vehicle equipment and roadside equipment.

Because standardized data transmission protocols will be used, other CV-enabled vehicles on the roadway network (not equipped as part of this deployment effort) will be able to receive data from the roadside to support applications that may be installed on those vehicles. Drivers of these vehicles are considered indirect users of the system. These vehicles are expected to transmit vehicle location and motion information that can be captured by the CC System.

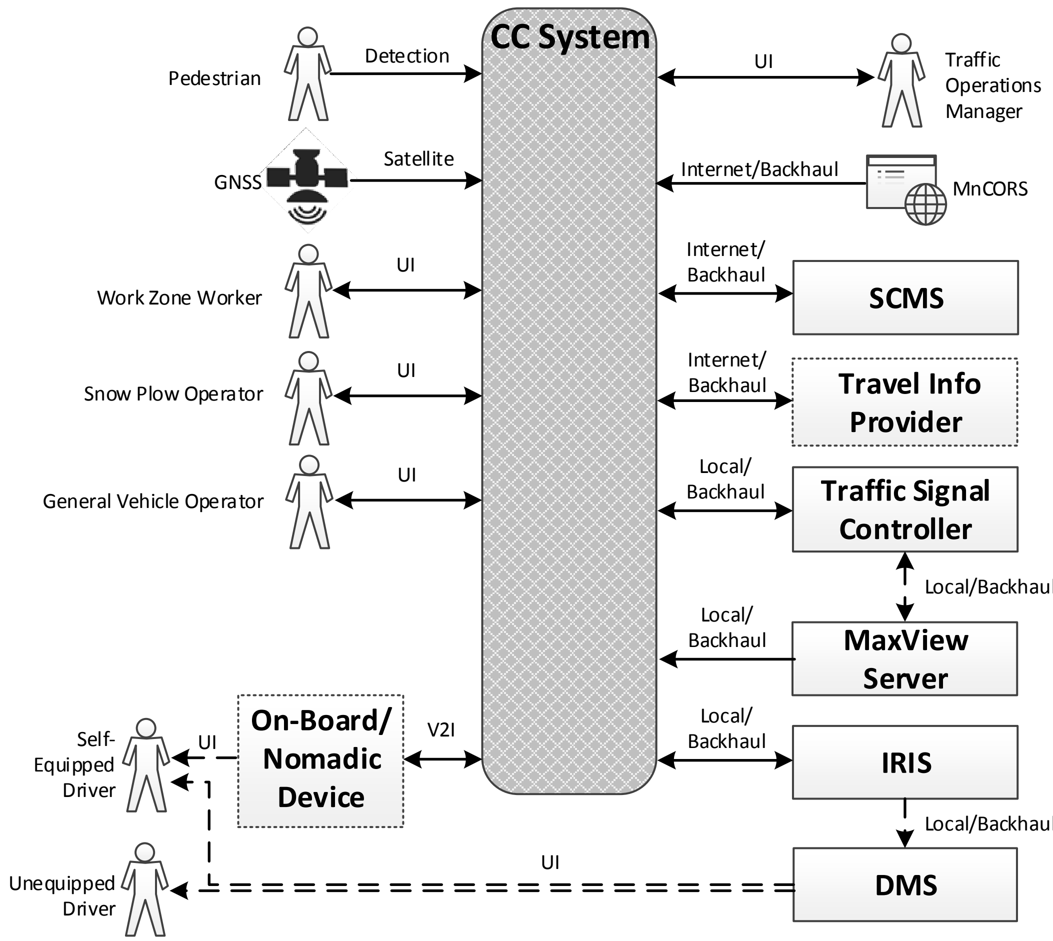

Figure 1: Connected Corridor High-Level System of Interest

The CC System will provide a means to manage and monitor the configuration, operation, and data associated with the connected vehicle system, and will also provide support for maintenance staff to help with diagnosing and repairing problems. The system will provide wired and wireless communication security (not shown in Figure 1), and will interface with Global Navigation Satellite System (GNSS) to provide positioning and allow time synchronization between devices.

1.3 Connected Corridor Geographic Scope

While not all elements of the CC System will have a defined physical or geographic boundary, any physical infrastructure deployment to be conducted as part of the CC System will generally be conducted within an area bounded by Trunk Highway 55 (TH-55) to the north, I-394 to the south, I-494 to the west and downtown Minneapolis to the east. The area is entirely within Hennepin County, and encompasses the municipal jurisdictions of Minneapolis, St. Louis Park, Golden Valley, Plymouth and Minnetonka.

A map of the MnDOT-owned traffic signal locations within the geographic area of the Connected Corridor is provided in Figure 2, and a summary of the physical characteristics of TH-55 and I-394 are provided in Table 1.

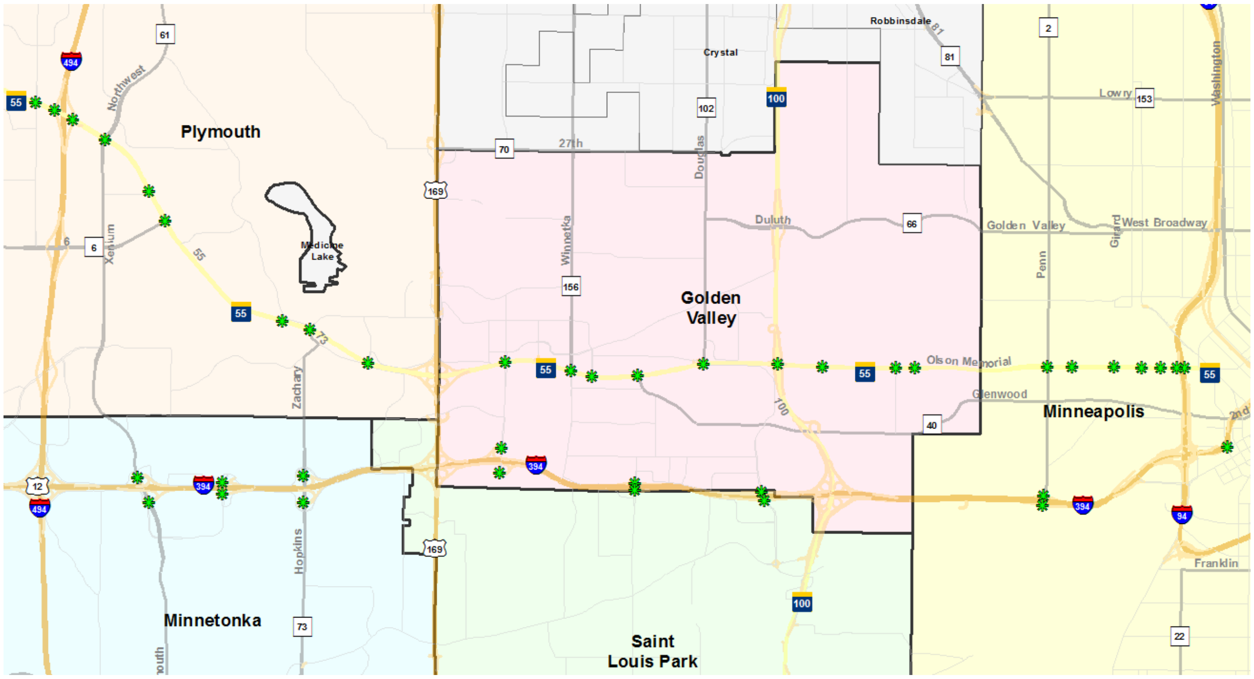

Figure 2: MnDOT Traffic Signal Locations

Table 1: TH-55 and I-394 Corridor Summary

Corridor	From	To	Speed Limit	Lanes of Travel		Notes*
				WB	EB	
MINNESOTA 55	I-494	Xenium/Northwest	55	2	3	
	Xenium/Northwest	Industrial Park	55	2	2	
	Industrial Park	CR-6	55	2	2	
	CR-6	Medicine Lake	55	2	2	School Bus Loading Area WB
	Medicine Lake	CR-73	55	2	2	
	CR-73	Revere	55	2	2	
	Revere	US-169	55	2	2	
	US-169	Boone	55	2	2	
	Boone	Winnetka	55	2	2	
	Winnetka	Rhode Island	55	2	2	
	Rhode Island	Glenwood	55	2	2	
	Glenwood	Douglas	55	2	2	
	Douglas	MN-100	50	2	2	
	MN-100	Schaper	50	2	2	
	Schaper	Theodore Wirth	50	2	2	BoS**
	Theodore Wirth	Thomas	50	2	2	
	Thomas	Penn	40	3	3	
	Penn	Bryant	40	3	3	
	Bryant	I-94	30	3	3	
INTERSTATE 394	I-494	Plymouth	55	2(1)	2(1)	
	Plymouth	Ridgedale	55	2(1)	2(1)	
	Ridgedale	Hopkins	55	2(1)	2(1)	
	Hopkins	US-169	55	2(1)	2(1)	
	US-169	General Mills	55	2(1)	2(1)	
	General Mills	Louisiana	55	2(1)	2(1)	
	Louisiana	Xenia/Park	55	2(1)	2(1)	
	Xenia/Park	MN-100	55 (60)	2(1)	2(1)	BoS**
	MN-100	Penn	55 (60)	3(2)	3(2)	
	Penn	Dunwoody	55 (60)	3(2)	3(2)	
	Dunwoody	I-94	55 (60)	3(1)	3(1)	
	I-94	12^{th}	40	3	2	

*Values in parenthesis () indicate express lane information.

**BoS: Bus on Shoulder

2 Current Situation and Needs

2.1 Current System Overview

It is important to document the transportation infrastructure currently in place in the location where the CC System will be deployed.

2.1.1 Traffic Signal Controllers and Traffic Signals

Existing traffic signal systems provide visual indications to drivers and do not communicate electronically with the vehicle. Countdown pedestrian indications are commonly used and may provide the driver with some basis for anticipating when the associated green indication may end, although they are not intended for that purpose.

Some existing traffic signal controllers may not be capable of outputting the real-time data needed to generate a SPaT message. At a minimum, the controllers may need a software upgrade to provide this function. Older controllers may not possess the processing power to support the function, and would need a hardware upgrade or complete replacement to provide the function. Standards governing the signal controller interface for SPaT related data are still evolving, and so even a controller that is currently outputting real time data supporting SPaT may need to be upgraded to interoperate with other roadside equipment and vehicles that utilize newer versions of the standards. Room in the signal controller cabinet for any additional equipment that will be needed for SPaT is also necessary.

2.1.2 ATMS: Arterial Operations

MnDOT uses a centralized control system for traffic signals with NEMA ASC3 controllers at the individual intersections connected to a wide-area network. The signal controllers are a mixture of types, but are migrating to Advanced Traffic Controller (ATC) units with Intelight's MaxView software for monitoring and system management functions.

The ASC controllers will meet the ATC 5201 standard version 6. These controllers will also support NTCIP 1202 traffic controller communication protocols. Signal Phase and Timing (SPaT) messages can be produced and transmitted DSRC roadside units, if connected. In addition, it is anticipated that connected vehicle applications will be supported by future ASC units.

The MaxView software supports several signal controllers, including:

- Intelight
  - MaxTime v1.7.x – HTTP
  - MaxTime v1.6.x – HTTP
  - MaxTime v1.6.x – NTCIP
- Econolite
  - ASC3 v2.47.00 – NTCIP
  - ASC2 v1.X – NTCIP
- McCain

- BiTran - AB3418E
- Generic NTCIP
  - Any NTCIP 1201/1202 Compliant Controllers – NTCIP

MnDOT's MaxView deployment allows them to "host" the signal control systems for the MnDOT Metro District (where the system resides) and other MnDOT districts. In the hosting configuration, MnDOT maintains the MaxView servers in a centralized location. Communication links are then established to the field network where signal controllers reside and the system configured to operate those controllers as desired by their respective owners. Access to the system user interface is also provided so that individual system owners can monitor, operate and maintain signal systems.

Dakota County, Minnesota also uses MaxView, purchased under the MnDOT contract agreement with Intellight. Hennepin County is evaluating a similar arrangement as an option for future signal upgrades.

MaxView does not currently provide real-time SPaT status for each signal controller through a common software interface. However, several private service providers are known to be engaged with Intelight to provide this functionality. It is anticipated that MaxView Version 2.0 (to be operational Summer 2018) will have this feature. MnDOT has recently implemented Arterial Traffic Signal Performance Measures (ATSPM). This system collects high resolution data from the signal controllers and calculates performance measures such as arrivals on green, arrivals on red and the Purdue Coordination Diagram[i].

Arterial operations share much of the infrastructure used for freeway operations (described in Section 2.1.3). The communications network used for arterial signal controllers in the metro area is the same fiber optic facility used for vehicle detection data, ramp metering, video surveillance and other functions. The RTMC facility consolidates video distribution and video wall functionality, so that arterial management assets such as DMS and CCTV cameras are available across both management domains.

2.1.3 ATMS: Freeway Operations

Freeway operations covers the limited-access highways statewide in Minnesota as well as major roadways and arterials in the Twin Cities Metro Area. These roadways are managed using an internally-developed software package called Intelligent Roadway Information System or "IRIS".

IRIS encompasses a wide range of functionality, including:

- Vehicle detection data collection
- Ramp meter operation
- Surveillance CCTV camera control
- Video wall control

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[i] Visualization and Assessment of Arterial Progression Quality Using High-Resolution Signal Event Data and Measured Travel Time. ftp://ftp.ecn.purdue.edu/darcy/379a/2009_07/Objective1_TRB_10-0039_offsetl.pdf

- Dynamic Message Sign Control
- Work zone queue detection and warning
- Incident management
- Weather sensor data management
- Road closure gate control
- Tolling system tag reader control and toll computation algorithms

IRIS was developed internally at MnDOT and has been released under an open source license (GPL v2) which has enabled its adoption by other agencies. Other users include the Wyoming DOT, Nebraska DOT, Kansas DOT, Caltrans (CA), Scott County (MN), City of Bloomington (MN), Mall of America and other private and academic institutions. The open nature of the software has led to numerous modifications and refinements of the software since its initial release in 2008.

The MnDOT IRIS deployment resides on servers located at the Regional Transportation Management Center (RTMC) in Roseville, Minnesota. This facility has multiple, redundant connections to the field network (primarily 1 and 10 gigabit fiber optic Ethernet loops) and provides back-up power for the system.

IRIS server software is written in Java and intended to run on GNU/Linux-family operating systems, although the software has been used on MS Windows platforms. The client (operator) software is delivered through Java NetStart technology, which eliminates the need for local software installations on individual workstations. The client software has been used on MS Windows and Linux workstations with identical functionality.

IRIS can communicate (poll) field devices on configurable intervals ranging from 5 seconds to 18 hours. The data from detectors (both lane by lane and aggregated "station" data) are published every 30 seconds. In addition, all DMS messages, incidents managed by the system and current geography and configuration data (analogous to the MAP message) are published on the same 30 second cycle.

The vehicle detection data is archived by MnDOT and can be accessed through a set of tools they have developed, but is not made available through an "on-line" API. Other information, such as DMS messages, is stored within the IRIS database, but is not accessible to the public.

IRIS remains under active development by its users and new versions are published by MnDOT every 4 to 8 weeks.

2.1.4 Dynamic Message Signs

The existing system contains Dynamic Message Signs (DMS) that are used to convey information to drivers on the roadway. DMSs are located periodically along limited-access highways and select arterial corridors. Information provided to drivers includes but is not limited to travel times, weather conditions, traffic conditions, special events, parking availability (includes park and ride), evacuation routes, and/or jurisdictional information. The messages displayed on DMSs are controlled by IRIS.

2.1.5 Backhaul Communications

The proposed Connected Corridor features an extensive and robust communications system. Each roadway (TH-55 and I-394) are serviced by a segment of a redundant fiber-optic loop. The metropolitan area is covered by several such loops, which terminate at the RTMC in Roseville, MN.

Primary loops offer 10 gigabit Ethernet-over-fiber connections, accessible in permanent, environmentally conditioned shelters throughout the area. Smaller segments and secondary loops use 1 gigabit Ethernet. All segments have multi-protocol label switching (MPLS) enabled for traffic shaping and access control.

This network is used for low-bandwidth applications such as traffic signal controller management as well as digital video distribution. MnDOT has roughly 550 cameras in the metro area, all of which encode 30 fps, D1 or higher resolution video. In addition, there is a dedicated fiber optic network for transporting uncompressed digital video for legacy camera systems that use an analog camera and separate video digitizer to encode data for transmission over the fiber.

Ethernet connections are available at all of the proposed sited for roadside installations for the CC System and the bandwidth needs of the project are not anticipated to be burdensome on the network. Proper access control, routing and network segmentation will be necessary to use the existing network and ensure the security of MnDOT operations.

2.2 Operational Polices and Constraints

There are no regulations in place that require a driver to receive CV data or to react to notifications 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, static signage, and lane markings).

- Minnesota Statutes Chapter 169 – Traffic Regulations
- Minnesota Statutes Chapter 13 – Government Data Practices
- Minneapolis Code of Ordinances Chapter 9 – Traffic
- Golden Valley City Code Chapter 8 – Traffic Regulations
- Plymouth City Code Chapter 13 Traffic, Motor Vehicles, and Other Vehicles, Section 1305 – Streets; Traffic[ii]
- St. Louis Park City Code Chapter 30 – Traffic and Vehicles[iii]
- City of Minnetonka Home Rule Charter Chapter 9 Public Safety, Section 930 – General Traffic Regulations[iv]

[ii] Plymouth City Code. http://www.plymouthmn.gov/home/showdocument?id=751
[iii] Plymouth https://www.stlouispark.org/home/showdocument?id=624
[iv] City of Minnetonka Home Rule Charter http://library.amlegal.com/nxt/gateway.dll/Minnesota/minneton/cityofminnetonkahomerulecharter?f=templates$fn=default.htm$3.0$vid=amlegal:minnetonka_mn

The current transportation system is designed in accordance with state design documents, including the MN MUTCD[v], the Traffic Signal Timing and Coordination Manual[vi], and the Signal Design Manual[vii]. While none of these documents pertain to outputs from a CV system, they can be used as a guide for determining when/where notifications and warnings should be issued to drivers.

2.3 Project Stakeholder Meeting Overview

A project stakeholder meeting designed to understand user needs and proposed solution concepts was held on October 24, 2017 to collect feedback from agencies that have an interest in leveraging the deployment of CV technology to solve various issues faced by those agencies. Stakeholders consist of representatives of cities that the TH-55 corridor passes though, MnDOT, Metro Transit, third-party data aggregators, United States Department of Transportation (USDOT), University of Minnesota, and members of the project team involved in the systems engineering process. A full list of attendees and the organizations they represent is given in **Error! Reference source not found.** in **Error! Reference source not found.**.

2.4 Current System User Classes

System Users will experience safety and mobility benefits from CV technology deployed on the roadside as part of the system designed in this document. Recall that the primary goal of the SPaT Challenge deployment is to deploy SPaT broadcasts via DSRC Roadside Units (RSU) that can serve as supporting infrastructure to CV Applications in passenger and fleet vehicles. In addition to broadcasting SPaT, the RSU will be able to broadcast and receive other types of messages (discussed in detail later in this document) to support needs specific to the TH-55 and I-394 corridors. CV drivers along with staff responsible for operating and maintaining the new equipment and systems are both considered to be System Users. Each user type is explained in the subsections below.

2.4.1 General Equipped Vehicle Operator

The General Equipped Vehicle Operator is a user class that is comprised of drivers of vehicles that will be equipped with CV technology as part of the Connected Corridor deployment. These vehicles may include, but are not limited to light-duty vehicles and trucks. In the current system, these drivers are typically responsible for operating their vehicle in a safe manner (according to regulations that govern the operation of motor vehicles) and utilize information from static and dynamic signage along the roadway, or other existing sources.

2.4.2 Transit Vehicle Operator

The Transit Vehicle Operator operates a transit vehicle along the TH-55 corridor that will be equipped with CV technology as part of the Connected Corridor deployment. Transit Vehicle Operators operate transit

[v] http://www.dot.state.mn.us/trafficeng/publ/mutcd/mnmutcd2015/mnmutcd-revision4.pdf
[vi] http://www.dot.state.mn.us/trafficeng/publ/signaloperations/2017signaloptandtimingmanual.pdf
[vii] http://www.dot.state.mn.us/trafficeng/publ/signaldesign/2016signaldesignmanual.pdf

vehicles along routes where CV roadside technology will be deployed and pedestrians utilize crosswalks at signalized intersections to cross the street. The role of the Transit Vehicle Operator involves picking up and dropping off passengers and safely operating the transit vehicle in the roadway environment. When the transit vehicle operator makes a movement through an intersection, they must be aware of pedestrians using signalized crosswalks in the transit vehicle's path of travel. The Transit Vehicle Operator must exercise caution to ensure that transit vehicle a-pillar does not occlude the pedestrian from view. Metro Transit lines that use or cross the TH-55 corridor: 19, 740, 741, 742, 755, 756, 772, 774, 777, 795.

2.4.3 Self-Equipped Drivers

Self-Equipped Drivers drive vehicles that are not directly involved in the Connected Corridor deployment, but are independently equipped with CV technology, and who travel through the corridors where CV roadside technology will be deployed, or in other areas where data will be shared wirelessly through non-infrastructure based mechanisms. Examples of Self-Equipped Drivers include those which carry a nomadic wireless device (such as a mobile device carried in and out of the vehicle), an after-market wireless device which is tethered to the vehicle, or are factory-equipped with an integrated CV system. Similar to the equipped vehicle operator, in the current system these drivers are typically responsible for operating their vehicle in a safe manner (according to regulations that govern the operation of motor vehicles) and utilize information from static and dynamic signage along the roadway, or other existing sources.

2.4.4 Unequipped Drivers

Unequipped Drivers are those which will not have an intermediate device or factory-integrated system that allows them to leverage data that is made available through the CC System. Currently, these drivers are typically responsible for operating their vehicle in a safe manner (according to regulations that govern the operation of motor vehicles) and utilize information from static and dynamic signage along the roadway, or other existing sources.

2.4.5 Snow Plow Operator

The primary responsibility of the snow plow operator is to operate a snow plow prior to, during, and after winter weather events where CV roadside technology will be deployed. This includes clearance of snow and ice, as well as the spreading of snow removal chemicals to improve the amount of time it takes to return to bare pavement after a winter weather event.

2.4.6 Pedestrian

Pedestrians, including pedestrians with disabilities, use crosswalks where CV roadside technology will be deployed. Pedestrians are expected to follow all rules and regulations associated with the use of crosswalks at signalized and unsignalized intersections. Furthermore, pedestrians may exercise added caution when using crosswalks to prevent an unsafe situation with a vehicle. Pedestrians are expected to push the pedestrian push button to request a 'walk' signal for certain crosswalks at signalized intersections.

2.4.7 Traveler Information Provider

Traveler Information Providers are typically private, third-party services which obtain traffic system data directly from vehicles (typically via mobile devices) and from traffic management systems (among other sources of data), process/aggregate it, and provide it to travelers through a smartphone app or cellular-enabled integrated vehicle system. Another example of a Traveler Information Provider is Minnesota 511. Similar to third-party services, the Minnesota 511 system provides travelers access to specific information in the traffic management system including traffic information, speeds, camera feeds, weather station information, plow locations and plow cameras via a web browser (511mn.org) and smartphone application (Minnesota 511 – Google Play Store and Apple App Store).

2.4.8 Work Zone Worker

Work zone workers are currently responsible for temporary maintenance activities that may occur within the roadway or along the shoulder of the roadway. Such activities are often short in duration or move very slowly in the roadway. Examples of maintenance activities performed by work zone workers include but are not limited to pavement repair (sealing cracks, filling potholes), pavement inspection, street sweeping, and landscaping. Prior to engaging in maintenance activities, a work zone worker must establish the required temporary traffic control measures that warn drivers about the work zone upstream of the work zone location. This is done in order to give the driver of approaching vehicle increased awareness of downstream roadway activity that will ultimately improve the safety of both the driver and the work zone worker.

2.4.9 Traffic Operations Manager

The Traffic Operations Manager is responsible for managing roadway network operations. Through IRIS and MaxView, it is the responsibility of the Traffic Operations Manager to monitor traffic conditions and to implement traffic management strategies when warranted. Furthermore, the software used by the Traffic Operations Manager makes data available to third-party data aggregators to disseminate roadway condition information to the public.

2.5 User Needs and General System Needs

Collectively, feedback from the stakeholder group and the MnDOT leadership team on challenges encountered with the current system culminated in a list of specific user needs, as summarized in **Error! Reference source not found.**. These user needs will be addressed through the deployment of applications enabled through the CC System. Use cases and scenarios are developed in Section 5 of this document to ensure that the CC System concept addresses these needs. The last group of needs in **Error! Reference source not found.** are system needs. It is important to note that these needs are essentially constraints on the CC System that allow it to operate as intended. System needs are not explicitly captured in the scenarios in Section 5 of this document.

Table 2: User Needs and General System Needs to Support MnDOT Connected Corridor Functions and Applications

Challenge	Need ID	Need
General Equipped Vehicle Operator and Transit Vehicle Operator Needs		
In-Vehicle equipment running applications need intersection data to support those applications	UN-CC-1.01-v01	**Signal Phase and Timing**. A General Equipped Vehicle Operator needs advance notice of signal phase and timing changes to safely approach an intersection.
Vehicle Operators may be unaware that they are approaching a short term mobile work zone or snow plow actively engaging in operations	UN-CC-1.02-v01	**Dynamic Roadway Maintenance Activity Awareness**. A General Equipped Vehicle Operator needs to be aware of dynamic maintenance activities (e.g. snow plowing, pothole filling) in/along the path of travel
General Vehicle Operator and Transit Vehicle Operator are not aware of pedestrian in crosswalk due to a-pillar occlusion	UN-CC-1.03-v01	**Pedestrian in Crosswalk Awareness.** A General Equipped Vehicle Operator Driver and Transit Vehicle Operator need increased awareness of a pedestrian in a crosswalk when making a movement at a signalized intersection due to occlusion by the vehicle a-pillar to reduce the likelihood of a pedestrian crash
Self-Equipped Driver and Unequipped Driver User Needs		
CV Self-Equipped Drivers do not have direct, real-time access to data from roadside devices	UN-CC-2.01-v01	**On-Board/Nomadic Device Data.** A Self-Equipped Driver needs freely available CV data to support CV applications for On-Board/Nomadic Devices that provide safety/mobility/etc. benefits to the driver. The data provided to On-Board/Nomadic Devices is expected to be the same data that is used to address the needs of General Equipped Vehicle Operators.
Drivers may be unaware that they are approaching a short term mobile work zone or snow plow actively engaging in operations	UN-CC-2.02-v01	**Unequipped Driver Dynamic Roadway Maintenance Activity Awareness**. An Unequipped Driver needs to be aware of dynamic maintenance activities (e.g. snow plowing, pothole filling) in and along the path of travel
Snow Plow Operator Needs		
Uneven application of snow removal chemicals from stopping and raising plow blade to accelerate from a stopped position at a signalized intersection	UN-CC-3.01-v01	**Reduced Disruption of Plow Operations at Signalized Intersections.** A Snow Plow Operator needs reduced disruption of snow plow operations at signalized intersections, otherwise this will result in incomplete snow removal and uneven application of surface treatments

Table 2: User Needs and General System Needs to Support MnDOT Connected Corridor Functions and Applications

Challenge	Need ID	Need
Disruption of Gang Plow operations due to stopping at offramp/onramp signalized intersection	UN-CC-3.02-v01	**Minimize Disruption to Gang Plow Operations.** A Snow Plow Operator needs to reduce delay at an interchange ramp intersection to minimize disruptions of freeway gang plow operations.
Drivers may create unsafe operating conditions around snow plows actively engaged in operations	UN-CC-3.03-v01	**Improve Snow Plow Operator Safety.** A Snow Plow Operator needs safe work environment where approaching vehicle operators are aware of the snow plow actively engaged in plowing operations
Pedestrian Needs		
Not noticed by drivers when in a crosswalk	UN-CC-4.01-v01	**Pedestrian in Crosswalk Safety.** A Pedestrian in a crosswalk needs to be seen by drivers and vehicle operators to maintain safety while in crosswalk
Traveler Information Provider Needs		
Traveler Information Providers do not have direct, real-time access to SPaT data from traffic signal controllers	UN-CC-5.01-v01	**Third-Party Data Services.** A Traveler Information Provider needs access to real-time SPaT data to provide traveler information services to its users.
Work Zone Worker Needs		
Drivers may create unsafe operating conditions in mobile short-term work zones.	UN-CC-6.01-v01	**Work Zone Worker Safety.** A Work Zone Worker needs a safe work environment where approaching vehicle operators are aware of the work zone activity
Traffic Operations Manager Needs		
Obtaining more accurate data that represents roadway network operations	UN-CC-7.01-v01	**Traffic Management Data.** The Traffic Operations Manager needs to collect timely, accurate, and reliable vehicle location/motion and signal status data to better inform traffic management decision support systems and for the implementation of traffic management strategies
Disseminating system data in real-time so that it can be used by drivers	UN-CC-7.02-v01	**Data Dissemination.** The Traffic Operations Manager needs to quickly disseminate vehicle location/motion and signal status data to provide travelers with actionable information
Providing information to all vehicle operators and drivers regarding work zone and snow plow operations	UN-CC-7.03-v01	**Dynamic Roadway Maintenance Activity Information.** The Traffic Manager needs to be able to provide work zone information and dynamic maintenance activity information to travelers

Table 2: User Needs and General System Needs to Support MnDOT Connected Corridor Functions and Applications

Challenge	Need ID	Need
Processing all roadway network operations data in a timely manner to support operations	UN-CC-7.04-v01	**Data Processing Support System.** The Traffic Operations Manager needs to process network operations data received from field devices to better inform traffic management decision support systems and for the implementation of traffic management strategies (This could be done by IRIS or performed by a third-party)
Services are required to keep the CC System functioning as intended	UN-CC-7.05-v01	**CC System Support.** The Traffic Operations Manager needs to maintain and update intersection geometry data to ensure travelers are receiving up-to-date intersection geometry data
Degraded Operating Conditions may arise	UN-CC-7.06-v01	**Remote Diagnostic.** The Traffic Operations Manager needs to be aware of and diagnose system malfunctions so that they can be quickly resolved
Agency Needs		
Lack of institutional experience with deploying CV systems	UN-CC-8.01-v01	**DSRC Experience.** The Agency needs to gain institutional knowledge of DSRC systems to: 1. Benefit from valuable procurement, licensing, installation, and operation experience, 2. Understand staffing needs and core competencies required to support such systems, and 3. Demonstrate a commitment (to auto manufacturers and app developers) toward establishing DSRC roadside infrastructure
Demonstrating the successful deployment of CV technology	UN-CC-8.02-v01	**DSRC Demonstration.** The Agency Needs to demonstrate that CV technology has been deployed successfully, and provides in-vehicle devices with standardized fundamental messages (SPaT, MAP, RTCM, TIM) that can be used to support in-vehicle applications.
System Needs		
Wireless communication between equipment on the roadside and equipment in a vehicle	SN-CC-9.01-v01	**Roadside/Vehicle Connectivity.** A roadside device needs to communicate with in-vehicle devices in the roadway environment to enable vehicle-based and infrastructure-based safety, mobility, and environmental applications.
Communications between CC System and Traffic Signal Controller	SN-CC-9.02-v01	**CC System/Traffic Signal Controller Connectivity.** The CC System needs to communicate with the Traffic Signal Controller to support the transmission of data that supports and infrastructure-based safety, mobility, and environmental applications.
Communications between CC System and MaxView	SN-CC-9.03-v01	**CC System/MaxView Connectivity.** The CC System needs to communicate with MaxView to support the transmission of data that supports Data Exchange activities
Communications between CC System and IRIS	SN-CC-9.04-v01	**CC System/IRIS Connectivity.** The CC System needs to communicate with IRIS to support the transmission of data that supports dissemination of information via DMS.

Table 2: User Needs and General System Needs to Support MnDOT Connected Corridor Functions and Applications

Challenge	Need ID	Need
Positioning a vehicle in the roadway environment	SN-CC-9.05-v01	**Vehicle Positioning.** An in-vehicle device needs to have available positioning information to position itself in the roadway environment.
Correcting positioning errors	SN-CC-9.06-v01	**Roadside Position Correction.** Fixed-location roadside devices require access to position correction information so that vehicles can receive corrections and update their positioning data.
Synchronizing time sources across multiple devices	SN-CC-9.07-v01	**Vehicle Time Synchronization.** An in-vehicle device needs to be synchronized with a common time source to be synchronized with roadside devices.
Synchronizing time sources across multiple devices	SN-CC-9.08-v01	**Roadside Time Synchronization.** A roadside device needs to be synchronized with a common time source to be synchronized with in-vehicle devices.
Protecting data sent via physical communications media from unauthorized access	SN-CC-9.09-v01	**Physical Communications Security.** A Roadside Device needs to implement state of the practice security to support wired communications security protocols for physical networks.
Protecting data sent via wireless communications media from unauthorized access	SN-CC-9.10-v01	**Roadside Wireless Communications Security.** A Roadside Device needs to be connected to a Security Credential Management System (SCMS) to support wireless communications security protocols for roadside DSRC devices.
Protecting data sent via wireless communications media from unauthorized access	SN-CC-9.11-v01	**Vehicle Wireless Communications Security.** An in-vehicle device needs to be connected to the SCMS to support wireless communications security protocols for in-vehicle DSRC devices.

3 Concept of Operations for the Connected Corridor System

3.1 Proposed System Overview

The CC System will be deployed along the TH-55 and I-394 corridors from downtown Minneapolis (I-94) to I-494 and in select vehicles. The deployment of in-vehicle devices will be targeted toward general equipped vehicles, snow plows and work zone vehicles. For the purpose of initial deployment, it is anticipated that transit vehicles will be used to represent general equipped vehicle users due to the partnership with Metro Transit and the controlled nature of the vehicle fleet. Other CV-equipped vehicles are expected to interact with the Connected Corridor, but are considered part of the existing system for the purposes of the operational concept. The Connected Corridor 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 (includes security and privacy concerns), modes of operation, user classes, and the support environment.

This section will be the primary source for functional requirements defined in a subsequent requirements documents. For this reason, paragraphs are numbered to allow each requirement to reference the operational function that is the source of the requirement. Figures 3 and 4 illustrate the context diagram of the CC System.

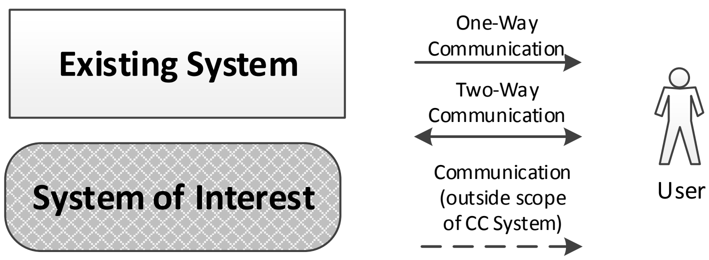
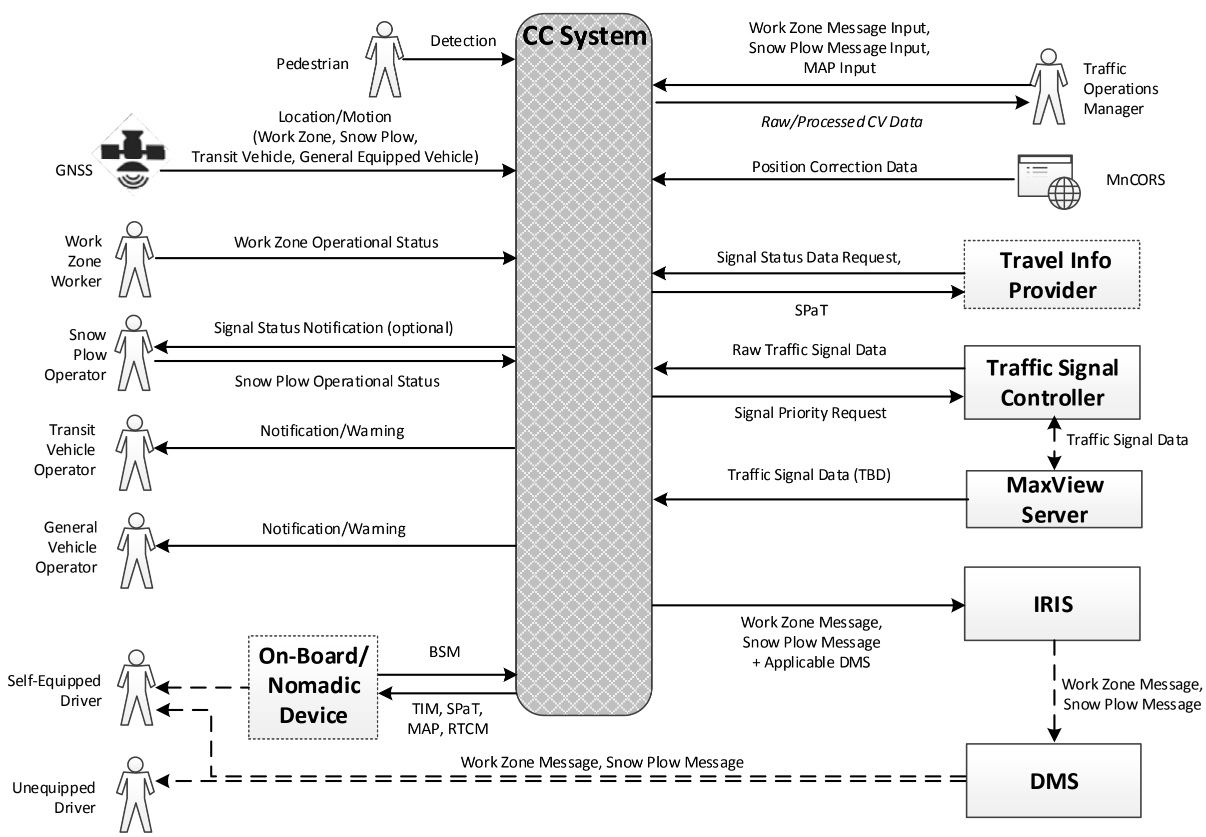


Figure 3: Context Diagram Legend



Acronym	Definition	Acronym	Definition
BSM	Basic Safety Message	MnCORS	Minnesota DOT Continuously Operating Reference Station
DMS	Dynamic Message Sign	RTCM	Radio Technical Commission for Maritime Services Correction Message
GNSS	Global Navigation Satellite System	SPaT	Signal Phase and Timing Message
IRIS	Intelligent Roadway Information System	TIM	Traveler Information Message
MAP	MapData Message		

*Private On-Board/Nomadic Devices are not specifically designed as part of the MnDOT Connected Corridor system. However, the RSU is expected to receive BSMs (that conform to current DSRC messaging standards) from private vehicles to support traffic management activities.

Figure 4: MnDOT Connected Corridor System Context Diagram

3.2 Use Cases for the System

As discussed in Section 2.3, several overarching issues were elicited from the stakeholder meeting. After the conclusion of the stakeholder meeting, the project leadership team met to confirm that the issues discussed during the stakeholder meeting conformed to project goals. The leadership team refined the details of stakeholder needs to develop objectives for the system. The resulting Connected Corridor objectives include:

- Communicating SPaT data (along with other vehicle-based data, such as Basic Safety Messages (BSM)) in order to respond to the SPaT Challenge and gain experience with DSRC infrastructure and CV data management
- Reducing crashes between vehicles and pedestrians (esp. left/right turning)
- Improving the efficiency of spreading de-icing treatments by reducing stops at signalized intersections
- Improving the efficiency and safety of snow clearance operations by reducing stops at signalized intersections
- Enhancing mobility by providing real-time traffic signal data to motorists via third-party data aggregators
- Providing improved, real-time traveler information regarding short-term maintenance operations

Six use cases were identified to address these objectives. Table 3 shows the proposed use cases for the CC System and their relationship to the users of the system, as identified in Section 2.

Table 3: User Classes Involved with Proposed Use Cases

User Class	Use Cases					
	SPaT	Vehicle-Pedestrian Intersection Conflict Warning	Snow Plow Signal Priority	CV Data Mgmt	Third-Party Traffic Signal Data Sharing	Mobile Work Zone Warning System

General Equipped Vehicle Operator	X	X				X
Transit Vehicle Operator		X				
Self-Equipped Driver	X*	X*			X*	X*
Unequipped Driver						X
Snow Plow Operator			X			X
Pedestrian		X				
Traveler Information Provider					X	
Work Zone Worker						X
Traffic Operations Manager	X			X	X	X

*Use cases are enabled for Self-Equipped Drivers if they are properly equipped. The scope of the CC System is to make data available to these drivers so that they can use personal nomadic/in-vehicle devices to enable processes and outputs associated with these use cases.

3.2.1 Signal Phase and Timing (SPaT)

The Signal Phase and Timing use case provides SPaT and other associated messages to properly equipped vehicles in order to provide information regarding the signal state and the amount of time until the current phase ends to equipped drivers and vehicle operators. The messages enabling SPaT are governed by the Society of Automotive Engineers (SAE) J2735 DSRC message set dictionary. In addition, the SPaT use case supports other use cases both included and outside of the scope of the CC System.

This data enables a General Equipped Vehicle Operator to accurately obtain in-vehicle information regarding the signal state (phase) and the amount of time until the next phase ends. On-Board/Nomadic Devices on self-equipped vehicles are expected to receive SPaT data, though it is outside of the scope of the CC System to specify what On-Board/Nomadic Devices should do with this data once it is received.

3.2.2 Vehicle-Pedestrian Intersection Conflict Warning

The Vehicle-Pedestrian Intersection Conflict Warning use case alerts drivers when a pedestrian is in a crosswalk at a signalized intersection along the vehicle's intended path of travel. Given that the CC System will include SPaT-capable DSRC-based CV infrastructure to fulfill the SPaT use case, it is assumed that the vehicle-pedestrian intersection conflict warning will utilize this infrastructure to illustrate the potential use cases of DSRC-based infrastructure.

The 'active detection' of pedestrians is enabled through the deployment of one or more infrastructure-based detection units that senses the presence of pedestrians in a specified area (corresponding to crosswalks at an intersection). An alternative means of 'passive detection' may also be implemented based on the activation of the pedestrian push button. In either case, the CC System utilizes either active or passive pedestrian detection as a means of determining when to modify the 'pedestrian-in-crosswalk' content of a SPaT message at the intersection.

A vehicle on-board system would receive information from the infrastructure and determine if its projected path will traverse the crosswalk occupied by the pedestrian. If so, the vehicle on-board system would produce an alert to the driver as a warning to increase the driver's awareness of the situation, which may result in the driver acting to avoid a potential collision with the pedestrian.

3.2.3 Snow Plow Signal Priority

The Snow Plow Signal Priority use case allows a snow plow to request priority at a signalized intersection. Given that the CC System will include SPaT-capable DSRC-based CV infrastructure in order to fulfill the SPaT use case, it is assumed that snow plow signal priority will utilize this infrastructure as a way to illustrate the potential use cases of DSRC-based infrastructure.

Requesting priority is enabled through the broadcast of a message by the snow plow. Once received on the roadside, the traffic signal controller determines if the priority request can be granted. Equipment of the roadside then broadcasts a message in response, which indicates whether the request was granted. Though received by the vehicle, this information may or may not be provided to the snow plow operator.

3.2.4 Connected Vehicle Data Management

CV technology deployed on vehicles as part of the CC System will broadcast BSMs and other messages based on the SAE J2735 message set, and On-Board/Nomadic Devices are expected to be capable of broadcasting BSMs. While these messages are typically used to enable safety or mobility applications, they can also be captured by roadside CV equipment and sent to a transportation management center where it can be used to support traffic management activities. The CV data management use case will involve the capture, processing and storage of BSM data in order to support MnDOT in gaining experience with CV data management, and to create a platform for future processing of this data for other purposes, such as asset management, traffic operations, and traveler information. This use case will be facilitated via the **Connected Vehicle Data Exchange** subsystem of the CC System.

The CV Data Exchange subsystem will ingest, process, and store vehicle- and infrastructure-based CV messages produced by the CC System (and future system expansions), into an information management system. In the future, the information management system may process the incoming data to screen out any sensitive elements and provide access to other stakeholders for use in traffic management, planning, asset management, or other functions. Details regarding the management of CV Data will be provided in the Connected Corridor Data Governance Plan.

3.2.5 Third-Party Traffic Signal Data Sharing

Real-time traffic signal data can be used to support a range of mobility and environmental applications. Traveler Information Providers have an interest in obtaining this real-time traffic signal data to provide services to their customers, through both smart-phone applications and integrated vehicle systems. In this use case, MnDOT will share available regional real-time traffic signal data to Traveler Information Providers in order to indirectly provide benefits to Self-Equipped Drivers in the region. It is important to note that dissemination of this data by Traveler Information Providers and the end-use of the data by Self-Equipped Drivers is outside the scope of the CC System. However, Traveler Information Providers are known to use traffic signal data elements provide drivers with a countdown to the signal phase change, which can support improved fuel efficiency by allowing drivers to modify an approach speed to a signal to avoid coming to a full stop. In addition, Traveler Information Providers are known to be using this data to develop predictive algorithms for phase changes in order to provide other value-added services.

This use case will be facilitated via the **Connected Vehicle Data Exchange** sub-system of the CC System. All Traveler Information Providers will be treated equally by the system, enabling any entity to access the data to encourage the development of new driver-focused applications or to enhance existing applications. Without a well-documented, centralized interface to the data, it may be difficult for third party developers to create innovative applications to use it. While the interface has not been finalized, there are certain protocols and data formats/structures that have traditionally been used to allow developers to interface a remote device with an enterprise (such as the CV Data Exchange).

3.2.6 Mobile Work Zone Warning

The Mobile Work Zone Warning use case provides information to drivers and vehicle operators regarding moving work zones, including short-term maintenance, street sweeping and snow plow activity. In this application, the work zone worker or snow plow operator provides an input to the system to indicate that they are actively engaged in work zone or snow plow operations (this input could be explicit, or automatic - a function of the state of the existing system, such as the status of a flashing arrow board or if a plow blade is lowered). When active, the system provides the location of the active work zone or snow plow to the traffic management center. The Traffic Operations Manager provides a message that should be displayed to drivers regarding the work zone or snow plow. Based on the location of the work zone or snow plow, the system will provide the Traffic Operations Manager-specified message to drivers via a nearby DMS (temporarily overwrites existing message, if existing message is of lower priority) and in-vehicle messages to general equipped vehicle operators, and self-equipped drivers with properly outfitted on-board systems.

When presented with this information, the driver's awareness of work zone or snow plow activities is heightened. The driver can exercise caution (e.g. change lanes or decrease speed) as they approach the work zone or snow plow, improving their safety and the safety of the work zone worker or snow plow operator.

After a period of time (fixed or variable depending on conditions), the DMS reverts back to the message it was originally displaying prior to the mobile work zone or snow plow warning.

3.3 Description of the Proposed System

3.3.1 Physical System Deployment

The CC System relies on communication between back-end systems, roadside devices and vehicle operators, which will require equipment on the roadside and in vehicles to provide a means of receiving and transmitting data, as well as processing it to perform system functions. The following sections discuss the nature of this physical deployment.

3.3.1.1 Roadside Equipment

Roadside Equipment is the terminology used for all equipment that is located on the roadside that enable CC System functions. Roadside equipment may be co-located with signalized intersections, but also may be located at unsignalized intersections or intermittently along roadway corridors.

A message handler/processor on the roadside is responsible for receiving data from other roadside devices and the ATMS, processing it, and forwarding the output onto the proper device or ATMS to support CC System functions. Devices that may be on the on the roadside that need to communicate may include:

- Traffic Signal Controller
- GPS receiver
- Pedestrian Detection Equipment (depending on the need to support Vehicle-Pedestrian Intersection Collision Warning at each specific roadside deployment location)
- DSRC Roadside Unit communications equipment (RSU)

Should DSRC be used to enable V2I communications, the RSU would be responsible for broadcasting messages and receiving messages via DSRC (Note: the system is not limited to DSRC). A document detailing the RSU specifications was produced by FHWA in April 2017 (Revision 4.1, Version 5, at the time this document was written). The RSU specification establishes the base functionality of a carrier-grade device capable of acting as the infrastructure first point-of-contact for vehicles and other mobile devices.[viii] V2I communications could also occur via 4G LTE, which would be accomplished by routing the data through a wireless data service provider.

3.3.1.2 In-Vehicle Equipment

In-Vehicle Equipment is the terminology used to describe all equipment inside of vehicles that enable CC System functions. The two primary types of in-vehicle communications equipment are On-Board Units (OBUs) and mobile devices. OBUs are characterized by their ability to communicate via DSRC, while mobile devices communicate via 4G LTE. As communications technology evolves, OBUs and mobile devices are expected to become C-V2X- and 5G-capable (these media are discussed in more detail in Section 3.3.4.1). Most if not all OBUs and mobile devices are also able to communicate via Wi-Fi and Bluetooth.

The vehicle-based CV technology used by general equipped vehicle operators, snow plow operators, and work zone workers will be designed and deployed as part of this project. Devices in these vehicles, at a minimum, will be expected to receive GNSS data via satellite, and have a user interface with which to communicate with the vehicle operator. These in-vehicle devices may also may receive data from the vehicle databus, and will likely be able to communicate via DSRC and/or 4G LTE.

[viii] Dedicated Short Range Communications Roadside Unit Specifications
https://ntl.bts.gov/lib/61000/61700/61794/FHWA-JPO-17-589.pdf

Snow Plows are expected to be equipped with in-vehicle equipment that support the Snow Plow Signal Priority and Mobile Work Zone Warning System use cases. Work Zone Vehicles are expected to be equipped with in-vehicle equipment that support the Mobile Work Zone Warning use case. Finally, Work Zone Vehicles will be equipped with in-vehicle equipment that support Mobile Work Zone Warning use case.

3.3.1.3 Back-End Equipment

Back-end equipment refers to any equipment necessary to enable the CC System that would reside neither at the roadside nor on a vehicle. This may include equipment necessary to support the CV data exchange subsystem, network equipment to support linkages to Internet-enabled connections, such as third-party data sharing and security services, and necessary interfaces to the Traffic Operations Manager. This equipment is most likely to be co-located with MnDOT's RTMC in Roseville, although a final location is not yet determined.

3.3.2 Information Exchanged Over the System

The use cases will be enabled through the exchange of various types of information between the CC System and external components. Messages between the CC System and external components must adhere to established industry message standards in order to achieve CC System functionality. These standards apply to any communications internal to the CC System (established later in the system design process). Other non-standardized inputs and outputs (such as work zone and snow plow operational status input, work zone and snow plow message input, and notification and warning outputs) will also be discussed.

Various data standards will govern communications for the CC System. The Society of Automotive Engineers (SAE) is the recognized authority for establishing standards for communication to and from vehicle systems. The National Transportation Communications for ITS Protocol (NTCIP) establishes standards for communication to and from infrastructure-based ITS devices. A summary of these data standards is provided in Table 4.

Table 4: Data Standards

Standard Number and Title	
SAE J2735	Dedicated Short Range Communications (DSRC) Message Set Dictionary
SAE J2945/1	On-Board System Requirements for V2V Safety Communications
SAE J2540/2	International Traveler Information Systems Phrase Lists
NTCIP 1202	National Transportation Communications for ITS Protocol - Object Definitions for Actuated Traffic Signal Controller (ASC) Units
NTCIP 1203	National Transportation Communications for ITS Protocol - Object Definitions for Dynamic Message Signs

3.3.2.1 Signal Phase and Timing (SAE J2735 SPaT Message)

The Signal Phase and Timing (SPaT) message is used to convey the current status of one or more signalized intersections. Along with the MapData (MAP) message (which describes a full geometric layout of an intersection) the receiver of this message can determine the state of the signal phasing and when the next expected phase will occur. The SPaT message uses the same intersection ID that the MAP message uses. For each intersection, the message can provide information for up to 254 signal groups, which relate to signal phases.

The SPaT message contains the current signal state of each approach to an intersection. Additionally, it may optionally include timing details such as the start time of the phase, the min/max end times of the phase, and the best estimate of the end time of the phase. Movements are mapped to specific approaches and connections of ingress to egress lanes are specified. The current signal preemption and priority status values (when present or active) are also sent.

In the Context of the CC System SPaT messages are expected to be constructed using data made available by the traffic signal controller. Once constructed, the SPaT message can be used by the CC System to enable functions associated with the SPaT application and the Vehicle-Pedestrian Intersection Conflict Warning application. SPaT messages can also be broadcasted from the roadside and received by In-Vehicle/Nomadic Devices to support the SPaT application. Though not designed as part of this project, In-Vehicle/Nomadic Devices can use these SPaT messages to enable applications on self-equipped vehicles.

3.3.2.2 Intersection Geometry (SAE J2735 MAP Message)

The MAP message conveys many types of geographic road information. Its primary use is to convey one or more intersection lane geometries within a single message. A given single MAP message may convey descriptions of one or more geographic areas or intersections. The contents of this message involve defining the details of indexing systems that are used in SPaT messages to relate additional information (such as the current signal state) to specific geographic locations on the roadway.

Map messages are provided to the CC System by the Traffic Operations Manager, who is responsible for providing intersection geometry updates as intersection geometry is altered. The MAP message can be used by the CC System to enable functions associated with the SPaT application, Vehicle-Pedestrian

Intersection Conflict Warning application, and the Snow Plow Signal Priority application. MAP messages can also be broadcast from the roadside and received by In-Vehicle/Nomadic Devices to support the SPaT application. Though not designed as part of this project, In-Vehicle/Nomadic Devices can use these MAP messages to enable applications on self-equipped vehicles.

3.3.2.3 Position Correction (SAE J2735 RTCM Corrections Message)

The Radio Technical Commission for Maritime Services (RTCM) Corrections message provides differential corrections for GPS and other radio navigation signals. In the Context of the CC System RTCM Corrections messages are expected to be constructed using data made available by MnCORS. Once constructed, the RTCM Corrections message can be used by the CC System to enable functions associated with the SPaT, application, Vehicle-Pedestrian Intersection Conflict Warning application, and the Snow Plow Signal Priority application. RTCM Corrections messages can also be broadcasted from the CC System and received by In-Vehicle/Nomadic Devices to support the SPaT application. Though not designed as part of this project, In-Vehicle/Nomadic Devices can use these RTCM Corrections messages to enable applications on self-equipped vehicles.

3.3.2.4 Location and Motion (SAE J2735 BSM Part I)

The Basic Safety Message (BSM) is used in a variety of CV applications to exchange safety data regarding vehicle state. From a vehicle, this message is broadcasted frequently to surrounding vehicles with data content as required by safety and other applications. Part I of the Basic Safety Message (BSM) is typically used to support safety-of-life applications through wireless communications. Data contained in this messages includes location (latitude/longitude), elevation, positioning accuracy, transmission state, speed, heading, steering wheel angle, acceleration (lateral, longitudinal, vertical, yaw), brake system status, and the vehicle size. Such data is generally obtained from a GNSS and/or a vehicle data bus. These messages are nominally broadcast from a vehicle at a rate of 10 times per second, when congestion algorithms do not specify a reduced rate (specified in SAE J2945-1).

In the context of this project, BSMs could be used to enable the communication of location/motion data of vehicles operating in the roadway environment to the CC System. Though outside the scope of the system, On-Board/Nomadic devices are expected to be capable of broadcasting BSMs. If the CC System is designed to receive and decode messages to the same standards used to send BSMs from On-Board/Nomadic devices, the system will be able to receive these BSMs, which can be used as an input to the CV Data Exchange subsystem. Furthermore, BSMs could be used to communicate snow plow or work zone location data from the vehicle to the roadside to determine which DMSs should display snow plow or work zone ahead messages as part of the Mobile Work Zone Warning application.

3.3.2.5 Traveler Information Message (SAE J2735 TIM)

The Traveler Information message is used to send various types of information (advisory and road sign types) to equipped devices. It makes heavy use of the International Traveler Information Systems (ITIS) encoding system (SAE J2540/2) to send well known phrases, but allows limited text for local place names. The expressed messages are active at a precise start and duration period, and contain an affected local area which can be expressed using either a radius system or a defined region.

The TIM message could be used by the CC System to enable functions associated with the Mobile Work Zone Warning application. For further details regarding the Mobile Work Zone Warning System, see Section 5.4. TIM messages can also be broadcast from the CC System and received by In-Vehicle/Nomadic Devices. Though not designed as part of this project, In-Vehicle/Nomadic Devices can use these TIM messages to enable applications on self-equipped vehicles.

3.3.2.6 Signal Priority Request (SAE J2735 SRM)

The Signal Request Message is used to request signal priority or preemption. Each request defines a path through the intersection which is desired in terms of lanes and approaches to be used. Each request can also contain the time of arrival and the expected duration of the service. In the context of the CC System, The Signal Request Message (SRM) could be used by the CC System to enable functions associated with the Snow Plow Signal Priority Application. For further details regarding the Snow Plow Signal Priority, see Section 5.3.

3.3.2.7 Signal Status Message (SAE J2735 SSM)

The Signal Status Message communicates the current status of the signal and the collection of pending or active preemption or priority requests acknowledged by the controller. It also sends information about preemption or priority requests which were denied. The data contained in this message provides a "ranking" among all requestors, as well as to see the currently active requests. Once priority has been executed, the active priority active event is also reflected in the contents of the SPaT message. In the Context of the CC System, the SSM can be used by the CC System to enable functions associated with the Snow Plow Signal Priority application. For further details regarding the Snow Plow Signal Priority application, see Section 5.3.

3.3.2.8 Work Zone and Snow Plow Operational Status (input)

The CC System will accept input from the snow plow operator or work zone worker to indicate they are actively engaged in plowing or work zone operations. This input is used to determine when to provide a notification to General Equipped Vehicle Operators or a message to a DMS. This input could be manually provided by the snow plow operator or work zone worker, or could be a function of the output of an existing system on the snow plow (such as the blade status) or work zone vehicle (such as the flashing arrow status).

3.3.2.9 Work Zone and Snow Plow Message (input)

The CC System will accept input from the Traffic Operations Manager that specifies a message to display to General Equipped Vehicle Operators and on DMSs when snow plow and work zone operations are active. Ideally, the traffic manager provides this message input once, and the message is utilized in the CC System as needed.

3.3.2.10 Notifications and Warnings (output)

The CC System will provide various types of notifications and warnings to drivers that operate vehicles that will be equipped as part of the CC System. The SPaT use case provides a notification to a General Equipped Vehicle Operator that specifies the current signal state, and the amount of time until the next phase ends. The Vehicle-Pedestrian Intersection Conflict Warning provides a notification to a General Equipped Vehicle Operator when there is a pedestrian in the path of the vehicles, and a warning when a pedestrian collision is more imminent. The Snow Plow Signal Priority optionally provides a notification to the Snow Plow Operator regarding the status of a signal priority request. Finally, the Mobile Work Zone Warning System provides a notification to General Equipped Vehicle Operators when they are approaching an active work zone or snow plow.

3.3.3 External Hardware and Systems

3.3.3.1 Traffic Signal Controller

The Traffic Signal Controller is responsible for many of the same functions as it is in the current system, along with added functions that are needed to support the CC System. The Traffic Signal Controller will output the data elements need to form the SPaT message and to support all use cases that require traffic signal controller data (SPaT, Vehicle-Pedestrian Intersection Warning, Snow Plow Signal Priority, third-party data sharing). Due to the safety-of-life nature of some of these use cases, the traffic signal controller must make data available at a high frequency. Many newer signal controllers are capable of outputting the most recent signal status at a frequency of 10 times per second to meet the safety needs of users. The traffic signal controller must also output data that can be used to generate the optional output to the snow plow operator which indicates the status of the signal priority request.

Furthermore, the traffic signal controller must receive signal priority requests as they are generated by the CC System to enable the Snow Plow Signal Priority use case. These requests are expected to include the approach that priority is being requested for, as well as the estimated time of arrival at the intersection. The Traffic Signal Controller will process priority requests received from the CC System, together with other requests, according to the current algorithms for signal control. Depending on the existing system, this process may be performed by the traffic signal controller, or the traffic signal controller may communicate with the traffic central signal control system for to determine eligibility to receive priority and to arbitrate between multiple requests.

3.3.3.2 MaxView

As descried previously, MaxView is the centralized control system for traffic signals on the MnDOT roadways. It is a software that allows for monitoring and system management functions. In the context of the CC System, MaxView could potentially be used to support the Snow Plow Signal Priority as it has the ability to process and respond signal priority requests. It may also play crucial role in the CV Data Exchange, as MaxView supports the transmission of data that supports data exchange activities. However, it is important to note that this capability is only available on MaxView 2.0, which is expected to be deployed in Summer 2018.

3.3.3.3 IRIS

As described in Section 2.1, IRIS is an advanced traffic management system. It is used to control field devices and collect, store, process and distribute real-time and archived traffic flow data. IRIS enables the support of an increasing number of field devices and is considered a potential control system for any new ITS device. IRIS operates as a central control system for ITS and as new systems are developed in future years, they are intended to be engineered to be managed through IRIS.[ix] This potentially includes CV equipment that may eventually be installed on the roadside.

IRIS may eventually perform functions associated with the processing, filtering, aggregation, archiving, and dissemination of BSM and SPaT captured from roadside CV devices. These functions primarily support the CV Data Exchange. Furthermore, because the control of DMSs reside in IRIS, the CC System will need to be able to communicate messages regarding mobile work zones and which DMS those messages should be posted to. IRIS will need to receive this information from the CC System, prioritize it with other messages (if applicable), and display the messages to enable the Mobile Work Zone Warning use case.

3.3.3.4 On-Board/Nomadic Device

Most vehicles on the road today are not equipped with On-Board devices that will allow it to communicate via DSRC, and no known commercially available nomadic devices are equipped for DSRC. The deployment of communications equipment in private vehicles is not specifically being designed for this system. However, certain vehicle models (such as the 2017 Cadillac CTS) are equipped with DSRC technology, and are currently operating in the roadway environment. These vehicles can receive and broadcast DSRC messages, and can support use cases that provide outputs to the driver to support safety and mobility. While these vehicles make up a small fraction of vehicles on the roadway, the penetration of vehicles that are equipped with DSRC communications technology is expected to increase in the coming years.

On-Board/Nomadic Devices are expected to adhere to DSRC Communications (IEEE 802.11p) and messaging (SAE J2735, SAE J2945) standards. Thus, the CC System will output data (such as SPaT, MAP, RTCM, TIM) that can be received by On-Board/Nomadic devices, to enable applications that may be installed on those devices. These devices are expected to be capable of broadcasting BSMs, which the CC System will be designed to receive via the CV Data Exchange subsystem. It is important to note that the scope of the CC System is limited to making standardized SPaT, MAP, RTCM, and TIM available to On-Board/Nomadic Devices, and receiving standardized BSMs from On-Board/Nomadic Devices.

3.3.3.5 Third-Party Traveler Information Systems and Applications

The CC System will make real-time traffic signal data available to Traveler Information Providers through a subscription service. Traffic signal data is expected to enable the provision of new services in the region by the Traveler Information Provider. The systems needed to subscribe to this data, process it, and publish information to various applications, though outside of the scope of the CC System, are necessary to achieve the anticipated benefits of the use case.

3.3.3.6 Minnesota Continuously Operating Reference Station (MnCORS)

[ix] MnDOT Statewide ITS Plan. July 2015. http://www.dot.state.mn.us/its/projects/2006-2010/mnitsarchitecture/statewideitsplan.pdf

The Continuously Operating Reference Station Network is a cooperative effort between MnDOT, other state agencies and institutions, counties, cities and private enterprises with the goal of providing Global Navigation Satellite System (GNSS) corrections state-wide. It makes this data available to clients such as the CC System via the Internet. RTCM data obtained from MnCORS is used in RTCM (SAE J2735) messages output from the CC System. Ultimately, RTCM data allows for more accurate positioning of vehicles in the roadway environment.

3.3.4 Communications Mechanisms

Within the system of interest, a combination of V2I and local/backhaul communications are anticipated to be required to support the functions of the system. The following sections describe these various communications mechanisms.

Table 5 provides an overview of the various communications mechanisms used between the CC System, and external users and systems in the system of interest diagram show in the beginning of Section 3.1.

Within the system of interest, a combination of V2I and local/backhaul communications are anticipated to be required to support the functions of the system. The following sections describe these various communications mechanisms.

Table 5: External Communications Media for the Connected Corridor System

Communication Pair			Communications Mechanism	Message
CC System	to	Pedestrian	None	
Pedestrian	to	CC System	Detection	Presence
CC System	to	Work Zone Worker	None	
Work Zone Worker	to	CC System	User Interface	Work Zone Operational Status
CC System	to	Snow Plow Operator	User Interface	Notification of Signal Request Status (optional)
Snow Plow Operator	to	CC System	User Interface	Snow Plow Operational Status
CC System	to	General Equipped Vehicle Operator	User Interface	Signal System Information, Notifications/Warnings
General Equipped Vehicle Operator	to	CC System	None	
CC System	to	On-Board/ Nomadic Device*	V2I	SPaT, MAP, RTCM and TIM messages*
On-Board/ Nomadic Device*	to	CC System	V2I	BSM
CC System	to	GNSS	None	
GNSS	to	CC System	Satellite	Location/Motion Data
CC System	to	Traffic Operations Manager	User Interface	*Raw and/or processed CV data*
Traffic Operations Manager	to	CC System	User Interface	Work Zone/Snow Plow Message Input, MAP Input
CC System	to	MnCORS	None	
MnCORS	to	CC System	Internet	RTCM Data
CC System	to	Traffic Signal Controller	Local/Backhaul	Signal Priority Request
Traffic Signal Controller	to	CC System	Local/Backhaul	NTCIP data to form SPaT Message, Signal Status Message
CC System	to	Traveler Information Provider	Internet	Traffic Signal Data
Traveler Information Provider	to	CC System	None	
CC System	to	IRIS	Local/Backhaul	Mobile Work Zone Presence and Location
IRIS	to	CC System	None	

*On-board/nomadic device refers to self-equipped drivers only which are not explicitly part of the system of interest. Messages exchanged are dependent on equipment configuration and capability.

3.3.4.1 Vehicle-to-Infrastructure (V2I) Communications

CC System communications will involve transmitting data to devices in vehicles, both equipped as part of the CC System as well as with On-Board/Nomadic Devices on self-equipped vehicles. While there are many communications media that enable the transmission of messages between equipment on the roadside and equipment in vehicles, the two primary methods for wirelessly communicating with in-vehicle devices are Dedicated Short-Range Communications (DSRC) and 4G Long-Term Evolution (LTE). These two communications media are described below, followed by a discussion of the evolution of V2I-related communications: Connected Vehicle-to-Everything (C-V2X), which is a precursor to Fifth Generation of mobile networks (5G). Table 6 identifies the applicable standards for DSRC and 4G LTE.

Table 6: V2I Communications Media Standards

Communications Media	Standard Number and Title	
DSRC (V2I)	IEEE 802.11p	Wireless Access in Vehicular Environments
	IEEE 1609.2	Security Services for Applications and Management Messages
	IEEE 1609.3	Networking Services
	IEEE 1609.4	Multi-Channel Operation
	SCMS	EE Requirements and Specifications Supporting SCMS Software Release 1.1 [x]
	FHWA-JPO-17-589	Dedicated Short-Range Communications Roadside Unit Specifications [xi]
4G LTE (V2I)	CDMA 2000	Code Division Multiple Access
	3GPP	3rd Generation Partnership Project

DSRC. DSRC is a two-way short-to-medium range wireless communications capability that permits very high data transmission critical in communications-based active safety applications. Such applications require near-instant transmission of data (from one vehicle to another or from the roadside to a vehicle) to alert a driver when immediate action is required to prevent a crash or a potential unsafe maneuver. DSRC can be used to transmit several message types (standardized in SAE J2735 and SAE J2945/1) which enable applications the improve traveler safety and mobility. Another major benefit to DSRC is that it allows devices to communicate directly with each other (as opposed to relying on a network backbone) while ensuring message authenticity and preserving user anonymity.

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[x] Security Credential Management System Proof–of–Concept Implementation - EE Requirements and Specifications Supporting SCMS Software Release 1.1
https://www.its.dot.gov/pilots/pdf/SCMS_POC_EE_Requirements.pdf
[xi] Dedicated Short-Range Communications Roadside Unit Specifications
https://transops.s3.amazonaws.com/uploaded_files/Dedicated%20Short%20Range%20Communications%20Roadside%20Unit%20Specifications.pdf

In 2016, the National Highway Traffic Safety Administration (NHTSA) proposed a rule to "mandate V2V communication" via DSRC on light-duty vehicles, which would also enable V2I communications via DSRC. While this proposed rule has not been mandated, there have been several efforts moving forward using DSRC technology.

There are currently very few places where DSRC communications are used in a live transportation environment. DSRC is the specified communications technology to be used in CV Pilots projects sponsored by USDOT in New York City (New York), Tampa (Florida), and along Interstate 80 in Wyoming. These projects deploy CV technology in vehicles and on the roadside to support safety and mobility for system users. DSRC is also planned for deployment in Columbus (Ohio), as part of the USDOT Smart Cities Program.

The DSRC spectrum is currently protected for use in ITS systems[xii], though there is uncertainty regarding the future protected status of the DSRC spectrum. Furthermore, there is no timeline for a mandate for vehicles to be DSRC-compatible. DSRC is governed by IEEE 802.11p, IEEE 1609.2, IEEE 1609.3, and IEEE 1609.4 standards. Use of DSRC is necessary to address the SPaT use case (and to support the objectives of the SPaT Challenge, described in Section 1.1), and therefore most use cases to be supported by the system are anticipated to utilize DSRC to avoid deploying duplicate infrastructure or systems, and to illustrate early use cases for DSRC technology.

4G LTE. 4G LTE is currently one of the most popular methods of transmitting traveler information to travelers. Through in-vehicle systems or smart phones, travelers can receive roadway travel times, information on roadway closures, or real-time transit data. One of the major benefits of 4G LTE is its coverage area, particularly on highly-traveled corridors. However, because communication between devices on a 4G network are routed though fixed-location transceivers, communications latency may become an issue, which can preclude a system network relying on 4G LTE from supporting safety of life applications. Using 4G LTE to transmit messages to vehicles in a specific location would require a back-end process for determining which vehicles receive a specific message. Furthermore, since the 4G LTE network is managed through wireless telecommunications providers, a subscription to a mobile data plan is required for individuals to utilize 4G LTE, which may be a barrier of entry for some roadway users. Communication of data via 4G LTE is specified by the CDMA 2000 and 3rd Generation Partnership Project (3GPP) families of standards. Although outside of the scope of the CC System, it is understood that most consumer systems or applications used by Traveler Information Providers rely on 4G LTE to communicate between the Traveler Information Providers and the end-customer.

C-V2X, and 5G. Cellular V2X is an emerging communications technology that allows data to be transmitted from vehicle-to-vehicle, vehicle-to-infrastructure, vehicle-to-pedestrians (mobile devices), vehicle-to-cloud, and vehicle-to-network (to connect to systems that are accessible via the Internet). C-V2X utilizes two interfaces: one which allows it to communicate with the network (Uu interface), and one which allows it to directly communicate to other devices independent of the cellular network (PC5 interface). Direct

[xii] Federal Communications Commission. https://apps.fcc.gov/edocs_public/attachmatch/FCC-03-324A1.pdf

communication between devices utilizes the DSRC spectrum to allow for low-latency communications that supports safety-of-life applications. Communicating with the network requires a SIM card (and associated data plan, similar to 4G), while device-to-device communications does not. C-V2X has a forward compatible evolution path to 5G (the next generation of wireless communications). The major drawback to C-V2X is that it is currently under development. It has only been tested in a laboratory environment and is not expected to be ready for commercial deployment until 2020. As the concepts behind C-V2X and eventually 5G communications technology become more refined and becomes available for public use, it can be assessed to determine if it can meet the needs of transportation systems users.

3.3.4.2 Local/Backhaul Communications

Connectivity within CC System elements, and between the CC System and some external systems, including traffic signal controllers and IRIS, is required to support the system functions. Local communications refer to equipment or systems which are in close proximity to one another and communicate via a direct wired (e.g. Ethernet cable, coaxial cable, etc.) or local wireless connection. Backhaul communication typically refers to the connection between a remote device or system and a head-end system, often responsible for command and control of the broader system, or to provide access to other external systems. Backhaul communications can be provided via a direct physical (e.g. fiber optic cable, coaxial cable, etc.) or point-to-point wireless connection (e.g. licensed or unlicensed radio systems), or additionally via leased services from telecom providers (e.g. cellular, cable systems, or land-based telephonic systems). Local and backhaul communications will be necessary to link roadside equipment elements to each other, and to head-end system elements, as described in Section 3.3.1

For the CC System, it will be advantageous to utilize existing backhaul communications infrastructure. For all intersections in the TH-55 and I-394 corridors, a fiber backhaul already exists between roadside devices and head-end systems physically located at the RTMC. Despite the high bandwidth of fiber-optic communications, it will be important to ensure that transmission of CV data over the fiber-optic network will be accomplished in a way that does not interfere with other communications over the network. In the case the deployment of CV roadside technology expands beyond the scope of the fiber network and it is not feasible to expand the fiber network to the roadside locations, several options exist, including extending the fiber optic network, linking to a location on the fiber optic network using licensed or unlicensed radio backhaul, or use of leased communications.

3.3.4.3 Satellite Communications

GNSS is a generic term for systems that are available for satellite geolocation. The four primary GNSS systems include the Global Positioning System (US) (GPS), GLONASS (Russia), Galileo (EU), and BeiDou Navigation Satellite System (China) (BDS). The GNSS is generally considered to provide position, speed, and time information for receivers – which can be placed in/on a vehicle. Satellite communications is used to obtain vehicle location and motion data which is an input to the CC System. All CC System applications rely on vehicle positioning. It is important to note that this information exhibits varying degrees of accuracy depending on conditions, such as the number of satellites and interference.

3.3.4.4 User Interface

The use interface is the means by which users provide input to the CC System and the means by which the CC System provides information, notifications and warnings to drivers of vehicles that will be equipped with CV technology as part of the CC System. The user interface of On-Board/Nomadic Devices on the vehicles of self-equipped drivers are outside of the scope of the CC System. Snow Plow Operators and Work Zone Workers provide an input to indicate when they are actively engaged in plowing or work zone operations (alternatively, this could be an automated process, based on the status of the plow blade or flashing arrow sign). General Equipped Vehicle Operators receive outputs and warnings as part of the SPaT, Vehicle-Pedestrian Intersection Conflict Warning, and Mobile Work Zone Warning use cases, while snow plow operators optionally receive a notification to provide the priority status at an intersection.

3.3.4.5 Pedestrian Detection

Pedestrian detection equipment is a roadside-based pedestrian detection hardware that can be co-located with intersections to actively detect when pedestrians are in crosswalks. It communicates this pedestrian detection information to the CC System to support the Vehicle-Pedestrian Intersection Conflict Warning use case. Alternatively, this detection may be enabled in a 'passive manner' based on use of the pedestrian push button. Furthermore, the CC System can incorporate pedestrian detection information into SPaT messages, which would make this information to other CV-enabled vehicles.

3.3.5 Support Environment

3.3.5.1 Operations and Maintenance (O&M) Staff

O&M Staff are comprised of individuals that provide engineering services for traffic control performed by the agency with operating authority over the signalized intersections included in the SPaT broadcasts. They are responsible for the design, construction and operation of the traffic signal systems, including the signal controller, signal control box, mast arms and signal heads, as well as any equipment attached to the mast arm or added to the signal control box. This includes staff that perform routine maintenance of field equipment and monitors and responds to maintenance issues impacting the signalized intersections selected for the project.

3.3.5.2 Mapping / Geographical Information System (GIS) staff

Mapping and Geographical Information Systems (GIS) Staff includes the individuals or groups within the DOT that are responsible for maintaining the mapping and/or GIS data for the agency. Initially, intersection geometry data may be created by selected members of the project team. However, changes in intersection geometry will inevitably occur – making sure these changes are properly reflected in map messages may involve the mapping / GIS group.

3.3.5.3 System and Content Administrator

The system and content administrator is responsible for configuration, deployment, and ongoing operation of the Data Exchange. The administrator adds, updates, and deletes data from the system and monitors performance of the system.

Additional duties include, but are not limited to:

- Remove unwanted information or messages
- Run system backup
- Restore system from backup after a problem occurs
- Receive Users' questions and respond appropriately

3.3.5.4 IT Support Staff

IT Support Staff assist the System and Content Administrator in their duties as described above. Depending on individual responsibilities, only necessary permissions levels will be granted. The System Administrator and Content Manager are responsible for allocating permissions and assigning responsibilities to support staff.

3.3.5.5 V2I Communications Security and Privacy

Regardless of the media chosen to allow vehicle and infrastructure to communicate, it must be secure and ensure the privacy of CC System users. Both DSRC and 4G LTE have security features. Security for 4G LTE is governed by 3GPP and CDMA 2000 standards, while security for DSRC is governed by SAE 1609.2. With regard to DSRC, the Proof of Concept (POC) SCMS is designed to provide trusted, secure vehicle-to-vehicle and vehicle-to-infrastructure 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)[xiii][xiv][xv]. This allows devices that have never encountered each other to have confidence that the data received is trustworthy. While this system is not likely to be available for use to support the CC System, third-party SCMS service providers are available.

Measures also need to be taken to protect the anonymity of all users that may interact with the CC System. This is particularly for users of the CC System, as location and motion data is expected to be transmitted by On-Board/Nomadic Devices (see Section 3.3.3.4) that will communicate with the CC System, as well as in-vehicle devices (see Section **Error! Reference source not found.**) that will be deployed to enable functions associated with the CC System. This means that the content of information in messages cannot contain information that could be considered personally identifiable. It is important to note that though data from a single message cannot be used to identify an individual, data from multiple messages (from the same vehicle) or corroboration with other data sources could be used to identify an individual with the proper resources. This has implications for the CC System, as the CV Data Exchange contains functions that collect location/motion data from CV-equipped vehicles. The CC System will filter, aggregate, and

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[xiii] 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

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

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

securely store this data in a way that ensures that it cannot be used to identify individuals. Methodology regarding these processes will be provided in Data Governance Plan deliverable for this project.

3.4 CC System Functions

3.4.1 Obtain Raw Traffic Signal Data from Traffic Signal Controller

This function of the CC System involves receiving data that is output from the traffic signal controller. NTCIP 1202 is the standard by which traffic signal controllers are expected to output raw traffic signal data. Data types that are output from the controller are expected to be sufficient to build the SPaT (SAE J2735) message and the SSM (SAE J2735) message. For the Snow Plow Signal Priority use case, when the raw traffic signal data indicates that a signal priority request has been accepted, denied, or modified, there is an option to provide a notification to the snow plow operator containing the relevant priority request status information.

3.4.2 Notify General Vehicle Operator of Signal Status and Location with respect to Intersection

This function utilizes traffic signal data from the traffic signal controller, MAP message input from the traffic operations manager, and vehicle location and motion data to provide a General Vehicle Operator with an output that specifies the signal status (e.g. current signal state and time remaining for the current phase) and the location of the General Vehicle Operator with respect to the intersection.

3.4.3 Obtain MAP Message Input from Traffic Operations Manager

This function of the CC System allows the Traffic Operations Manager to input MAP message data for each intersection in the Connected Corridor. Should the system accept data in a standardized format that is not SAE J2735-compatible (e.g. JSON), this function will translate that message into a SAE J-2735 compatible message. MAP messages are used as inputs in the Signal Phase and Timing, Vehicle-Pedestrian Intersection Conflict Warning, and Snow Plow Signal Priority use cases.

3.4.4 Obtain Position Correction Data from MnCORS

This function of the CC System involves receiving position correction data from NTRIP caster. The data received must include all of the required data elements for the RTCM (SAE J2735) message.

3.4.5 Generate SPaT Message

This function translates the raw traffic signal data (NTCIP 1202) received from the traffic signal controller into a SPaT (SAE J2735) message. Furthermore, pedestrian detections received by the system will be incorporated into the SPaT message.

3.4.6 Generate RTCM from Position Correction Data

This function translates the position correction data received from MnCORS into a RTCM (SAE J2735) message.

3.4.7 Broadcast SPaT, MAP, RTCM, TIM

This function broadcasts SPaT, MAP, RTCM, TIM (SAE J2735) messages via DSRC. This data can be received by vehicles equipped as part of the CC System, or properly self-equipped vehicles.

3.4.8 Output Pedestrian Notification/Warning

This function provides an output to the driver which indicates signal state information pertaining to the approach, pedestrian-in-crosswalk information, and lane that the vehicle is traveling in and movements available to the vehicle given the lane that it is in. A vehicle is determined to be in the vicinity of an intersection if its position falls within the geometric extents of the MAP message associated with that intersection.

Position correction data from the RTCM message is used to correct the position of the vehicle included in the output.

3.4.9 Obtain Location/Motion Information (from all vehicles)

This function allows the system to determine the location and motion information of all equipped vehicles (general equipped vehicles, snow plow, work zone, vehicle). This information is expected to come from GNSS and potentially the vehicle databus. Location and motion data received will likely need to be sufficient to build the BSM Part I (SAE J2735) message.

3.4.10 Determine if Snow Plow is approaching Signal and Issue SRM

When the snow plow is engaged in active operations, the CC System will determine if the snow plow is approaching a traffic signal. If so, it will communicate a signal priority request to the traffic signal for the snow plow's approach. In order to accomplish this, the system is expected to use location and motion data from the snow plow, as well as MAP and RTCM data to know which intersection the snow plow is approaching and which approach the snow plow is using.

3.4.11 Process Priority Request

The CC System will determine if a priority request can be serviced. This is based on time-of day, and includes arbitrating between multiple priority requests. It accepts the signal priority request as an input, and provides a signal status message as an output. This function may reside in the traffic signal controller or within MaxView.

3.4.12 Issue Signal Status Notification to Snow Plow Operator

Based on raw traffic signal data, the CC System will provide an optional notification the snow plow operator to indicate the status of a priority request.

3.4.13 Obtain BSM from On-Board/Nomadic Device

This function allows the CC System to receive BSMs (SAE J2735) from On-Board/Nomadic Devices. Note that On-Board/Nomadic Devices are not part of the system, but are expected to be able to broadcast BSMs (SAE J2735).

3.4.14 Process/Archive BSMs

Once the CC System receives BSMs, it must process and archive them. Processing is performed to ensure that the data is sufficiently aggregated to protect potentially personally identifiable information that is found in BSMs, and/or filtered to lessen the amount of data that must be archived.

3.4.15 Publish Traffic Signal Data and MAP Data to Traveler Information Provider

The CC System will publish traffic signal data and MAP Data for Traveler Information Providers to obtain in real-time – data can be published within milliseconds so that it is available virtually immediately to Traveler Information Provider applications. The mechanism that does this will ultimately be designed in a way that ideally minimizes communications latency.

3.4.16 Obtain Pedestrian Detection Data

The CC System will be capable of determining when a pedestrian is in a marked crosswalk at an intersection, and is able to determine which of the intersection's crosswalk the pedestrian is occupying. This data is used to populate the SPaT message and used in a function to determine if a pedestrian in crosswalk warning will be issued to a general equipped vehicle operator.

3.4.17 Determine if Pedestrian in Crosswalk is in Path of Vehicle

The CC System will determine if a pedestrian in a crosswalk is in the path of a vehicle driven by a general equipped vehicle operator. If the pedestrian is in the vehicle's path, but a collision is not imminent, then a notification is issued to the general equipped vehicle operator. If the pedestrian is in the vehicle's path, and a collision is imminent, then warning (higher-priority) is issued to the general equipped vehicle operator. This is accomplished using intersection MAP data, pedestrian detection data, general equipped vehicle location and motion data and RTCM data to determine if the vehicle's intended path will traverse the crosswalk occupied by the pedestrian and to estimate the time until the vehicle will reach the crosswalk (used to determine if collision is imminent).

3.4.18 Obtain Snow Plow Active Status

The CC system will accept an input from the snow plow operator that indicates if the snow plow is actively engaged in snow plow operations. Ideally, the input to this function can be related to the status of a plow blade, to reduce manual inputs. This is used as a basis for disseminating snow plow warnings and requesting signal priority.

3.4.19 Obtain Work Zone Active Status

The system will accept an input from the work zone worker that indicates an active work zone or maintenance operations. Ideally, the input to this function can be related to the status of a flashing arrow board (or other construction traffic control equipment), to reduce manual inputs. This is used as a basis for disseminating work zone warnings.

3.4.20 Disseminate Snow Plow Warning

When the snow plow is engaged in active operations, the CC System will use snow plow location and motion data to determine which DMS should display a snow plow warning message and to determine upstream locations where TIMs (containing the snow plow warning message) should be broadcast via DSRC.

3.4.21 Disseminate Work Zone Warning

When engaged in active work zone operations, the CC System will use work zone vehicle location and motion data to determine which DMS should display a work zone warning message and to determine upstream locations where TIMs (containing the work zone plow warning message) should be broadcast via DSRC.

3.4.22 Obtain Snow Plow Message Input from Traffic Operations Manager

The CC System will accept an input from the Traffic Operations Manager containing the message that is displayed to drivers when a snow plow is active. This function may allow the Traffic Operations Manager to provide different inputs for a message displayed via DMS and for a message contained in a TIM.

3.4.23 Obtain Work Zone Message Input from Traffic Operations Manager

The CC System will accept an input from the Traffic Operations Manager containing the message that is displayed to drivers when a work zone is active. This function may allow the Traffic Operations Manager to provide different inputs for a message displayed via DMS and for a message contained in a TIM.

3.4.24 Over-the-Air Message Security

The CC system will provide message security for messages transmitted via DSRC. 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). This allows devices that have never encountered each other to have confidence that the data received is trustworthy.

3.4.25 Summary of CC System Functions

Table 7 provides a summary of the functions described in this section, and indicates which use cases (described in Section 3.2) each system function supports.

Table 7: Function-to-Use Case Support Matrix

Function	Use Case					
	SPaT	Veh-Ped Intersection Warning	Snow Plow Signal Priority	CV Data Mgmt	Third-Party Traffic Signal Data Sharing	Mobile Work Zone Warning
Obtain Raw Traffic Signal Data from Traffic Signal Controller	X	X	X		X	
Notify General Vehicle Operator of Signal Status and Location with res						
Obtain MAP Message Input from Traffic Operations Manager	X	X	X			
Obtain Position Correction Data from MnCORS	X	X	X			
Generate SPaT Message	X					
Generate RTCM from Position Correction Data	X					
Broadcast SPaT, MAP, RTCM, TIM	X					
Output Pedestrian Notification/Warning		X				
Obtain Location/Motion Information (from all vehicles)		X	X	X		X
Determine if Snow Plow is approaching Signal and Issue SRM			X			
Process Priority Request			X			
Issue Signal Status Notification to Snow Plow Operator			X			
Obtain BSM from On-Board/Nomadic Device				X		
Process/Archive BSMs				X		
Publish Traffic Signal Data and MAP Data to Traveler Information Provider					X	
Obtain Pedestrian Detection Data		X				
Determine if Pedestrian in Crosswalk is in Path of Vehicle		X				
Obtain Snow Plow Active Status			X			X
Obtain Work Zone Active Status						X
Disseminate Snow Plow Warning						X
Disseminate Work Zone Warning						X
Obtain Snow Plow Message Input from Traffic Operations Manager						X
Obtain Work Zone Message Input from Traffic Operations Manager						X
Over-the-Air Message Security	X	X	X	X	X	X

3.5 Modes of Operation

The system is intended to function normally at all hours of the day. Failure to do so is referred to as a "degraded" or "failure" condition. The definition for each mode of operation is given in Table 8 below.

Table 8: Modes of Operation

Mode	Definition
Mode 1: Normal Operating Conditions	Indicates the system is functioning as intended, generating outputs when appropriate, and not generating outputs when unnecessary. CV Environment users will be expected to adhere to existing regulations associated with traffic control devices (e.g. traffic signals, static signage, and lane markings) with the added benefit of notifications and warnings that complement these regulations.
Mode 2: Degraded Conditions	Represents a situation where primary functionality is lost due to poor data, nonfunctioning equipment, and/or communications failure. CC System users will be expected to adhere to existing regulations associated with traffic control devices (e.g. traffic signals, static signage, and lane markings) when the system is experiencing degraded conditions.

3.6 Operational Policies and Constraints

This section discusses operational policies and constraints that must be addressed prior to the design of the CC System. Items discussed in each subsection includes, Vehicle Operation Regulations, Connected Corridor Limitations, Physical Design Constraints, and Permit Requirements.

3.6.1 System Architecture

The Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT)[xvi] provides a common framework for planning, defining, and integrating intelligent transportation systems. ARC-IT combines the previous versions of the National ITS Architecture and the Connected Vehicle Reference Implementation Architecture (CVRIA). It provides common basis for planners and engineers with differing concerns to conceive, design and implement systems using a common language as a basis for delivering ITS, but does not mandate any particular implementation. Following the ARC-IT framework will improve the likelihood the Connected Corridor system will be compatible with the Minnesota Statewide Regional ITS Architecture.

3.6.2 Vehicle Operation Regulations

Policies governing driver behavior in the context of the Connected Corridor are the same as the existing operational polices described in Section 2.2. The Connected Corridor will be designed to provide notifications and warnings to drivers with an in-vehicle CV device (in-vehicle devices will be deployed in

[xvi] Architecture Reference for Cooperative and Intelligent Transportation http://local.iteris.com/arc-it/

general equipped vehicles, transit vehicle, snow plows, and work zone vehicles) that complement these existing regulations. There are no regulations in place that require the driver to react to notifications or warnings from a CV system, nor do notification or warnings relieve the driver from exercising the same judgement that is required to operate a motor vehicle in the current system. Drivers will be expected to adhere to existing regulations associated with traffic control devices (e.g. traffic signals, static signage, and lane markings). Any ITS device operation modification that results from the Connected Corridor – such as the modification of traffic signal timing plans – must adhere to State and City design documents, including the MN MUTCD, Traffic Signal Timing and Coordination Manual, and the Signal Design Manual.

3.6.3 Connected Corridor Limitations

While in-vehicle devices deployed for Connected Corridor may support the transmission and receipt of V2V messages (such as location and motion data), the system will not directly support V2V applications that require these message types. These messages are broadcast for the benefit of existing system in-vehicle devices and for the capture and use of these V2V message types for traffic management applications.

V2I applications that will be implemented on the Connected Corridor will only work in locations where vehicles and roadside equipment have access to communications infrastructure necessary to support the transmission of V2I data. V2I applications that require the roadside detection of pedestrians will be limited to areas detected by pedestrian detection equipment that is connected to a roadside communications device. V2I applications that require the transmission of signal state data will be limited to intersections where traffic signal state data can be obtained from the traffic signal controller and sent to a roadside communications device. Conversely, V2I applications that require the transmission of data originating from a vehicle will be limited to regions where vehicle data can be transmitted to the roadside.

The limited geographic scope of the CC System will require specific training for maintenance vehicle operators. Notifications may be perceived as redundant or superfluous since existing systems will remain in place and operators will be required to observe and obey traffic signals as they would when operating outside the CC System. Since all signals in the metro area will not be equipped with V2I-based priority systems, an operator may perceive the lack of priority at a non-equipped intersection as a failure of the CC and regard it as unreliable. Training on how to interact with CC intersection and their locations can minimize adverse reactions from the operators.

Different applications have different message transmission latency thresholds. For instance, the communication of signal state information that is used to support an in-vehicle safety application is more time-sensitive than the communication of traveler information that is used to support an in-vehicle mobility application. An application can only be supported if the messages transmitted fall below the required latency threshold required for that application. Note that various network types will exhibit different message transmission latency, and this could govern the communications media specified in the CC System design.

The enabling of signal priority via V2I communications may require modification of current signal plans. MnDOT may have to allow the signal controller to cycle through a non-standard phase sequence to support signal preemption or allow the signal controller to advance through the phases (early green) or modify the length of phases (extended green) to support signal priority. Granting priority or preemption is constrained on a time-of-day basis –priority is generally not granted during peak periods so that the system can most effectively handle traffic flow.

3.6.4 Physical Design Constraints

In order to support security credentialing and to collect data broadcast over the system, RSUs must be connected to the Internet via direct or indirect backhauled communications. The existing systems utilize the fiber network to transmit data for various purposes. Transmission of Connected Corridor data over the fiber optic network will be accomplished in a way that does not interfere with other communications over the network

3.6.5 Permit and Licensing Requirements

Permits from the State may be required before any CV hardware is deployed. CV hardware is currently not on the MnDOT Qualified Product List.[xvii] Obtaining the permit may include the installation and demonstration of the Connected Corridor hardware at an independent test facility.

Finally, DSRC-based CV systems operate in a licensed band which is controlled by the Federal Communications Commission (FCC). Licensure for each planned DSRC device must be obtained from the FCC in order to operate legally.

[xvii] Minnesota Department of Transportation – Approved/Qualified Products List. http://www.dot.state.mn.us/products/index.html

4 User-Oriented Operational Descriptions

User classes for the proposed system are the same as user classes for the current system. 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. The subsections below describe the role of each user in the context of the operational Connected Corridor System, and how the user would relate to the system, based on the operational concept defined in Section 3.

4.1 General Equipped Vehicle Operator

The General Equipped Vehicle Operator will have the same responsibilities to adhere to regulations governing vehicle operation in the roadway environment. However, General Equipped Vehicle Operators will receive several types of notifications and warnings from the CC System. By acquiring SPaT data from equipped traffic signals, the CC System will provide the operator with information on the current signal state, the countdown until the next phase change, and their location with respect to the intersection. In addition, the system will provide a notification to the General Equipped Vehicle Operator when the vehicle path may traverse a crosswalk occupied by a pedestrian, and a warning when a potential collision is imminent. Finally, the system will provide a notification to the General Equipped Vehicle Operator as they approach an active snow plowing operation or mobile work zone.

Should the General Equipped Vehicle Operator carry a personal mobile device into the vehicle, the operator may have access to additional regional traffic signal information through third-party sources and applications. Use of such devices and information would be subject to applicable laws, regulations and operator policies.

The General Equipped Vehicle Operator would also benefit from additional information available to non-equipped drivers, including warnings to vehicles approaching a mobile work zone which the system displays to all motorists using a DMS.

These notifications, warnings and supplemental information are intended to provide General Equipped Vehicle Operators with added awareness of events in the roadway environment. Existing regulation does not compel the General Equipped Vehicle Operator to adjust operation of the vehicle based on CC System outputs. However, it is expected that CC System notifications and warnings will complement existing regulations, providing the General Equipped Vehicle Operator an opportunity to react to a situation that they may not have been aware of otherwise.

4.2 Transit Vehicle Operator

The Transit Vehicle Operator will have the same responsibilities to adhere to regulations governing transit vehicle operation in the roadway environment. However, Transit Vehicle Operators will receive notifications and warnings from the Vehicle-Pedestrian Intersection Conflict Warning component of the CC System. By acquiring SPaT and MAP data from equipped traffic signals, the CC System will provide the Transit Vehicle Operator with a notification when the transit vehicle path may traverse a crosswalk occupied by a pedestrian, and a warning when a potential collision is imminent.

4.3 Self-Equipped Driver

Self-Equipped Drivers operating vehicles containing On-Board/Nomadic Devices that are capable of receiving data over various V2I Communication media, such as DSRC and 4G LTE.

There are currently very few vehicles on the road today that can send and receive data communicated via DSRC. However, the penetration of DSRC-equipped vehicles is expected to increase in coming years. Furthermore, vehicles used in CV test environments, such as in CAMP, are considered a self-equipped, as they contain the technology to communicate via DSRC. Drivers of properly equipped vehicles, which incorporate either aftermarket or factor-equipped DSRC-devices with associated applications, may receive information from the CC System via DSRC. CV applications installed on these devices would be responsible for processing CC System data to issue outputs (notifications or warnings) to the driver – it is not in the scope of the CC System to process data received by the On-Board/Nomadic device or issue notifications to Self-Equipped Drivers. Applications installed on deployed in-vehicle devices could be made available so that they could also be installed on an On-Board/Nomadic Device. This would allow self-equipped drivers to receive the same notifications and warnings that are issued to General Equipped Vehicle Operators.

Should the On-Board/Nomadic Device consist of a personal smartphone or an integrated wireless information system, the Self-Equipped Driver may have access to additional regional traffic signal information through third-party sources and applications. The development of these applications is outside of the scope of the CC System. Accessing these services generally requires a 4G LTE connection. Use of such devices and information would be subject to applicable laws and regulations.

The Self-Equipped Driver would also benefit from additional information available to non-equipped drivers, including warnings to vehicles approaching a mobile work zone which the system displays to all motorists using a DMS.

4.4 Unequipped Driver

Unequipped drivers assume the same responsibilities as they do in the current system. Unequipped drivers would benefit from the system through warnings to vehicles approaching a mobile work zone which the system displays to motorists via a DMS.

4.5 Snow Plow Operator

Snow plow operators assume the same responsibilities as they do in the current system. In addition, the Snow Plow Operator will assume the responsibility of providing input to the CC System to indicate that snow plow operations are active. Ideally, this input will be linked with actions already undertaken by snow plow operators, such as lowering and raising the snow plow blade (if this is not possible manual input will be necessary). They will also experience decreased wait times or increased likelihood of not stopping at intersections where the Snow Plow Signal Priority is enabled. It is assumed, due to workload requirements, that the operator would not have access to other information, notifications or warnings available through the CC System. Snow Plow Operators are expected to experience a safer operating environment around vehicles operated by drivers receiving notifications and warnings about the active snow plow operations from the CC System.

Should the Snow Plow Operator carry a personal mobile device into the vehicle, the operator may have access to additional regional traffic signal information through third-party sources and applications. Use of such devices and information would be subject to applicable laws, regulations and operator policies.

The Snow Plow Operator would also benefit from additional information available to non-equipped drivers, including warnings to vehicles approaching a mobile work zone which the system displays to all motorists using a DMS.

4.6 Pedestrian

In the scope of this deployment, the role of the Pedestrian remains unchanged from the current condition. Pedestrians will not receive any direct communications from the CC System. Pedestrians may experience fewer conflicts with vehicles operated by drivers receiving output from the CC System at intersections where pedestrian detection is enabled.

4.7 Traveler Information Provider

Traveler information Providers utilize traffic system data from traffic management systems. For traffic signals, currently (or planned to be) connected via backhaul to the regional MaxView signal system, the CC System will publish traffic signal information to Traveler Information Providers via a common Internet feed. Because acquisition of intersection data only requires a backhaul connection to MaxView, the dissemination of signal information is not necessarily constrained to intersection along the I-394 or TH-55 corridors. Ultimately, it is expected that the availability of this data will enhance the information provided to travelers who have access to a range of third-party applications for improving the safety and/or mobility of vehicles on the roadway. However, the CC System is limited making this data available to Traveler Information Providers, and use of this data and any provision of information to other users is the responsibility of third-party providers.

4.8 Work Zone Worker

Work Zone Workers will assume the responsibility of providing input to the CC System to indicate that work zone operations are active. Ideally, this input will be linked with actions already undertaken by work zone workers, such as activation of flashing arrow signs (if this is not possible manual input will be necessary). Work Zone Workers are expected to experience a safer operating environment around vehicles operated by drivers receiving notifications and warnings about the active work zone operations from the CC System.

4.9 Traffic Operations Manager

The responsibility of the Traffic Operations Manager is primarily associated with providing system support. They will survey intersections and input updated MAP data, input Work Zone and Snow Plow messages to be displayed to drivers, and arrange for system maintenance when connectivity issues are present. The Traffic Operations Manager will be able to leverage CV Data input, processed, filtered, aggregated, archived, and output by functions contained in roadside components of the CC System to gain knowledge of how such data must be managed, and how it can be used to support traffic management in the future. In the future, as CV data is collected and archived, it may also be made available to other stakeholders. The Traffic Operations Manager is expected to be one of the primary beneficiaries of gaining institutional experience with deploying CV systems (UN-CC-8.01-v01 – DSRC Experience).

5 Connected Corridor System Operational Scenarios

As described in Section 3.3.1, several CV applications have been determined based on the needs of MnDOT and various agency stakeholders that are involved in the TH-55 and I-394 corridors. The scenarios given in this section correspond to each application previously discussed. Figure 5 provides a legend for the functional diagrams contained in this section.

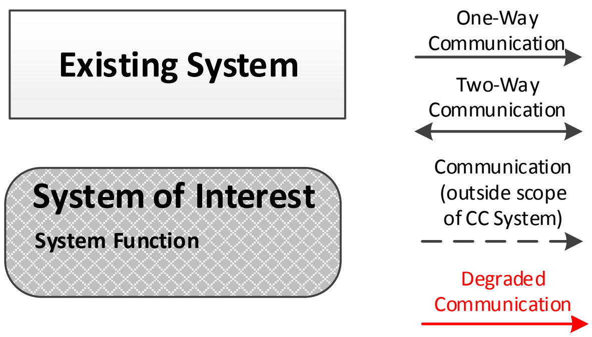
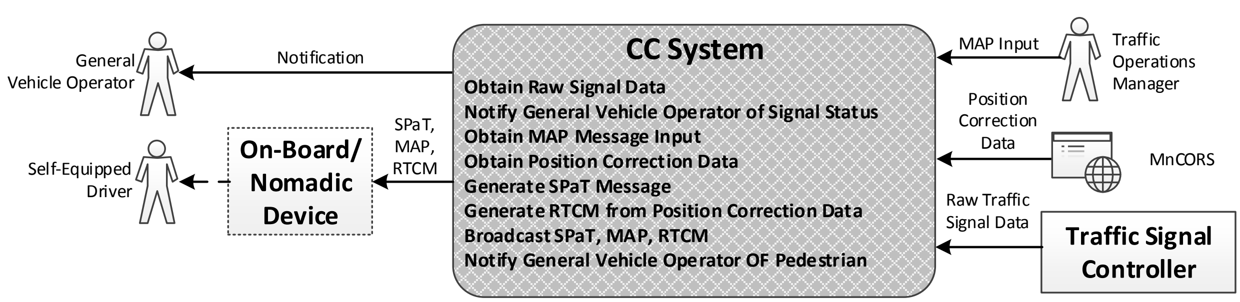


Figure 5: Context Diagram Legend

5.1 SPaT

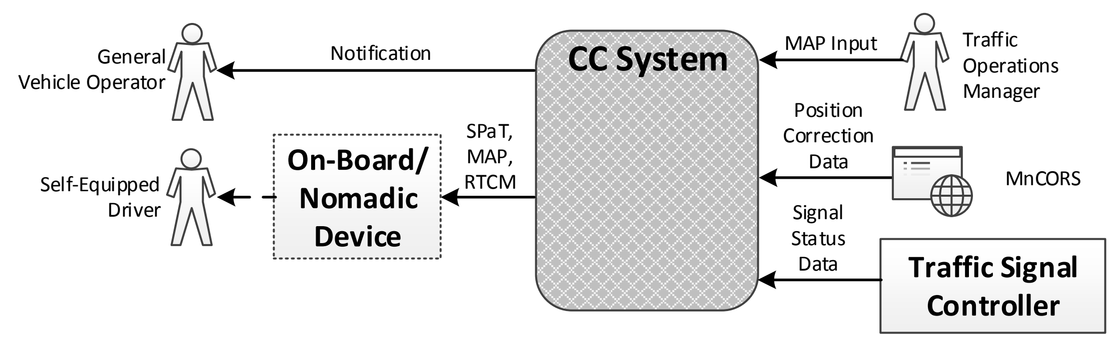
This scenario illustrates the expected operation of a SPaT Infrastructure System communicating to vehicles using low-latency wireless communications that utilize the SAE J2735 messaging standards, and interfacing with local Traffic Signal Systems. Though not an application, the dissemination of SPaT data is a critical function of this system. This use case contains scenarios associated with the dissemination of SPaT messages. Figure 6 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.



Note: The Over-The-Air-Message Security function is used for wireless communications within the CC System and wireless communications between the CC System and External Systems, such as the On-Board/Nomadic Device

Figure 6: Signal Phase and Timing (Function) Functional Diagram

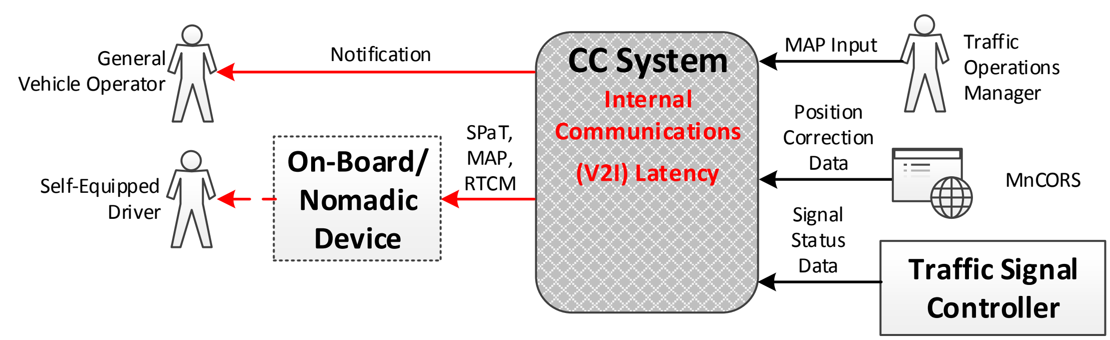
5.1.1 Use Case 1 Scenario 1: Normal Operating Conditions – Broadcast SPaT

<table>
<tr><th>Use Case</th><th colspan="4">Broadcast SPaT</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC1-S1: Normal Operating Conditions – Broadcast SPaT</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Allow a vehicle to utilize SPaT data and related data (e.g. MAP, RTCM) to enhance the safety and/or mobility of the driver or to allow the driver to operate the vehicle in an environmentally friendly manner</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• SPaT data is sent from the roadside to a vehicle approaching a signalized intersection</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">General Equipped Vehicle Operator</td><td colspan="2">Traverse the roadway network in a safe and efficient manner</td></tr>
<tr><td colspan="2">Self-Equipped Driver</td><td colspan="2">Traverse the roadway network in a safe and efficient manner</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• An On-Board/Nomadic device is within communications range of the CC System
• The Traffic Operations Manager has provided valid MAP (intersection geometry) data to the CC System
• The CC System is connected to MnCORS and receiving RTCM (position correction data)
• The CC System is operating normally, and is making SPaT, MAP, and RTCM messages available</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">
</td></tr>
<tr><td rowspan="8">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Traffic Signal Controller</td><td>1</td><td>Outputs information regarding the current signal state and the timing of subsequent phases (signal status data) to the CC System</td><td>Updates raw output at 10 Hz (nominal broadcast rate)</td></tr>
<tr><td>MnCORS</td><td>2</td><td>Outputs position Correction data</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>CC System</td><td>3a</td><td>Bundles the signal status data into a SPaT message</td><td></td></tr>
<tr><td>CC System</td><td>4a</td><td>Bundles the MAP data into a MAP message</td><td></td></tr>
<tr><td>CC System</td><td>5a</td><td>Bundles position correction data into an RTCM message</td><td></td></tr>
<tr><td>CC System</td><td>6a</td><td>Transmits SPaT, MAP, and RTCM messages</td><td>To On-Board/Nomadic Devices it is in communications range of</td></tr>
</table>

	On-Board/ Nomadic Device	7a	Receives SPaT, MAP, and RTCM data from a traffic signal prior to arriving at the signal	On-Board/Nomadic Device is found on a Self-Equipped vehicle
	On-Board/ Nomadic Device	8a	Processes the data and determines if a notification or warning should be issued to the driver	
	Self-Equipped Driver	9a	May take action in response to the notification or warning	
	CC System	3b	Provides a notification indicating position with respect to the intersection, signal state, and countdown to subsequent signal states	To the General Equipped Vehicle Operator. Information displayed in notification is limited to data found in SPaT message.
	General Equipped Vehicle Operator	4b	May take action in response to the notification	
Post-Conditions	• SPaT-enabled CV applications are supported on vehicles capable of receiving SPaT data via V2I communications.			
Traceability	UN-CC-1.01-v01 – Signal Phase and Timing UN-CC-2.01-v01 – On-Board/Nomadic Device Data UN-CC-7.05-v01 – CC System Support UN-CC-8.01-v01 – DSRC Experience UN-CC-8.02-v01 – DSRC Demonstration			
CC System Inputs	• MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller)			
CC System Outputs	• Notification of location within intersection (to General Equipped Vehicle Operator) • Current signal state information (to General Equipped Vehicle Operator) • Next phase countdown (to General Equipped Vehicle Operator) • SPaT, MAP, RTCM (to On-Board/Nomadic Device)			

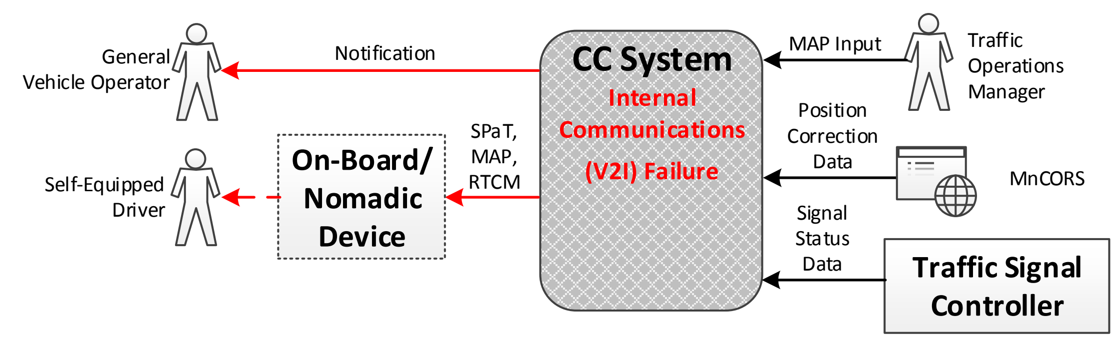
5.1.2 Use Case 1 Scenario 2: Degraded Conditions – Communications Latency

Use Case	**Broadcast SPaT**	
Scenario ID and Title	*UC1-S2: Degraded Conditions – System/Communications Latency*	
Scenario Objective	• Demonstrate the fall back scenario if there is latency associated with system processes that are responsible for transforming inputs into actionable outputs	
Operational Event(s)	• Latency in the system (processing, communication between CC System components, or communication between the CC System and external systems) result in an output that is not received in time to be of practical use to the recipient.	
User(s)	User	Role
	General Equipped Vehicle Operator	Traverse the roadway network in a safe and efficient manner

<table>
<tr><td></td><td colspan="2">Self-Equipped Driver</td><td colspan="2">Traverse the roadway network in a safe and efficient manner</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">An On-Board/Nomadic device is within communications range of the CC System
The Traffic Operations Manager has provided valid MAP (intersection geometry) data to the CC System
The CC System is connected to MnCORS and receiving RTCM (position correction data)
The CC System is making SPaT, MAP, and RTCM messages available
Limited system resources (processing, communications) adds latency to outputs compared to the normal operating condition.</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">
</td></tr>
<tr><td rowspan="11">Key Actions and Flow of Events</td><th>Source</th><th>Step</th><th>Key Action</th><th>Comments</th></tr>
<tr><td>Traffic Signal Controller</td><td>1</td><td>Outputs information regarding the current signal state and the timing of subsequent phases (signal status data) to the CC System</td><td>Updates raw output at 10 Hz (nominal broadcast rate), latency is typically not an issue</td></tr>
<tr><td>MnCORS</td><td>2</td><td>Outputs position Correction data</td><td>Connection between MnCORS and CC System could exhibit latency</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>CC System</td><td>3a</td><td>Bundles the signal status data into a SPaT message</td><td>Lack of processing resources could result in latency</td></tr>
<tr><td>CC System</td><td>4a</td><td>Bundles the MAP data into a MAP message</td><td></td></tr>
<tr><td>CC System</td><td>5a</td><td>Bundles position correction data into an RTCM message</td><td>Lack of processing resources could result in latency</td></tr>
<tr><td>CC System</td><td>6a</td><td>Transmits SPaT, MAP, and RTCM messages</td><td>To On-Board/Nomadic Devices it is in communications range of</td></tr>
<tr><td>On-Board/ Nomadic Device</td><td>7a</td><td>Receives SPaT, MAP, and RTCM data from a traffic signal prior to arriving at the signal</td><td>On-Board/Nomadic Device is found on a Self-Equipped vehicle</td></tr>
<tr><td>On-Board/ Nomadic Device</td><td>8a</td><td>Processes the data and determines if a notification or warning should be issued to the driver</td><td>Notification or warning may be issued late, reducing safety/mobility/ environmental impact</td></tr>
<tr><td>Self-Equipped Driver</td><td>9a</td><td>May take action in response to the notification or warning</td><td>Depending on the actual latency, the Self- Equipped Driver may need to take</td></tr>
</table>

				action prior to receiving notification
	CC System	3b	Provides a notification indicating position with respect to the intersection, signal state, and countdown to subsequent signal states	To the General Equipped Vehicle Operator. Information displayed in notification is limited to data found in SPaT message. Notification or warning may be issued late, reducing safety/mobility/ environmental impact. The system may issue an advisory to the General Equipped Vehicle Operator, and/or to the Traffic Operations Manager if latency is observed.
	General Equipped Vehicle Operator	4b	May take action in response to the notification	Depending on the actual latency, the General Equipped Vehicle Operator may need to take action prior to receiving notification
Post-Conditions	• Signal state notification outputs will provide outdated information. The signal state and time to next phase given to the general equipped vehicle operator may differ from what the traffic signal indicates. • Issues regarding latent MAP and RTCM data are not as consequential, as the changes from one message to the next are marginal in nature with respect to SPaT. • SPaT-enabled CV **safety** applications may not be supported for On-Board/Nomadic Devices, as latency in the communication of SPaT data does not support safety-of-life applications needs • SPaT-enabled CV **mobility** and **environmental** applications for On-Board/Nomadic Devices will issue notifications and/or warnings later than what may be desired by the Self-Equipped Drivers • General Equipped Vehicle Operators and Self-Equipped Drivers may lose trust in the system, and may be less likely to respond to notifications in the future.			
Traceability	UN-CC-7.06-v01 – Remote Diagnostic			
CC System Inputs	• MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller)			
CC System Outputs	• (Late) Notification of location within intersection (to General Equipped Vehicle Operator) • (Late) Current signal state information (to General Equipped Vehicle Operator) • (Late) Next phase countdown (to General Equipped Vehicle Operator) • (Late) SPaT, MAP, RTCM (to On-Board/Nomadic Device)			

5.1.3 Use Case 1 Scenario 3: Degraded Conditions – Communications Failure

<table>
<tr><th>Use Case</th><th colspan="4">Broadcast SPaT</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC1-S3: Degraded Conditions – Communications Failure</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the fall back scenario if failure of communication between CC System components, or communication between the CC System and external systems result in no output when output would have been given under normal operating conditions</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• General Equipped Vehicle Operator or Self-Equipped Driver is operating a vehicle within communications range of the Connected Corridor</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">General Equipped Vehicle Operator</td><td colspan="2">Traverse the roadway network in a safe and efficient manner</td></tr>
<tr><td colspan="2">Self-Equipped Driver</td><td colspan="2">Traverse the roadway network in a safe and efficient manner</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• The Traffic Operations Manager has provided valid MAP (intersection geometry) data to the CC System
• The CC System is connected to MnCORS and receiving RTCM (position correction data)
• The CC System is not able to communicate with an On-Board/Nomadic Device
• The CC System is not able to make SPaT, MAP, and RTCM messages available</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">


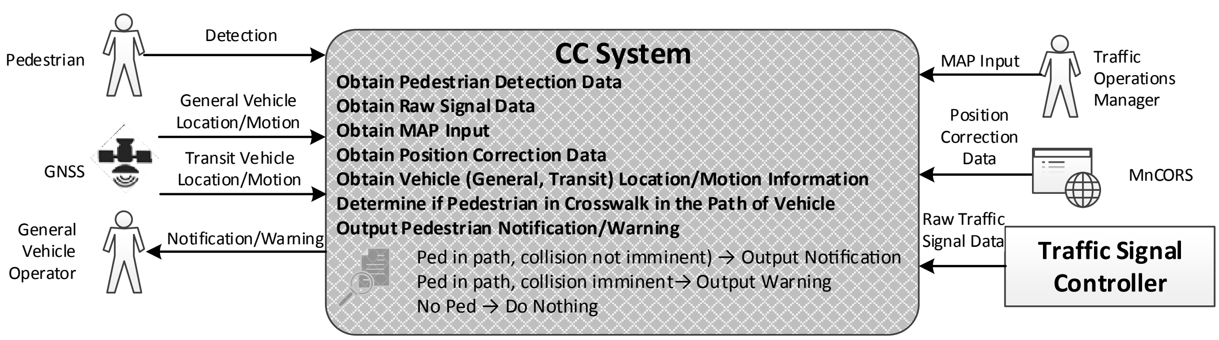
</td></tr>
<tr><td rowspan="4">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Traffic Signal Controller</td><td>1</td><td>Outputs information regarding the current signal state and the timing of subsequent phases (signal status data) to the CC System</td><td>Updates raw output at 10 Hz (nominal broadcast rate),</td></tr>
<tr><td>MnCORS</td><td>2</td><td>Outputs position Correction data</td><td>Connection between MnCORS and CC System could fail</td></tr>
<tr><td>CC System</td><td>3</td><td>Is not capable of producing system outputs</td><td>Resulting from inability to process data, communicate between system components, or communicate with external systems
The system may issue an advisory to the Traffic</td></tr>
</table>

				Operations Manager if internal failure conditions are observed.
	On-Board/Nomadic Device	4a	Does not receive output from the CC System	Which is typically used to enable applications that may be installed on the On-Board/Nomadic Device
	Self-Equipped Driver	4b	Does not receive notification	Responds to traffic control devices, similar to current conditions
	General Equipped Vehicle Operator	5a	Does not receive notification	Responds to traffic control devices, similar to current conditions
Post-Conditions	• All SPaT-enabled CV applications are not supported on vehicles capable of receiving SPaT data via V2I communications, similar to current conditions • The driver may lose trust in the system.			
Traceability	UN-CC-7.06-v01 – Remote Diagnostic			
CC System Inputs	• MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller)			
CC System Outputs	• *none*			

5.2 Vehicle-Pedestrian Intersection Conflict Warning

This use case contains scenarios associated with the Vehicle-Pedestrian Warning Application, which informs general equipped vehicle operators of the presence of pedestrians in signalized crosswalks. Figure 7 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.

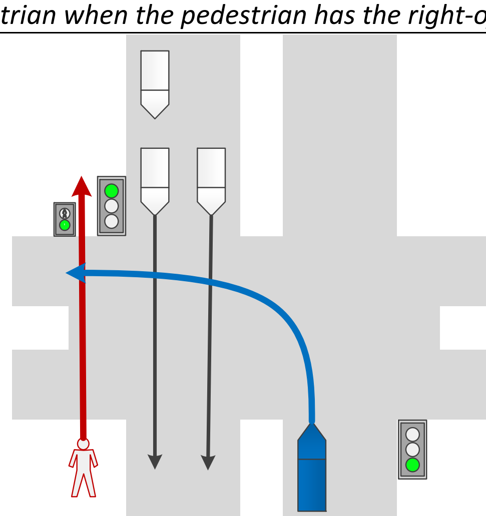
- Use Case 2 Scenario 1: Normal Operation Conditions – Normal Operation Conditions – Pedestrian in Signalized Crosswalk (True Positive Output)
- Use Case 2 Scenario 2: Normal Operating Conditions – Pedestrian in Crosswalk against Pedestrian Signal (True Positive Output)
- Use Case 2 Scenario 3: Normal Operating Conditions – No Pedestrian Conflict (True Negative Output)
- Use Case 2 Scenario 4: Degraded/Failure Conditions – Inaccurate Vehicle Positioning (False Positive Output)
- Use Case 2 Scenario 5: Degraded/Failure Conditions – Inaccurate Pedestrian Positioning (False Positive Output)
- Use Case 2 Scenario 6: Degraded/Failure Conditions – Inaccurate Vehicle Positioning (False Negative Output)
- Use Case 2 Scenario 7: Degraded/Failure Conditions – Inaccurate Pedestrian Positioning (False Negative Output)
- Use Case 2 Scenario 8: Degraded/Failure Conditions – Communications Latency
- Use Case 2 Scenario 9: Degraded/Failure Conditions – Communications Failure



Note: The Over-The-Air-Message Security function is used for wireless communications within the CC System

Figure 7: Vehicle-Pedestrian Warning Application Functional Diagram

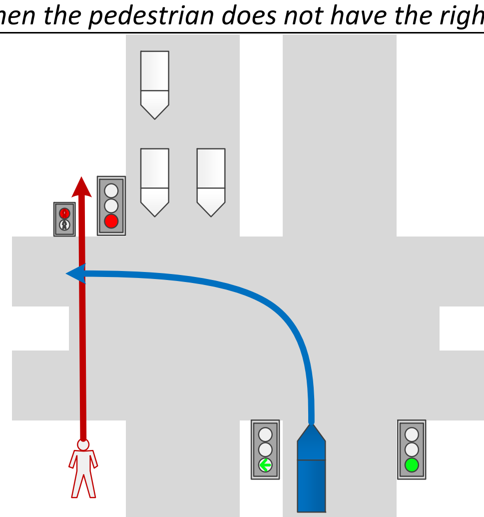
5.2.1 Use Case 2 Scenario 1: Normal Operation Conditions – Pedestrian in Signalized Crosswalk (True Positive Output)

<table>
<tr><th>Use Case</th><th colspan="4">Vehicle-Pedestrian Intersection Conflict Warning</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC2-S1: Normal Operating Conditions – Pedestrian in Signalized Crosswalk</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Improve awareness of Pedestrians to General Equipped/Transit Vehicle Operators
• Notify and warn General Equipped/Transit Vehicle Operators when their path of travel is across a crosswalk with a Pedestrian in it</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The system properly determines there is a Pedestrian in the vehicle’s path
• The system properly notifies the General Equipped/Transit Vehicle Operator of a pedestrian in the path of the vehicle</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Pedestrian</td><td colspan="2">Safely traverse the crosswalk at the intersection</td></tr>
<tr><td colspan="2">General Equipped/Transit Vehicle Operator</td><td colspan="2">Safely navigate through the intersection</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• A vehicle is waiting to make a permitted (not protected) left turn at a red light
• Opposing traffic is queued at the same signalized intersection
• A Pedestrian is waiting to cross the opposing crosswalk, but is traveling against the flow of opposing traffic
• The Pedestrian has performed all required actions (e.g. pressing the pedestrian crossing push button) to receive a walk signal during the next cycle
• Note: This scenario is generally applicable to any pedestrian movement and general equipped vehicle movement such that the path of the vehicle crosses the path of the pedestrian when the pedestrian has the right-of-way.</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4"></td></tr>
<tr><td rowspan="2">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>General</td><td>1</td><td>Traffic Signal turns green (permitted) for the vehicle and for opposing traffic</td><td>Solid green ball or flashing yellow arrow (no left turn arrow) indicates a permitted left turn</td></tr>
</table>

	Pedestrian	2	Simultaneously receives a walk signal and begins to cross the crosswalk to the left of the vehicle	Crosswalk is in the intended path of the vehicle
	CC System	4	Detects Pedestrian presence	
	CC System	5	Issues notification to Transit Vehicle Operator that there is a Pedestrian in the crosswalk.	As the system properly detects a potential conflict between the vehicle and the pedestrian
	General Equipped/Transit Vehicle Operator	6	Advances into the intersection and stops, waiting for opposing traffic to clear	
	General	7	Opposing traffic clears the intersection	
	Pedestrian	6	Continues to cross and remains in the crosswalk	
	CC System	8	Continues to issue notification to Transit Vehicle Operator that there is a Pedestrian in the crosswalk.	*See Step 3 comment*
	General Equipped/Transit Vehicle Operator	9a	Waits for the pedestrian to clear the group of receiving lanes that will be used by the vehicle	
	Pedestrian	10a	Clears the crosswalk	Notification ceases
	General Equipped/Transit Vehicle Operator	11a	Completes left turn maneuver and leaves the intersection	
	General Equipped/Transit Vehicle Operator	9b	Does not notice the notification or does not see the pedestrian, and begins to make a left turn	The a-pillar of the vehicle may occlude the Pedestrian from the view of the Transit Vehicle Operator
	General Equipped/Transit Vehicle Operator	10b	Receives a warning that there is a pedestrian in the crosswalk	
	General Equipped/Transit Vehicle Operator	11b	Stops and waits for the pedestrian to clear the group of receiving lanes that will be used by the vehicle	
	Pedestrian	12b	Clears the crosswalk	Notification ceases
	General Equipped/Transit Vehicle Operator	13b	Completes left turn maneuver and leaves the intersection	After ensuring that it does not interfere with opposing traffic

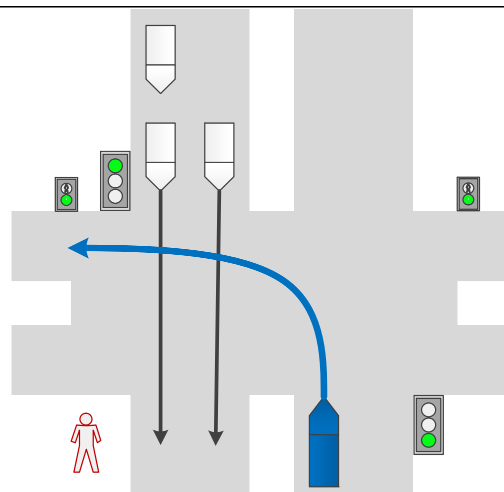
Post-Conditions	• The Pedestrian safely crosses the intersection in the crosswalk • The Transit Vehicle Operator completes the left turn without compromising the safety of the Pedestrian
Traceability	UN-CC-1.03-v01 Pedestrian in Crosswalk Awareness UN-CC-4.01-v01 Pedestrian Crosswalk Safety UN-CC-7.05-v01 – CC System Support
CC System Inputs	• Detection (of Pedestrian) (active detection via detection equipment) • MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • General Equipped Vehicle Location/Motion (from GNSS)
CC System Outputs	• Pedestrian in Crosswalk Notification (to General Equipped/Transit Vehicle Operator) • Pedestrian in Crosswalk Warning (to General Equipped/Transit Vehicle Operator)

5.2.2 Use Case 2 Scenario 2: Normal Operating Conditions – Pedestrian in Crosswalk against Pedestrian Signal (True Positive Output)

<table>
<tr><th>Use Case</th><th colspan="4">Vehicle-Pedestrian Intersection Conflict Warning</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC2-S2: Normal Operating Conditions – Pedestrian in Crosswalk against Pedestrian Signal</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Improve awareness of Pedestrians to Transit Vehicle Operators
• Notify and warn Transit Vehicle Operators when their path of travel is across a crosswalk with a Pedestrian in it</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The system properly determines there is a pedestrian in the vehicle’s path
• The system properly notifies the General Equipped/Transit Vehicle Operator of a pedestrian in the path of the vehicle</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Pedestrian</td><td colspan="2">Safely traverse the crosswalk at the intersection</td></tr>
<tr><td colspan="2">General Equipped/Transit Vehicle Operator</td><td colspan="2">Safely navigate through the intersection</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• A vehicle is waiting to make a protected left turn at a red light
• A Pedestrian is waiting to cross the opposing crosswalk
• The Pedestrian may or may not have performed all required actions (e.g. pressing the pedestrian crossing push button) to receive a walk signal during the next cycle
• Note: This scenario is generally applicable to any pedestrian movement and general vehicle movement such that the path of the vehicle crosses the path of the pedestrian when the pedestrian does not have the right-of-way.</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4"></td></tr>
<tr><td rowspan="4">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>General</td><td>1</td><td>Traffic Signal turns green (protected) for the vehicle and for opposing traffic</td><td>Green left arrow indicates a protected left turn</td></tr>
<tr><td>Pedestrian</td><td>2</td><td>Begins to cross the crosswalk, as cross traffic appears to have stopped</td><td>Does not receive a walk signal</td></tr>
<tr><td>CC System</td><td>3</td><td>Detects Pedestrian presence</td><td></td></tr>
</table>

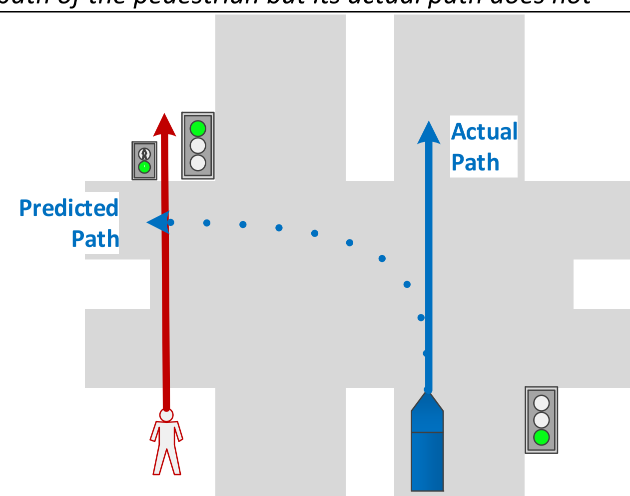
	CC System	4	Issues notification to Transit Vehicle Operator that there is a Pedestrian in the crosswalk.	As the system properly detects a potential conflict between the vehicle and the pedestrian
	General Equipped/Transit Vehicle Operator	5	Waits for the pedestrian to clear the group of receiving lanes that will be used by the vehicle	
	Pedestrian	6	Clears the crosswalk	Notification ceases
	General Equipped/Transit Vehicle Operator	7	Completes left turn maneuver and leaves the intersection	
Post-Conditions	• The Transit Vehicle Operator completes the left turn without compromising the safety of the Pedestrian			
Traceability	UN-CC-1.03-v01 Pedestrian in Crosswalk Awareness UN-CC-4.01-v01 Pedestrian in Crosswalk Safety UN-CC-7.05-v01 – CC System Support			
CC System Inputs	• Detection (of Pedestrian) (active detection via detection equipment) • MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • General Equipped Vehicle Location/Motion (from GNSS)			
CC System Outputs	• Pedestrian in Crosswalk Notification (to General Equipped/Transit Vehicle Operator) • Pedestrian in Crosswalk Warning (to General Equipped/Transit Vehicle Operator)			

5.2.3 Use Case 2 Scenario 3: Normal Operating Conditions – No Pedestrian Conflict (True Negative Output)

<table>
<tr><th>Use Case</th><th colspan="4">Vehicle-Pedestrian Intersection Conflict Warning</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC2-S3: Normal Operating Conditions – No Pedestrian Conflict</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the ability of the system to not output notifications or warnings to a General Equipped Vehicle Operator when no conflict present</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The system properly determines there is not a Pedestrian in the vehicle's path
• The system properly does not notify the General Equipped/Transit Vehicle Operator</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Pedestrian</td><td colspan="2">Safely traverse the crosswalk at the intersection</td></tr>
<tr><td colspan="2">General Equipped/Transit Vehicle Operator</td><td colspan="2">Safely navigate through the intersection</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• A vehicle is waiting to make a permitted (not protected) left turn at a red light
• Opposing traffic is queued at the same signalized intersection
• The pedestrian is waiting at the corner of the intersection and is not moving.
• Note: This scenario is generally applicable to any vehicle movement when the pedestrian is not in a crosswalk</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4"></td></tr>
<tr><td rowspan="4">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>General</td><td>1</td><td>Traffic signal turns green (permitted) for the vehicle and for opposing traffic</td><td>Solid green ball or flashing yellow arrow (no left turn arrow) indicates a permitted left turn</td></tr>
<tr><td>Pedestrian</td><td>2</td><td>Continues to wait at the corner of the intersection</td><td>Pedestrian is not in the intended path of the vehicle</td></tr>
<tr><td>CC System</td><td>3</td><td>Does not provide notification to the General</td><td>As the system properly does not detect a potential conflict</td></tr>
</table>

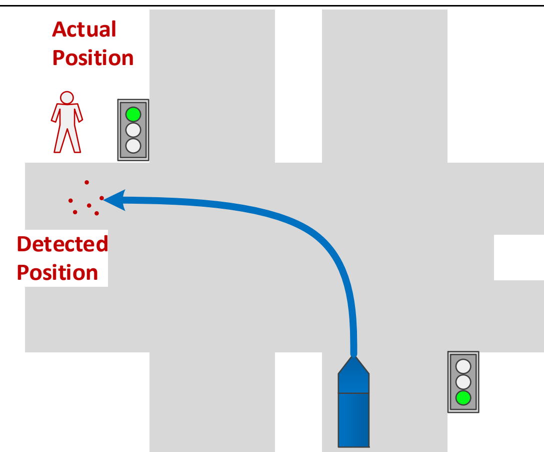
			Equipped/Transit Vehicle Operator	
	General Equipped/Transit Vehicle Operator	4	Advances into the intersection and stops, waiting for opposing traffic to clear	
	General	5	Opposing traffic clears the intersection	
	General Equipped/Transit Vehicle Operator	6	Completes left turn maneuver and leaves the intersection	After double checking by visual inspection that there are no Pedestrians in the path of travel. No notification or warning is received
Post-Conditions	• The Pedestrian safely crosses the intersection in the crosswalk • The Transit Vehicle Operator completes the left turn without compromising the safety of the pedestrian			
Traceability	UN-CC-1.03-v01 Pedestrian in Crosswalk Awareness UN-CC-7.05-v01 – CC System Support			
CC System Inputs	• MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • General Equipped Vehicle Location/Motion (from GNSS)			
CC System Outputs	• Pedestrian in Crosswalk Notification (to General Equipped/Transit Vehicle Operator) • Pedestrian in Crosswalk Warning (to General Equipped/Transit Vehicle Operator)			

5.2.4 Use Case 2 Scenario 4: Degraded Conditions – Inaccurate Vehicle Positioning (False Positive Output)

<table>
<tr><th>Use Case</th><th colspan="4">Vehicle-Pedestrian Intersection Conflict Warning</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC2-S4: Degraded Conditions – Inaccurate Vehicle Positioning</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the fall back scenario if the detected path of the vehicle is inaccurate.</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The system falsely determines the vehicle’s path.
• The system falsely determines there is a Pedestrian in the vehicle’s path
• The system falsely notifies the General Equipped/Transit Vehicle Operator of a Pedestrian in the path of the vehicle.</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Pedestrian</td><td colspan="2">Safely traverse the crosswalk at the intersection</td></tr>
<tr><td colspan="2">General Equipped/Transit Vehicle Operator</td><td colspan="2">Safely navigate through the intersection, using information from the warning system as well as traditional sources of information such as a visual inspection</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• A vehicle is waiting to make a through movement at a red light
• There are Pedestrians waiting to cross the opposing crosswalk, though there may be Pedestrians in other crosswalks in the intersection
• Note: This scenario is generally applicable to any pedestrian movement and general equipped vehicle movement such that the projected path of the vehicle crosses the path of the pedestrian but its actual path does not</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">
</td></tr>
<tr><td rowspan="3">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Traffic Signal</td><td>1</td><td>Turns green (permitted) for the vehicle</td><td>Solid green ball (no left turn arrow) indicates a permitted through movement</td></tr>
<tr><td>CC System</td><td>2</td><td>Issues notification to Transit Vehicle Operator that there is a pedestrian in the crosswalk.</td><td>Though there is no pedestrian in the path of the vehicle, the system detects a potential conflict as a</td></tr>
</table>

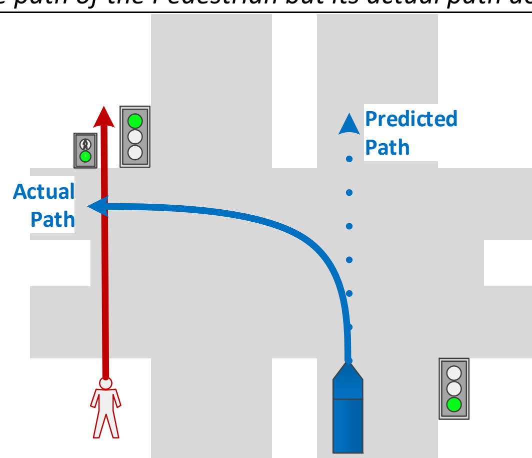
				result of inaccurate vehicle path detection (due to inaccurate vehicle positioning)
	General Equipped/Transit Vehicle Operator	3	Advances into the intersection	Looking carefully for pedestrians
	CC System	5	Continues to issue notification to Transit Vehicle Operator that there is a pedestrian in the crosswalk.	*See Step 2 comment*
	General Equipped/Transit Vehicle Operator	6	Visually inspects the opposing crosswalk	With extra care to ensure there is no pedestrian that was hidden from view
	General Equipped/Transit Vehicle Operator	7	Visually confirms there is not a pedestrian in the crosswalk	
	General Equipped/Transit Vehicle Operator	8	Completes through maneuver	Notification ceases when pedestrian clears the crosswalk or after the system properly detects the transit vehicle path
Post-Conditions	• The General Equipped/Transit Vehicle Operator completes the through movement without compromising the safety of any Pedestrians • The General Equipped/Transit Vehicle Operator may lose trust in the notification system, and may be less likely to respond to notifications in the future			
Traceability	*N/A for Degraded Conditions due to Inaccuracies*			
CC System Inputs	• Detection (of Pedestrian) • MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • (inaccurate) General Equipped Vehicle Location/Motion (from GNSS)			
CC System Outputs	• (false) Pedestrian in Crosswalk Notification (to General Equipped/Transit Vehicle Operator) • (false) Pedestrian in Crosswalk Warning (to General Equipped/Transit Vehicle Operator)			

5.2.5 Use Case 2 Scenario 5: Degraded Conditions – Inaccurate Pedestrian Positioning (False Positive Output)

<table>
<tr><th>Use Case</th><th colspan="4">Vehicle-Pedestrian Intersection Conflict Warning</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC2-S5: Degraded Conditions – Inaccurate Pedestrian Positioning</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the fall back scenario if the location of a Pedestrian (as detected by the PDE) is inaccurate.</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The system falsely detects the pedestrian in a crosswalk
• The system falsely determines there is a Pedestrian in the vehicle’s path
• The system falsely notifies the General Equipped/Transit Vehicle Operator of a Pedestrian in the path of the vehicle.</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Pedestrian</td><td colspan="2">Safely traverse the crosswalk at the intersection</td></tr>
<tr><td colspan="2">General Equipped/Transit Vehicle Operator</td><td colspan="2">Safely navigate through the intersection, using information from the warning system as well as traditional sources of information such as a visual inspection</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• A vehicle is waiting to make a left turn movement at a red light
• The pedestrian is waiting at the corner of the intersection and is not moving.
• Note: This scenario is generally applicable to any pedestrian movement and general equipped vehicle movement such that the vehicle crosses the detected path of the Pedestrian but the Pedestrian is not in the crosswalk</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">
</td></tr>
<tr><td rowspan="3">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Traffic Signal</td><td>1</td><td>Turns green (permitted) for the vehicle and for opposing traffic</td><td>Solid green bulb (no left turn arrow) indicates a permitted left turn</td></tr>
<tr><td>CC System</td><td>2</td><td>Issues notification to vehicle operator that there is a Pedestrian in the crosswalk.</td><td>Though there is no pedestrian in the path of the vehicle, the system detects a potential conflict as a result of inaccurate pedestrian-in-crosswalk detection (due to</td></tr>
</table>

				inaccurate PDE calibration)
	General Equipped/Transit Vehicle Operator	3	Advances into the intersection and stops, waiting for opposing traffic to clear	
	General	4	Opposing traffic clears the intersection	
	CC System	5	Continues to issue notification to General Equipped Vehicle Operator that there is a pedestrian in the crosswalk.	*See Step 2 comment*
	General Equipped/Transit Vehicle Operator	6	Visually inspects the opposing crosswalk	With extra care to ensure there is no pedestrian that was hidden from view
	General Equipped/Transit Vehicle Operator	7	Visually confirms there is not a pedestrian in the crosswalk	
	General Equipped/Transit Vehicle Operator	8	Completes left turn maneuver	Notification ceases when transit vehicle clears the crosswalk or after the system properly detects the pedestrian
Post-Conditions	• The General Equipped/Transit Vehicle Operator completes the left turn without compromising the safety of any pedestrians • The General Equipped/Transit Vehicle Operator may lose trust in the notification system, and may be less likely to respond to notifications in the future			
Traceability	*N/A for Degraded Conditions due to Inaccuracies*			
CC System Inputs	• (inaccurate) Detection (of Pedestrian) • MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • General Equipped Vehicle Location/Motion (from GNSS)			
CC System Outputs	• (false) Pedestrian in Crosswalk Notification (to General Equipped/Transit Vehicle Operator) • (false) Pedestrian in Crosswalk Warning (to General Equipped/Transit Vehicle Operator)			

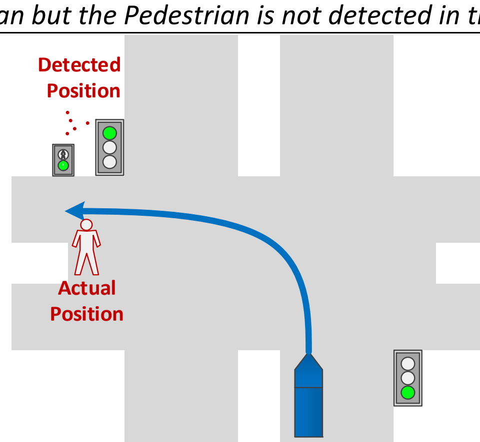
5.2.6 Use Case 2 Scenario 6: Degraded Conditions – Inaccurate Vehicle Positioning (False Negative Output)

<table>
<tr><th>Use Case</th><th colspan="4">Vehicle-Pedestrian Intersection Conflict Warning</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC2-S6: Degraded Conditions – Inaccurate Vehicle Positioning</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the fall back scenario if the detected path of the vehicle is inaccurate.</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The system falsely determines the vehicle’s path.
• The system falsely determines there is not a pedestrian in the vehicle’s path.
• The system falsely does not notify the General Equipped/Transit Vehicle Operator that there is a Pedestrian in the path of the vehicle.</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Pedestrian</td><td colspan="2">Safely traverse the crosswalk at the intersection</td></tr>
<tr><td colspan="2">General Equipped/Transit Vehicle Operator</td><td colspan="2">Safely navigate through the intersection, using information from the warning system as well as traditional sources of information such as a visual inspection</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• A vehicle is waiting to make a permitted (not protected) left turn at a red light
• Opposing traffic is queued at the same signalized intersection
• A Pedestrian is waiting to cross the opposing crosswalk, but is traveling against the flow of opposing traffic
• The Pedestrian has performed all required actions (e.g. pressing the pedestrian crossing push button) to receive a walk signal during the next cycle
• Note: This scenario is generally applicable to any pedestrian movement and general equipped vehicle movement such that the projected path of the vehicle does not cross the path of the Pedestrian but its actual path does</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">
</td></tr>
<tr><td rowspan="3">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Traffic Signal</td><td>1</td><td>Turns green (permitted) for the vehicle and for opposing traffic</td><td>Solid green bulb (no left turn arrow) indicates a permitted left turn</td></tr>
<tr><td>Pedestrian</td><td>2</td><td>Simultaneously receives a walk signal and begins to cross the crosswalk to the</td><td></td></tr>
</table>

			left of the vehicle, in the intended path of the vehicle	
	General	3a	Notification has not been provided to the General Equipped/Transit Vehicle Operator	Though there is a pedestrian in the path of the vehicle, the system does not detect a potential conflict as a result of inaccurate vehicle path detection (due to inaccurate vehicle positioning)
	General Equipped/Transit Vehicle Operator	4	Advances into the intersection and stops, waiting for opposing traffic to clear	
	General	5	Opposing traffic clears the intersection	
	Pedestrian	6	Continues to cross and remains in the crosswalk	
	General	7	Notification has still not been provided to the General Equipped Vehicle Operator	*See Step 3 comment*
	General Equipped/Transit Vehicle Operator	8a	Notices Pedestrian before beginning to turn left	
	General Equipped/Transit Vehicle Operator	8b	Begins left turn maneuver before noticing Pedestrian, and stops immediately.	Obstacles (such as an a-pillar) may occlude the Pedestrian. The vehicle may block the opposing lane of traffic
	Pedestrian	9	Clears the crosswalk	
	General Equipped/Transit Vehicle Operator	10	Completes left turn maneuver and leaves the intersection	
Post-Conditions	• The Pedestrian safely crosses the intersection in the crosswalk • The General Equipped/Transit Vehicle Operator completes the left turn without compromising the safety of any Pedestrians • Oncoming traffic may have to decrease speed or stop while the vehicle clears the intersection.			
Traceability	*N/A for Degraded Conditions due to Inaccuracies*			
CC System Inputs	• Detection (of Pedestrian) • MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller)			

	• (inaccurate) General Equipped Vehicle Location/Motion (from GNSS)
CC System Outputs	• *none*

5.2.7 Use Case 2 Scenario 7: Degraded Conditions – Inaccurate Pedestrian Positioning (False Negative Output)

<table>
<tr><th>Use Case</th><th colspan="4">Vehicle-Pedestrian Intersection Conflict Warning</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC2-S7: Degraded Conditions – Inaccurate Pedestrian Positioning</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the fall back scenario if the location of a Pedestrian (as detected by the PDE) is inaccurate.</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The system falsely detects the pedestrian is not in a crosswalk
• The system falsely determines there is not a Pedestrian in the vehicle's path.
• The system falsely does not notify the General Equipped/Transit Vehicle Operator that there is a Pedestrian in the path of the vehicle.</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Pedestrian</td><td colspan="2">Safely traverse the crosswalk at the intersection</td></tr>
<tr><td colspan="2">General Equipped/Transit Vehicle Operator</td><td colspan="2">Safely navigate through the intersection, using information from the warning system as well as traditional sources of information such as a visual inspection</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• A vehicle is waiting to make a permitted (not protected) left turn at a red light
• Opposing traffic is queued at the same signalized intersection
• A Pedestrian is waiting to cross the opposing crosswalk, but is traveling against the flow of opposing traffic
• The Pedestrian has performed all required actions (e.g. pressing the pedestrian crossing push button) to receive a walk signal during the next cycle
• Note: This scenario is generally applicable to any pedestrian movement and general equipped vehicle movement such that the vehicle crosses the actual path of the Pedestrian but the Pedestrian is not detected in the crosswalk</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">
</td></tr>
<tr><td></td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
</table>

Key Actions and Flow of Events	Traffic Signal	1	Turns green (permitted) for the vehicle and for opposing traffic	Solid green bulb (no left turn arrow) indicates a permitted left turn
	Pedestrian	2	Simultaneously receives a walk signal and begins to cross the crosswalk to the left of the vehicle, in the intended path of the vehicle	
	General	3a	Notification has not been provided to the General Equipped Vehicle Operator	Though there is a pedestrian in the path of the vehicle, the system does not detect a potential conflict as a result of inaccurate pedestrian-in-crosswalk detection (due to inaccurate PDE calibration)
	General Equipped/Transit Vehicle Operator	4	Advances into the intersection and stops, waiting for opposing traffic to clear	
	General	5	Opposing traffic clears the intersection	
	Pedestrian	6	Continues to cross and remains in the crosswalk	
	General	7	Notification has still not been provided to the General Equipped Vehicle Operator	*See Step 3 comment*
	General Equipped/Transit Vehicle Operator	8a	Notices Pedestrian before beginning to turn left	
	General Equipped/Transit Vehicle Operator	8b	Begins left turn maneuver before noticing Pedestrian, and stops immediately.	Obstacles (such as an a-pillar) may occlude the Pedestrian. The vehicle may block the opposing lane of traffic
	Pedestrian	9	Clears the crosswalk	
	General Equipped/Transit Vehicle Operator	10	Completes left turn maneuver and leaves the intersection	
Post-Conditions	• The Pedestrian safely crosses the intersection in the crosswalk • The General Equipped/Transit Vehicle Operator completes the left turn without compromising the safety of any Pedestrians			

	• Oncoming traffic may have to decrease speed or stop while the vehicle clears the intersection.
Traceability	*N/A for Degraded Conditions due to Inaccuracies*
CC System Inputs	• (inaccurate) Detection (of Pedestrian) • MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • General Equipped Vehicle Location/Motion (from GNSS)
CC System Outputs	• *none*

5.2.8 Use Case 2 Scenario 8: Degraded Conditions – Communications Latency

<table>
<tr><th>Use Case</th><th colspan="4">Vehicle-Pedestrian Intersection Conflict Warning</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC2-S8: Degraded Conditions – Communications Latency</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the fall back scenario if there is latency associated with system processes that are responsible for transforming inputs into actionable outputs</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• Latency in the system (processing, communication between CC System components, or communication between the CC System and external systems) result in an output that is received in time to be of practical use to the recipient.
• The system cannot determine there is a Pedestrian in the vehicle’s path in a timely manner.
• The system does notify the General Equipped/Transit Vehicle Operator that there is a Pedestrian in the path of the vehicle until the window for General Equipped/Transit Vehicle Operator action has already passed.</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Pedestrian</td><td colspan="2">Safely traverse the crosswalk at the intersection</td></tr>
<tr><td colspan="2">General Equipped/Transit Vehicle Operator</td><td colspan="2">Safely navigate through the intersection, using information from the warning system as well as traditional sources of information such as a visual inspection</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• A vehicle is waiting to make a permitted (not protected) left turn at a red light
• Opposing traffic is queued at the same signalized intersection
• A Pedestrian is waiting to cross the opposing crosswalk, but is traveling against the flow of opposing traffic
• The Pedestrian has performed all required actions (e.g. pressing the pedestrian crossing push button) to receive a walk signal during the next cycle</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">• Same as Scenario 1</td></tr>
<tr><td rowspan="4">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Traffic Signal</td><td>1</td><td>Turns green (permitted) for the vehicle and for opposing traffic</td><td>Solid green bulb (no left turn arrow) indicates a permitted left turn</td></tr>
<tr><td>Pedestrian</td><td>2</td><td>Simultaneously receives a walk signal and begins to cross the crosswalk to the left of the vehicle, in the intended path of the vehicle</td><td>A notification is sent to the General Equipped Vehicle Operator of the potential conflict, but it is not instantly received by the vehicle operator due to communications latency</td></tr>
<tr><td>General Equipped/Transit Vehicle Operator</td><td>3</td><td>Advances into the intersection and stops, waiting for opposing traffic to clear</td><td></td></tr>
</table>

	General	4	Opposing traffic clears the intersection	
	Pedestrian	5	Continues to cross and remains in the crosswalk	
	General Equipped/Transit Vehicle Operator	6	Begins left turn maneuver, sees Pedestrian, and stops immediately and waits for the Pedestrian to clear the group of receiving lanes that will be used by the vehicle	The General Equipped Vehicle Operator could see the Pedestrian before beginning to turn left, but if there are any obstacles (such as an a-pillar) blocking their view until they are about to cross the crosswalk, the vehicle may be stuck blocking the opposing lane of traffic
	CC System	7	Issues a notification that there is a Pedestrian in the crosswalk	The system may issue a latency advisory to the General Equipped Vehicle Operator and/or to the Traffic Operations Manager if latency is observed.
	Pedestrian	8	Clears the crosswalk	Notification ceases
	General Equipped/Transit Vehicle Operator	9	Completes left turn maneuver and leaves the intersection	
Post-Conditions	• The Pedestrian safely crosses the intersection in the crosswalk • The General Equipped/Transit Vehicle Operator completes the left turn without compromising the safety of the Pedestrian • The General Equipped/Transit Vehicle Operator may lose trust in the notification system, and may be less likely to respond to notifications in the future			
Traceability	UN-CC-7.06-v01 – Remote Diagnostic			
CC System Inputs	• Detection (of Pedestrian) • MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • General Equipped Vehicle Location/Motion (from GNSS)			
CC System Outputs	• (late) Pedestrian in Crosswalk Notification (to General Equipped/Transit Vehicle Operator) • (late) Pedestrian in Crosswalk Warning (to General Equipped/Transit Vehicle Operator)			

5.2.9 Use Case 2 Scenario 9: Degraded Conditions – Communications Failure

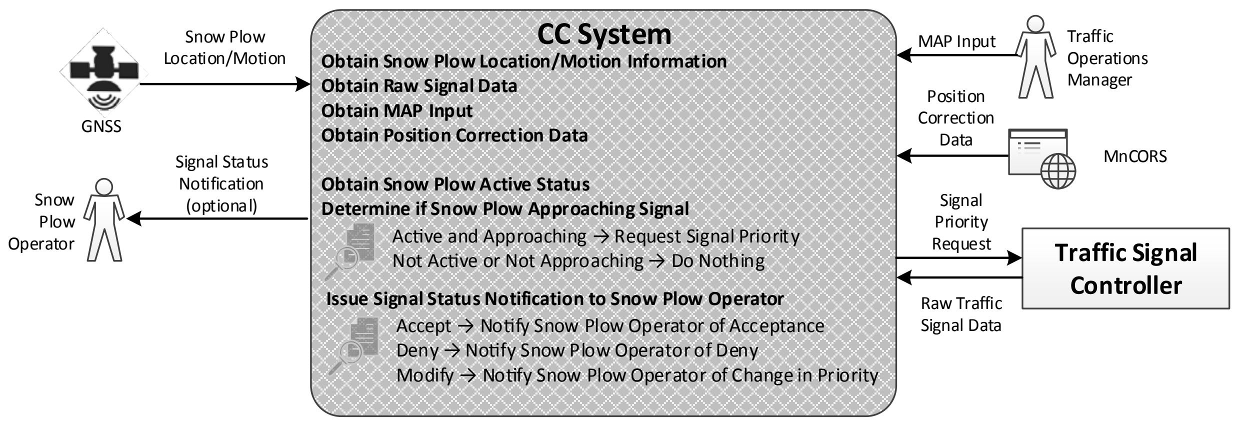
<table>
<tr><th>Use Case</th><th colspan="4">Vehicle-Pedestrian Intersection Conflict Warning</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC2-S9: Degraded Conditions – Communications Failure</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the fall back scenario if failure of communication between CC System components, or communication between the CC System and external systems result in no output when output would have been given under normal operating conditions</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• Failure of communication between CC System components, or communication between the CC System and external systems result in an output that is never received
• The system cannot determine there is a Pedestrian in the vehicle's path
• The system cannot notify the General Equipped/Transit Vehicle Operator that there is a Pedestrian in the path of the vehicle.</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Pedestrian</td><td colspan="2">Safely traverse the crosswalk at the intersection</td></tr>
<tr><td colspan="2">General Equipped/Transit Vehicle Operator</td><td colspan="2">Safely navigate through the intersection, using information from the warning system as well as traditional sources of information such as a visual inspection</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• A vehicle is waiting to make a permitted (not protected) left turn at a red light
• Opposing traffic is queued at the same signalized intersection
• A Pedestrian is waiting to cross the opposing crosswalk, but is traveling against the flow of opposing traffic
• The Pedestrian has performed all required actions (e.g. pressing the pedestrian crossing push button) to receive a walk signal during the next cycle</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">• Same as Scenario 1</td></tr>
<tr><td rowspan="7">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Traffic Signal</td><td>1</td><td>Turns green (permitted) for the vehicle and for opposing traffic</td><td>Solid green bulb (no left turn arrow) indicates a permitted left turn</td></tr>
<tr><td>Pedestrian</td><td>2</td><td>Simultaneously receives a walk signal and begins to cross the crosswalk to the left of the vehicle, in the intended path of the vehicle</td><td></td></tr>
<tr><td>General Equipped/Transit Vehicle Operator</td><td>3</td><td>Advances into the intersection and stops, waiting for opposing traffic to clear</td><td></td></tr>
<tr><td>General</td><td>4</td><td>Opposing traffic clears the intersection</td><td></td></tr>
<tr><td>Pedestrian</td><td>5</td><td>Continues to cross and remains in the crosswalk</td><td></td></tr>
<tr><td>General Equipped/Transit Vehicle Operator</td><td>6</td><td>Begins left turn maneuver, sees Pedestrian, and stops immediately and waits for the</td><td></td></tr>
</table>

			Pedestrian to clear the group of receiving lanes that will be used by the vehicle	
	Pedestrian	7	Clears the crosswalk	
	General Equipped/Transit Vehicle Operator	8	Completes left turn maneuver and leaves the intersection	
Post-Conditions	• The Pedestrian safely crosses the intersection in the crosswalk • The General Vehicle Operator completes the left turn without compromising the safety of the Pedestrian			
Traceability	UN-CC-7.06-v01 – Remote Diagnostic			
CC System Inputs	• Detection (of Pedestrian) • MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • General Equipped Vehicle Location/Motion (from GNSS)			
CC System Outputs	• *none*			

5.3 Snow Plow Signal Priority

This use case contains scenarios associated with the Snow Plow Signal Priority Application. Figure 8 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.

- Use Case 3 Scenario 1: Normal Operating Conditions – Early Green / Green Extension
- Use Case 3 Scenario 2: Normal Operating Conditions – Priority Request Arbitration
- Use Case 3 Scenario 3: Normal Operating Conditions – Denying Snow Plow Priority Request
- Use Case 3 Scenario 4: Normal Operating Conditions – Denying Unauthorized Priority Request
- Use Case 3 Scenario 5: Degraded Operating Conditions – Deficient Vehicle Data Quality
- Use Case 3 Scenario 6: Degraded Operating Conditions – Accepting Unauthorized Priority Request
- Use Case 3 Scenario 7: Degraded Operating Conditions – Communications Latency
- Use Case 3 Scenario 8: Degraded Operating Conditions – Communications Failure

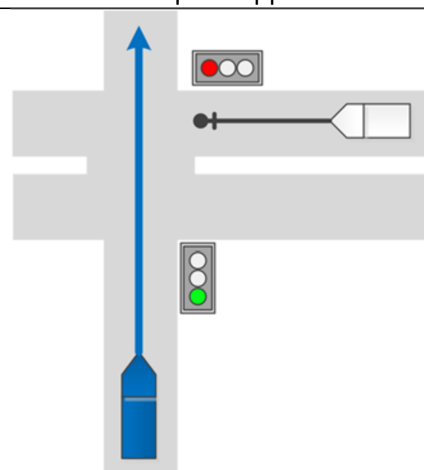


Note: The Over-The-Air-Message Security function is used for wireless communications within the CC System

Figure 8: Snow Plow Signal Priority Application Functional Diagram

5.3.1 Use Case 3 Scenario 1: Normal Operating Conditions – Early Green / Green Extension

Use Case	Snow Plow Signal Priority
Scenario ID and Title	*UC3-S1: Normal Operating Conditions – Early Green / Green Extension*
Scenario Objective	• Providing efficient movement through intersections for snow plows actively involved in snow plowing and chemical spreading operations • Reduce the amount of time it takes for snow plow(s) (that are part of a gang plow) to clear an offramp/onramp before rejoining the gang plow of the freeway mainline (if involved in gang plow operations)

<table>
<tr><td>Operational Event(s)</td><td colspan="4">• Snow Plow Operator approaches a signalized intersection while actively plowing or spreading chemicals on the roadway
• The CC System sends signal priority requests to the signalized intersection that the Snow Plow Operator is approaching</td></tr>
<tr><td rowspan="2">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Snow Plow Operator</td><td colspan="2">Quickly traverse an intersection without stopping to improve operations efficiency and to reduce the unequal spread of snow removal chemicals</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• A snow plow is operating on a roadway where Snow Plow Signal Priority is enabled during a time of day when Snow Plow Signal Priority can be granted
• A traffic signal is red for the snow plow approach</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4"></td></tr>
<tr><td rowspan="6">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Snow Plow Operator</td><td>1</td><td>Approaches the intersection</td><td></td></tr>
<tr><td>CC System</td><td>2</td><td>Determines the snow plow is approaching the intersection, in actively engaged in plowing or spreading chemicals, and communicates a signal priority request to the Traffic Signal Controller</td><td>to request signal priority</td></tr>
<tr><td>Traffic Signal Controller</td><td>3</td><td>Determines it can accommodate the priority request and prioritizes the received request with other received requests</td><td>Prioritization could be performed locally on the roadside, or through communication with MaxView.</td></tr>
<tr><td>Traffic Signal Controller</td><td>4</td><td>Responds to the CC System with the priority order and status (accepted/denied) of all received requests</td><td>No other vehicles are requesting priority</td></tr>
<tr><td>CC System</td><td>5</td><td>(optional) Notifies Snow Plow Operator that priority has been granted</td><td>As the snow plow approaches the intersection at nominal speed</td></tr>
</table>

	Traffic Signal Controller	6	Services the approach of the Snow Plow	
	Snow Plow Operator	7	Makes the intended maneuver through the intersection	Without stopping
Post-Conditions	• The snow plow does not have to stop at the intersection, resulting in reduced clearance time, even spread of snow removal chemicals, and minimal inefficiencies to gang plow operations (if involved in gang plow operations)			
Traceability	UN-CC-3.01-v01 Reduce Disruption of Plow Operations at Signalized Intersections UN-CC-3.02-v01 Minimize Gang Plow Disruptions UN-CC-7.05-v01 – CC System Support			
CC System Inputs	• MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • Snow Plow Location/Motion (from GNSS)			
CC System Outputs	• Signal Priority Request (to Traffic Signal Controller) • Signal Priority Status Notification (optional, to Snow Plow Operator)			

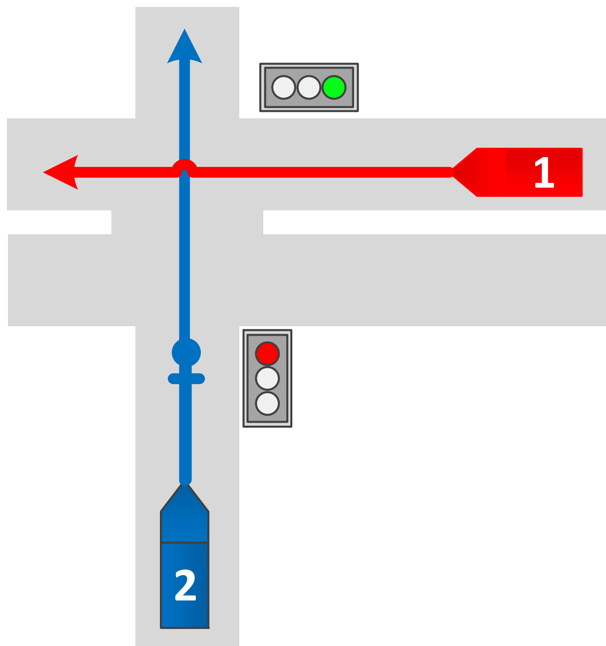
5.3.2 Use Case 3 Scenario 2: Normal Operating Conditions – Priority Request Arbitration

Use Case	**Snow Plow Signal Priority**	
Scenario ID and Title	*UC3-S2: Normal Operating Conditions – Priority Request Arbitration*	
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 Traffic Signal Controller arbitrates between priority messages. • Priority requests are served in priority order as determined by arbitration. • This scenario focuses on two snow plows, but could take place between any two vehicles requesting signal priority.	
User(s)	User	Role
	Snow Plow Operator 1	Quickly and safely traverse an intersection to improve mobility while participating in snow plow activities on an intersecting arterial.
	Snow Plow Operator 2	Quickly and safely traverse an intersection to improve mobility while participating in snow plow activities on a primary arterial.
Initial Conditions	• Snow Plow 1 is operating on a primary arterial where Snow Plow Signal Priority is enabled during a time of day when Snow Plow Signal Priority can be granted	

<table>
<tr><td></td><td colspan="4">

- Snow Plow 2 is operating on an intersecting arterial where Snow Plow Signal Priority is enabled during a time of day when Snow Plow Signal Priority can be granted
- A traffic signal is red for the intersecting approach, and green for the primary arterial approach
- Signal Priority Requests from the primary approach (Snow Plow Operator 2) have a greater priority than Signal Priority Requests from the Intersecting approach (Snow Plow Operator 1)

</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">



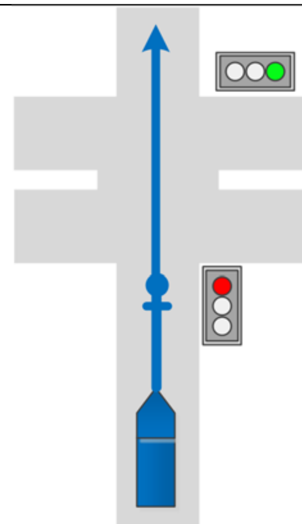
</td></tr>
<tr><td rowspan="5">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Snow Plow Operator 1</td><td>1</td><td>Approaches the intersection</td><td>From the primary arterial</td></tr>
<tr><td>CC System</td><td>2</td><td>Determines Snow Plow 1 is approaching the intersection, in actively engaged in plowing or spreading chemicals, and communicates a signal priority request to the Traffic Signal Controller</td><td>to request signal priority</td></tr>
<tr><td>Traffic Signal Controller</td><td>3</td><td>Determines it can accommodate the priority request and prioritizes the received request with other received requests.</td><td>Prioritization could be performed locally on the roadside, or through communication with MaxView.</td></tr>
<tr><td>Traffic Signal Controller</td><td>4</td><td>Responds to the CC System with the priority order and status (accepted/denied) of all received requests</td><td></td></tr>
</table>

	CC System	5	(optional) Notifies Snow Plow Operator 1 that priority has been granted	
	Snow Plow Operator 2	6	Approaches the intersection	From an intersecting arterial
	CC System	7	Determines Snow Plow 2 is approaching the intersection, in actively engaged in plowing or spreading chemicals, and communicates a signal priority request to the Traffic Signal Controller	
	Traffic Signal Controller	8	Prioritizes the received request with other received requests.	Snow Plow 2 is given higher priority than Snow Plow 1. Prioritization could be performed locally on the roadside, or through communication with MaxView.
	Traffic Signal Controller	9	Responds to the CC System with the priority order and status (accepted/denied) of all received requests	No other vehicles are requesting priority
	CC System	10	(optional) Notifies Snow Plow Operator 2 that priority has been granted	
	CC System	11	(optional) Notifies Snow Plow Operator 1 that priority order has changed	
	Traffic Signal Controller	12	Services the approach of snow plow 2	As the snow plow approaches the intersection at nominal speed.
	Snow Plow Operator 2	13	Makes the intended maneuver through the intersection	Without stopping
	Traffic Signal Controller	14	Determines that Snow Plow 2 has exited the intersection	
	Traffic Signal Controller	15	Services the approach for Snow Plow Operator 1	As quick as phasing will allow. (Note: skipping phases may not be a permitted practice)
	Snow Plow Operator 1	16	Makes its intended maneuver through the intersection	May need to stop depending on the approach timing

Post-Conditions	• Competing signal priority requests are properly arbitrated by the Traffic Signal Controller • All users experience improved mobility compared to current operations.
Traceability	UN-CC-3.01-v01 Reduce Disruption of Plow Operations at Signalized Intersections UN-CC-3.02-v01 Minimize Gang Plow Disruptions UN-CC-7.05-v01 – CC System Support
CC System Inputs	• MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • Snow Plow Location/Motion (from GNSS)
CC System Outputs	• Signal Priority Request (to Traffic Signal Controller) • Signal Priority Status Notification (optional, to Snow Plow Operator)

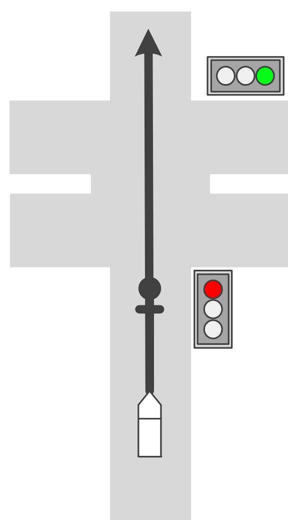
5.3.3 Use Case 3 Scenario 3: Normal Operating Conditions – Denying Snow Plow Priority Request

<table>
<tr><th>Use Case</th><th colspan="2">Snow Plow Signal Priority</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="2">UC3-S4: Normal Operating Conditions – Denying Unauthorized Priority Request</td></tr>
<tr><td>Scenario Objective</td><td colspan="2">• Providing efficient movement through intersections for snow plows actively involved in snow plowing and chemical spreading operations
• Reduce the amount of time it takes for snow plow(s) (that are part of a gang plow) to clear an offramp/onramp before rejoining the gang plow of the freeway mainline (if involved in gang plow operations).</td></tr>
<tr><td>Operational Event(s)</td><td colspan="2">• Snow Plow Operator approaches a signalized intersection while actively plowing or spreading chemicals on the roadway
• The CC System sends signal priority requests to the signalized intersection that the Snow Plow Operator is approaching</td></tr>
<tr><td rowspan="3">User(s)</td><td>User</td><td>Role</td></tr>
<tr><td>Snow Plow Operator</td><td>Quickly traverse an intersection without stopping to improve operations efficiency and to reduce the unequal spread of snow removal chemicals</td></tr>
<tr><td>Traffic Operations Manager</td><td>Provide efficient movement of traffic on the roadway network during peak hour</td></tr>
<tr><td>Initial Conditions</td><td colspan="2">• The snow plow is operating during peak hour.
• A snow plow is operating on a roadway where Snow Plow Signal Priority is enabled
• A traffic signal is red for the snow plow approach</td></tr>
</table>

Scenario Diagram				
Key Actions and Flow of Events	**Source**	**Step**	**Key Action**	**Comments**
	Snow Plow Operator	1	Approaches the intersection	
	CC System	2	Determines Snow Plow is approaching the intersection, in actively engaged in plowing or spreading chemicals, and communicates a signal priority request to the Traffic Signal Controller	to request signal priority
	Traffic Signal Controller	3	Determines that it cannot accept the priority request	Due to peak hour signal priority limitations
	Traffic Signal Controller	4	Responds to the CC System with the priority order and status (accepted/denied) of all received requests	
	CC System	5	(optional) Notifies Snow Plow Operator 1 that priority has been denied	
	Traffic Signal Controller	6	Continues through its normal cycle	
	Snow Plow Operator	7	Comes to a stop at the intersection	
	Snow Plow Operator	8	Makes the intended maneuver through the intersection.	
Post-Conditions	• The snow plow has to stop at the intersection before continuing snow removal operations. This is similar to existing conditions			
Traceability	UN-CC-3.01-v01 Reduce Disruption of Plow Operations at Signalized Intersections UN-CC-3.02-v01 Minimize Gang Plow Disruptions UN-CC-7.05-v01 – CC System Support			

CC System Inputs	• MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • Snow Plow Location/Motion (from GNSS)
CC System Outputs	• Signal Priority Request (to Traffic Signal Controller) • Signal Priority Status Notification (optional, to Snow Plow Operator)

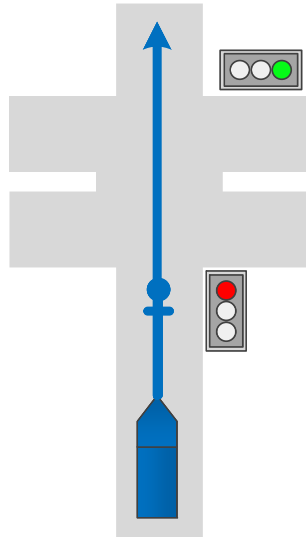
5.3.4 Use Case 3 Scenario 4: Normal Operating Conditions – Denying Unauthorized Priority Request

<table>
<tr><th>Use Case</th><th colspan="4">Snow Plow Signal Priority</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC3-S4: Normal Operating Conditions – Denying Unauthorized Priority Request</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Intersection is able to deny a priority request made from an unauthorized vehicle</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• A signal priority request is received from a vehicle unauthorized to receive signal priority
• The Traffic Signal Controller denies the request and continues to operate as normal.</td></tr>
<tr><td rowspan="2">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Self-Equipped Driver</td><td colspan="2">Receive signal priority (unauthorized)</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• Self-Equipped Driver is driving on a roadway.
• A traffic signal is red for the vehicle approach</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4"></td></tr>
<tr><td rowspan="3">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Self-Equipped Driver</td><td>1</td><td>Approaches the intersection</td><td></td></tr>
<tr><td>On-Board/ Nomadic Device</td><td>2</td><td>Communicates a signal priority request to the intersection</td><td>To request signal priority</td></tr>
</table>

	CC System	3	Communicates the signal priority request to the traffic signal controller	
	CC System	4	Determines that the request is from a vehicle that is not authorized to receive priority	Prioritization could be performed locally on the roadside, or through communication with MaxView.
	CC System	5	Communicates to the vehicle that signal priority has not been granted	
	Traffic Signal Controller	6	Continues operations	Signal timing is not impacted
	Self-Equipped Driver	7	Continues driving along the corridor	Obeying all traffic control devices
Post-Conditions	• CC System properly denies priority request from unauthorized source. • Intersection operations are not impacted			
Traceability	UN-CC-3.01-v01 Reduce Disruption of Plow Operations at Signalized Intersections UN-CC-3.02-v01 Minimize Gang Plow Disruptions UN-CC-7.05-v01 – CC System Support			
CC System Inputs	• MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • Snow Plow Location/Motion (from GNSS)			
CC System Outputs	• Signal Priority Request (to Traffic Signal Controller) • Signal Priority Status Notification (optional, to Snow Plow Operator)			

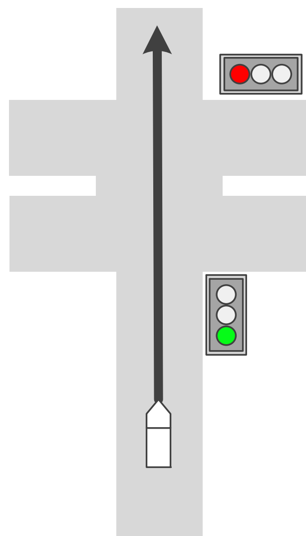
5.3.5 Use Case 3 Scenario 5: Degraded Conditions – Deficient Vehicle Data Quality

Use Case	**Snow Plow Signal Priority**	
Scenario ID and Title	*UC3-S5: Degraded Conditions – Deficient Vehicle Data Quality*	
Scenario Objective	• Demonstrate the fall back scenario if the Snow Plow Operator location is inaccurate resulting in an incorrect determination of the approach the snow plow is on	
Operational Event(s)	• The CC System falsely determines the Snow Plow Operator's approach and requests priority for the incorrect approach.	
User(s)	User	Role
	Snow Plow Operator	Quickly traverse an intersection without stopping to improve operations efficiency and to reduce the unequal spread of snow removal chemicals
Initial Conditions	• A snow plow is operating on a roadway where Snow Plow Signal Priority is enabled • A traffic signal is red for the snow plow approach	

<table>
<tr><td>Scenario Diagram</td><td colspan="4"></td></tr>
<tr><td rowspan="10">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Snow Plow Operator</td><td>1</td><td>Approaches the intersection</td><td></td></tr>
<tr><td>CC System</td><td>2</td><td>Determines Snow Plow is approaching the intersection, in actively engaged in plowing or spreading chemicals, and communicates a signal priority request to the Traffic Signal Controller</td><td>to request signal priority, the incorrect approach is detected</td></tr>
<tr><td>Traffic Signal Controller</td><td>3</td><td>Prioritizes the received request with other received requests</td><td>Prioritization could be performed locally on the roadside, or through communication with MaxView.</td></tr>
<tr><td>Traffic Signal Controller</td><td>4</td><td>Responds to the CC System with the priority order and status (accepted/denied) of all received requests</td><td>No other vehicles are requesting priority</td></tr>
<tr><td>CC System</td><td>5</td><td>(optional) Notifies Snow Plow Operator that priority has been granted</td><td>As the snow plow approaches the intersection at nominal speed</td></tr>
<tr><td>Traffic Signal Controller</td><td>6</td><td>Services the detected approach</td><td>Incorrect approach is serviced</td></tr>
<tr><td>Snow Plow Operator</td><td>7</td><td>Stops at the intersection</td><td></td></tr>
<tr><td>Traffic Signal Controller</td><td>8</td><td>Continues through its programmed signal plan</td><td></td></tr>
<tr><td>Snow Plow Operator</td><td>9</td><td>Makes the intended maneuver through the intersection</td><td>Once signal for snow plow approach turns green</td></tr>
</table>

Post-Conditions	• The snow plow has to stop at the intersection until the snow plow's approach is serviced, resulting in increased clearance time, uneven spread of snow removal chemicals, and added inefficiencies to gang plow operations (if involved in gang plow operations). Operating conditions may be worse than the existing condition. • Snow Plow Operator may lose trust in the system
Traceability	*N/A for Degraded Conditions due to Inaccuracies*
CC System Inputs	• MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • (inaccurate) Snow Plow Location/Motion (from GNSS)
CC System Outputs	• (inaccurate) Signal Priority Request (to Traffic Signal Controller) • Signal Priority Status Notification (optional, to Snow Plow Operator)

5.3.6 Use Case 3 Scenario 6: Degraded Conditions – Accepting Unauthorized Priority Request

<table>
<tr><th>Use Case</th><th colspan="4">Snow Plow Signal Priority</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC3-S6: Degraded Conditions – Accepting Unauthorized Priority Request</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the scenario where a priority request is made by a vehicle unauthorized to make a signal priority request.</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• An On-Board/Nomadic Device sends signal priority requests while approaching an intersection</td></tr>
<tr><td rowspan="2">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Self-Equipped Driver</td><td colspan="2">Receive signal priority (unauthorized)</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• Self-Equipped Driver is driving on a roadway.
• A traffic signal is red for the vehicle approach</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4"></td></tr>
<tr><td rowspan="7">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Self-Equipped Driver</td><td>1</td><td>Approaches the intersection</td><td></td></tr>
<tr><td>On-Board/Nomadic Device</td><td>2</td><td>Communicates a signal priority request to the intersection</td><td>To request signal priority</td></tr>
<tr><td>CC System</td><td>3</td><td>Receives signal priority request and communicates a signal priority request to the Traffic Signal Controller</td><td>to request signal priority</td></tr>
<tr><td>Traffic Signal Controller</td><td>4</td><td>Responds to the CC System with the priority order and status (accepted/denied) of all received requests</td><td>Unauthorized request accepted</td></tr>
<tr><td>Traffic Signal Controller</td><td>5</td><td>Services the approach of the vehicle</td><td></td></tr>
<tr><td>Self-Equipped Driver</td><td>6</td><td>Makes its intended maneuver through the intersection.</td><td>Without stopping</td></tr>
</table>

Post-Conditions	• Traffic Signal Controller does not deny priority request from unauthorized source. • Intersection operations are impacted; other intersection users experience decrease in mobility.
Traceability	UN-CC-7.06-v01 – Remote Diagnostic
CC System Inputs	• MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • Snow Plow Location/Motion (from GNSS)
CC System Outputs	• Signal Priority Request (to Traffic Signal Controller) • Signal Priority Status Notification (optional, to Snow Plow Operator)

5.3.7 Use Case 3 Scenario 7: Degraded Conditions – Communications Latency

Use Case	**Snow Plow Signal Priority**			
Scenario ID and Title	*UC3-S7: Degraded Conditions – Communications Latency*			
Scenario Objective	• Demonstrate the fall back scenario if there is latency associated with system processes that are responsible for transforming inputs into actionable outputs			
Operational Event(s)	• Latency in the system (processing, communication between CC System components, or communication between the CC System and external systems) result in an output that is not received in time to be of practical use to the recipient. • The system cannot determine that a vehicle is requesting priority in a timely manner • The system provides priority for the Snow Plow Operator, but not until the snow plow has moved significantly closer to the intersection			
User(s)	User	Role		
	Snow Plow Operator	Quickly traverse an intersection without stopping to improve operations efficiency and to reduce the unequal spread of snow removal chemicals		
Initial Conditions	• Snow plow actively involved in gang plow must split away from freeway mainline to clear an offramp/onramp. • A traffic signal at the end/beginning of the offramp/onramp is red for the snow plow approach • Limited system resources (processing, communications) adds latency to outputs compared to the normal operating condition.			
Scenario Diagram	*Same as Scenario 5*			
Key Actions and Flow of Events	Source	Step	Key Action	Comments
	Snow Plow Operator	1	Approaches the intersection	
	CC System	2	Determines Snow Plow is approaching the intersection, in actively engaged in plowing or spreading chemicals, and	to request signal priority

			communicates a signal priority request to the Traffic Signal Controller	
	CC System	3	Experiences communications or processing resource limitations	Introduces latency into CC System Processes
	CC System	4	Communicates a signal priority request to the Traffic Signal Controller	
	Traffic Signal Controller	3	Prioritizes the received request with other received requests	Prioritization could be performed locally on the roadside, or through communication with MaxView.
	Traffic Signal Controller	4	Responds to the CC System with the priority order and status (accepted/denied) of all received requests	No other vehicles are requesting priority
	CC System	5	(optional) Notifies Snow Plow Operator that priority has been granted	As the snow plow approaches the intersection at nominal speed, the system may issue a latency advisory to the Snow Plow Operator and/or to the Traffic Operations Manager if latency is observed.
	Traffic Signal Controller	6	Services the approach of the Snow Plow	
	Snow Plow Operator	7	Makes the intended maneuver through the intersection	May have to stop
Post-Conditions	• The snow plow may have to stop at the intersection until the snow plow's approach is serviced, resulting in increased clearance time, uneven spread of snow removal chemicals, and added inefficiencies to gang plow operations (if involved in gang plow operations). Operating conditions are likely still better than the existing condition. • Snow Plow Operator may lose trust in the system			
Traceability	UN-CC-7.06-v01 – Remote Diagnostic			
CC System Inputs	• MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • Snow Plow Location/Motion (from GNSS)			
CC System Outputs	• (late) Signal Priority Request (to Traffic Signal Controller) • (late) Signal Priority Status Notification (optional, to Snow Plow Operator)			

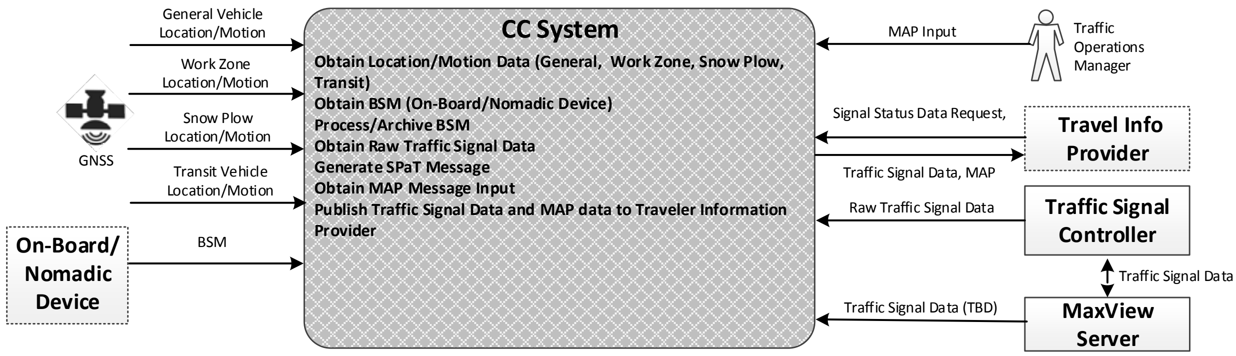
5.3.8 Use Case 3 Scenario 8: Degraded Conditions – Communications Failure

<table>
<tr><th>Use Case</th><th colspan="4">Snow Plow Signal Priority</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC3-S8: Degraded Conditions – Communications Failure</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the fall back scenario if failure of communication between CC System components, or communication between the CC System and external systems result in no output when output would have been given under normal operating conditions</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• Failure of communication between CC System components, or communication between the CC System and external systems result in an output that is never received
• The CC System cannot determine that a snow plow is requesting signal priority</td></tr>
<tr><td rowspan="2">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Snow Plow Operator</td><td colspan="2">Quickly traverse an intersection without stopping to improve operations efficiency and to reduce the unequal spread of snow removal chemicals</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• Snow plow actively involved in gang plow must split away from freeway mainline to clear an offramp/onramp.
• A traffic signal at the end/beginning of the offramp/onramp is red for the snow plow approach</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">Same as Scenario 5</td></tr>
<tr><td rowspan="7">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Snow Plow Operator</td><td>1</td><td>Approaches the intersection</td><td></td></tr>
<tr><td>CC System</td><td>2</td><td>Determines Snow Plow is approaching the intersection, in actively engaged in plowing or spreading chemicals, and communicates a signal priority request to the Traffic Signal Controller</td><td>to request signal priority</td></tr>
<tr><td>CC System</td><td>3</td><td>Experiences communications or processing resource failure</td><td>The system may issue an advisory to the Traffic Operations Manager if internal failure conditions are observed.</td></tr>
<tr><td>Traffic Signal Controller</td><td>4</td><td>Continues through its programmed signal plan</td><td></td></tr>
<tr><td>Traffic Signal Controller</td><td>5</td><td>Services the approach of the Snow Plow</td><td></td></tr>
<tr><td>Snow Plow Operator</td><td>6</td><td>Makes the intended maneuver through the intersection</td><td>May have to stop</td></tr>
<tr><td>Post-Conditions</td><td colspan="4">• The snow plow may have to stop at the intersection until the snow plow’s approach is serviced, resulting in increased clearance time, uneven spread of snow removal chemicals, and added inefficiencies to gang plow operations (if involved in gang plow operations). Operating conditions are the same as existing conditions</td></tr>
</table>

	• Snow Plow Operator may lose trust in the system
Traceability	UN-CC-7.06-v01 – Remote Diagnostic
CC System Inputs	• MAP Input (from Traffic Operations Manager) • Position Correction Data (from MnCORS) • Raw Traffic Signal Data (from Traffic Signal Controller) • Snow Plow Location/Motion (from GNSS)
CC System Outputs	• *none*

5.4 CV Data Exchange Subsystem

This section contains use cases and scenarios associated with the CV Data Exchange . Figure 9 provides a context diagram for all scenarios associated with these use cases. Scenarios for these use cases are listed below, and are described in detail in tables following the context diagram.



Note: The Over-The-Air-Message Security function is used for wireless communications within the CC System and wireless communications between the CC System and External Systems, such as the On-Board/Nomadic Device

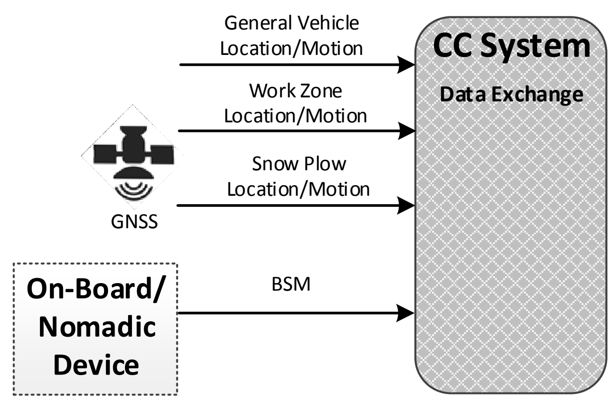
Figure 9 - Data Exchange Subsystem Functional Diagram

There are several scenarios associated with the Data Exchange Subsystem, which ingests, transforms, and distributes data from several disparate systems. Scenarios for this use case are listed below, and are described in detail in tables following.

- Use Case 4 Scenario 1: Normal Operating Conditions – Basic Safety Message Management
- Use Case 4 Scenario 2: Degraded Conditions – Basic Safety Message Communications Failure
- Use Case 5 Scenario 1: Normal Operating Conditions – Traffic Signal Data Dissemination
- Use Case 5 Scenario 2: Degraded Conditions – Traffic Signal Communications Failure
- Use Case 5 Scenario 3: Degraded Conditions – Traveler Information Provider Communications Failure

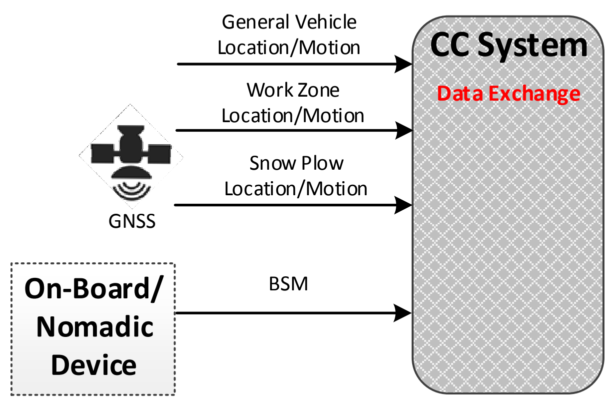
5.4.1 Use Case 4 Scenario 1: Normal Operating Conditions – Basic Safety Message Management

Use Case	CV Data Exchange Subsystem – CV Data Management	
Scenario ID and Title	*UC4-S1: Normal Operating Conditions –Basic Safety Message Management*	
Scenario Objective	• Store BSM data broadcast from in-vehicle equipment that was captured by roadside equipment.	
Operational Event(s)	• CC System receives BSM data from the field • CC System processes/packages the data (optional) • CC System archives data	
User(s)	User	Role

	CC System		Receive, process, filter, aggregate, and archive real-time Vehicle Location/Motion data and BSM data	
Initial Conditions	• A vehicle that is capable of sending location and motion information to the CC System is operating on the roadway, and is able to communicate with the CC System • CC System obtains real-time vehicle location and motion data (from general equipped vehicles, snow plows, work zone vehicles)			
Scenario Diagram				
Key Actions and Flow of Events	Source	Step	Key Action	Comments
	CC System	1	Receives location/motion data	originating from a vehicle (e.g. general equipped vehicle, work zone vehicle, and snow plow)
	CC System	2	(optional) Filters location/motion data	to remove Personally Identifiable Information, etc.
	CC System	3	Archives raw data (Step 1) or processed data (Step 2)	
	General	4	Data is post-processed for assessing operations	
Post-Conditions	• Vehicle Location and Motion data is archived			
Traceability	UN-CC-7.01-v01 Traffic Management Data UN-CC-7.02-v01 Data Dissemination UN-CC-7.04-v01 Data Processing Support System UN-CC-7.05-v01 – CC System Support			
CC System Inputs	• General Equipped Vehicle Location and Motion (from GNSS) • Work Zone Vehicle Location and Motion (from GNSS) • Snow Plow Location and Motion (from GNSS) • BSM (from On-Board Nomadic Device)			

CC System Outputs	• *none*

5.4.2 Use Case 4 Scenario 2: Degraded Conditions – Basic Safety Message Communications Failure

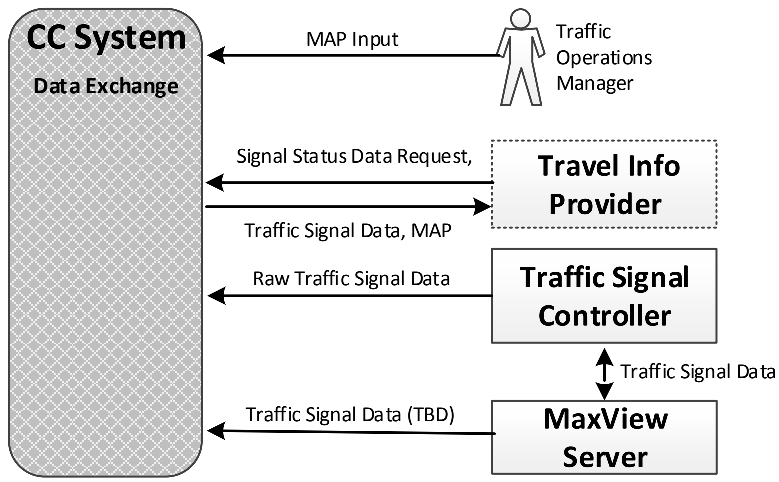
<table>
<tr><th>Use Case</th><th colspan="4">CV Data Exchange Subsystem – CV Data Management</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC4-S2: Degraded Conditions – Basic Safety Message Communications Failure</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Describe results when internal CC System communications fail</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• CC System receives BSM data from the field
• CC System processes/packages the data (optional)
• CC System is not able to archive data</td></tr>
<tr><td rowspan="2">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">CC System</td><td colspan="2">Receive, process, filter, aggregate, and archive real-time Vehicle Location/Motion data and BSM data</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• A vehicle that is capable of sending location and motion information to the CC System is operating on the roadway, and is able to communicate with the CC System
• CC System obtains real-time vehicle location and motion data (from general equipped vehicles, snow plows, work zone vehicles)
• The CC System has internal communications issues that prevent it from archiving the data</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">
</td></tr>
<tr><td rowspan="3">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>CC System</td><td>1</td><td>Receives Vehicle Location/Motion data and BSM data</td><td>originating from a vehicle (e.g. general equipped vehicle, work zone vehicle, and snow plow)</td></tr>
<tr><td>CC System</td><td>2</td><td>(optional) Filters Vehicle Location/Motion data and BSM data</td><td>to remove Personally Identifiable Information, etc. depending on the nature of the</td></tr>
</table>

				communication failure, this step may not be possible
	CC System	3	Is not able to archive raw data (Step 1) or process data (Step 2)	Due to the communication failure within the CC System and supporting infrastructure. The system may issue an advisory to the Traffic Operations Manager if internal failure conditions are observed.
Post-Conditions	• Vehicle Location and Motion data is not archived			
Traceability	UN-CC-7.06-v01 – Remote Diagnostic			
CC System Inputs	• General Equipped Vehicle Location and Motion (from GNSS) • Work Zone Vehicle Location and Motion (from GNSS) • Snow Plow Location and Motion (from GNSS) • BSM (from On-Board Nomadic Device)			
CC System Outputs	• *none*			

5.4.3 Use Case 5 Scenario 1: Normal Operating Conditions – Traffic Signal Data Dissemination

Use Case	**CV Data Exchange subsystem – Traffic Signal Data Sharing**	
Scenario ID and Title	*UC5-S1: Normal Operating Conditions – Traffic Signal Data Dissemination*	
Scenario Objective	• Make real-time signal status data available to Traveler Information Providers • Make real-time MAP data available to Traveler Information Providers	
Operational Event(s)	• CC System receives Traffic Signal Data from the traffic signal controller and/or MaxView • CC System sends contents of MAP data and Traffic Signal Data to the Traveler Information Provider • CC System archives data	
User(s)	User	Role
	Traveler Information Provider	User of real-time signal status data. Note: this could include the MnDOT 511 System
	CC System	Provide access to archived CC System data

<table>
<tr><td>Initial Conditions</td><td>A Traffic Signal Controller capable of sending signal status data to the CC System is able to communicate with the CC System
Traveler Information Provider has connectivity to the Data Exchange interface
The Traffic Operations Manager has provided valid MAP (intersection geometry) data to the CC System</td></tr>
<tr><td>Scenario Diagram</td><td>

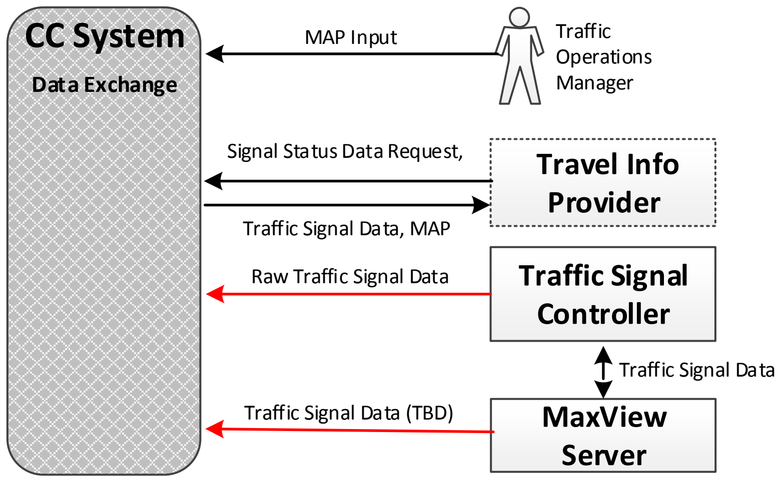


</td></tr>
<tr><td>Key Actions and Flow of Events</td><td>
<table>
<tr><th>Source</th><th>Step</th><th>Key Action</th><th>Comments</th></tr>
<tr><td>CC System</td><td>1</td><td>Receives real-time signal status data</td><td>originating from a Traffic Signal Controller or directly from MaxView</td></tr>
<tr><td>CC System</td><td>2</td><td>Archives raw signal status data and MAP data</td><td>This step is optional</td></tr>
<tr><td>Traveler Information Provider</td><td>3</td><td>Initiates a request for real-time signal status data and MAP data or archived signal status data and MAP data (if available)</td><td>This could be performed in advance. This step is included because the system needs a way of determining which Traveler Information Providers to send data to.</td></tr>
<tr><td>CC System</td><td>4</td><td>Sends real-time or archived Traffic Signal Data and MAP data to the Traveler Information Provider</td><td></td></tr>
<tr><td>Traveler Information Provider</td><td>5</td><td>Receives and uses the real-time or archived Traffic Signal data and MAP data</td><td></td></tr>
</table>
</td></tr>
</table>

Post-Conditions	• The Traveler Information Provider receives real-time Traffic Signal Data and MAP data • Users of the Traveler Information provider services benefit from use of CC System data • Traffic Signal Data is archived (optional)
Traceability	UN-CC-5.01-v01 Third-Party Data Services UN-CC-7.01-v01 Traffic Management Data UN-CC-7.02-v01 Data Dissemination UN-CC-7.04-v01 Data Processing Support System UN-CC-7.05-v01 – CC System Support
CC System Inputs	• Raw Traffic Signal Data (from Traffic Signal Controller) • Traffic Signal Data Request (from Traveler Information Provider) • Predictive Data/Signal Timing Strategy (from Traveler Information Provider)
CC System Outputs	• Traffic Signal Data (to Travel Information Provider)

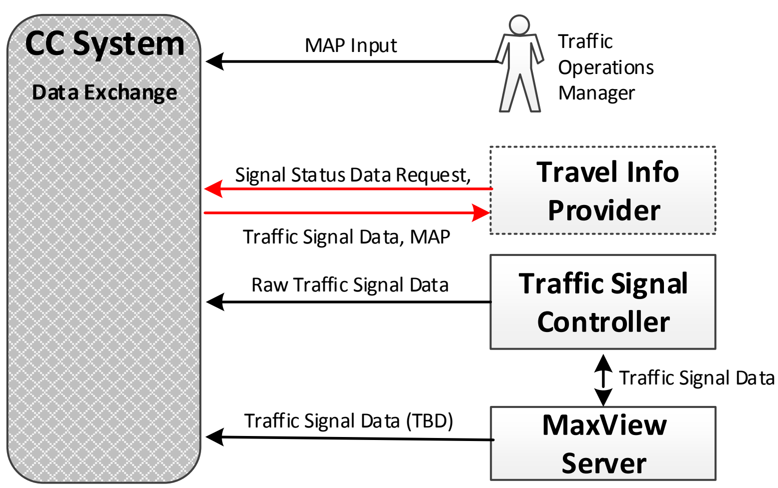
5.4.4 Use Case 5 Scenario 2: Degraded Conditions – Communications Failure to Traffic Signal or Server

Use Case	**CV Data Exchange Subsystem – Traffic Signal Data Sharing**	
Scenario ID and Title	*UC5-S2: Degraded Conditions – Traffic Signal Communications Failure*	
Scenario Objective	• Describe results when communications between the CC System and the traffic signal data source (either the traffic signal controller or the MaxView server) fails	
Operational Event(s)	• User makes a data request via the API	
User(s)	User	Role
	Traveler Information Provider	User of real-time Traffic Signal Data. Note: this could include the MnDOT 511 System
	CC System	Provide access to archived CC System data
Initial Conditions	• A Traffic Signal Controller capable of sending Traffic Signal Data to the CC System is able to communicate with the CC System • The CC System has internal communications issues that prevent it from archiving the data • The Traveler Information Provider is not able to connect with the CC System through the Data Exchange interface	

<table>
<tr><td>Scenario Diagram</td><td colspan="4">
</td></tr>
<tr><td rowspan="6">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>CC System</td><td>1</td><td>Not able to receive real-time Traffic Signal Data</td><td>Due to communications failure. The system may issue an advisory to the Traffic Operations Manager if internal failure conditions are observed.</td></tr>
<tr><td>CC System</td><td>2</td><td>Is not able to archive raw Traffic Signal Data</td><td>Due to communications failure.</td></tr>
<tr><td>Traveler Information Provider</td><td>3</td><td>Initiates a request for archived system data.</td><td></td></tr>
<tr><td>CC System</td><td>4</td><td>Is not able to send real-time Traffic Signal Data to the Traveler Information Provider</td><td>Due to inability to communicate Traffic Signal Data source</td></tr>
<tr><td>Traveler Information Provider</td><td>5</td><td>Is not able to provide services to its users that require Traffic Signal Data</td><td>Services provided may need to be suspended or change the operating state to account for lack of Traffic Signal Data.</td></tr>
<tr><td>Post-Conditions</td><td colspan="4">• The Traveler Information Provider does not receive real-time Traffic Signal Data.
• Benefits for users of the Traveler Information Provider services benefit from use of CC System data are suspended until communications are restored
• Traffic Signal Data is not archived</td></tr>
<tr><td>Traceability</td><td colspan="4">UN-CC-7.06-v01 – Remote Diagnostic</td></tr>
</table>

CC System Inputs	• Raw Traffic Signal Data (from Traffic Signal Controller) • Traffic Signal Data Request (from Traveler Information Provider)
CC System Outputs	• *none*

5.4.5 Use Case 5 Scenario 3: Degraded Conditions – Travel Information Provider Communications Failure

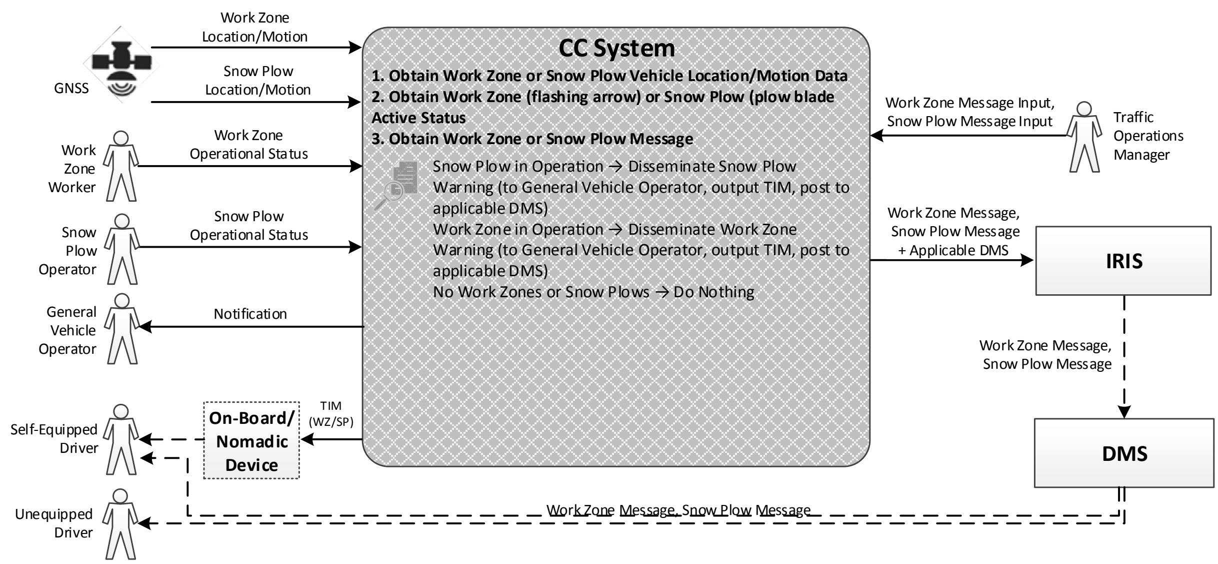
Use Case	**CV Data Exchange Subsystem – Traffic Signal Data Sharing**			
Scenario ID and Title	*UC5-S3: Degraded Conditions – Travel Information Provider Communications Failure*			
Scenario Objective	• Describe results when the CC System is not able to communicate with the Traveler Information Provider			
Operational Event(s)	• User makes a data request via the API			
User(s)	User	Role		
	Traveler Information Provider	User of real-time Traffic Signal Data. Note: this could include the MnDOT 511 System		
	CC System	Provide access to archived CC System data		
Initial Conditions	• A traffic signal controller capable of sending Traffic Signal Data to the CC System is able to communicate with the CC System • The Traveler Information Provider is not able to connect with the CC System through the Data Exchange interface			
Scenario Diagram				
Key Actions and Flow of Events	Source	Step	Key Action	Comments
	CC System	1	Receives real-time Traffic Signal Data	Originating from a Traffic Signal Controller or directly from MaxView

	CC System	2	Archives raw signal status data	
	Traveler Information Provider	3	Initiates a request for archived system data.	Request is not received due to communications failure
	CC System	4	Is not able to send real-time Traffic Signal Data to the Traveler Information Provider	Due to inability to communicate with Traveler Information Provider. The system may issue an advisory to the Traffic Operations Manager if internal failure conditions are observed.
	Traveler Information Provider	5	Is not able to provide services to its users that require Traffic Signal Data	Services provided may need to be suspended or change the operating state to account for lack of Traffic Signal Data.
Post-Conditions	• The Traveler Information Provider does not receive real-time Traffic Signal Data. • Benefits for users of the Traveler Information Provider services benefit from use of CC System data are suspended until communications are restored • Traffic Signal Data is not archived			
Traceability	UN-CC-7.06-v01 – Remote Diagnostic			
CC System Inputs	• Raw Traffic Signal Data (from Traffic Signal Controller) • Traffic Signal Data Request (from Traveler Information Provider)			
CC System Outputs	• *none*			

5.5 Mobile Work Zone Warning System

This use case contains scenarios associated with the Mobile Work Zone Warning System. Figure 10 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.

- Use Case 6 Scenario 1: Snow Plow Warning
- Use Case 6 Scenario 2: Moving Work Zone on Shoulder Warning
- Use Case 6 Scenario 3: Degraded Operating Conditions – Inaccurate Vehicle Positioning (False Negative Output)
- Use Case 6 Scenario 4: Degraded Operating Conditions – Inaccurate Vehicle Positioning (False Positive Output)
- Use Case 6 Scenario 5: Degraded Operating Conditions – Communications Latency
- Use Case 6 Scenario 6: Degraded Operating Conditions – Communications Failure

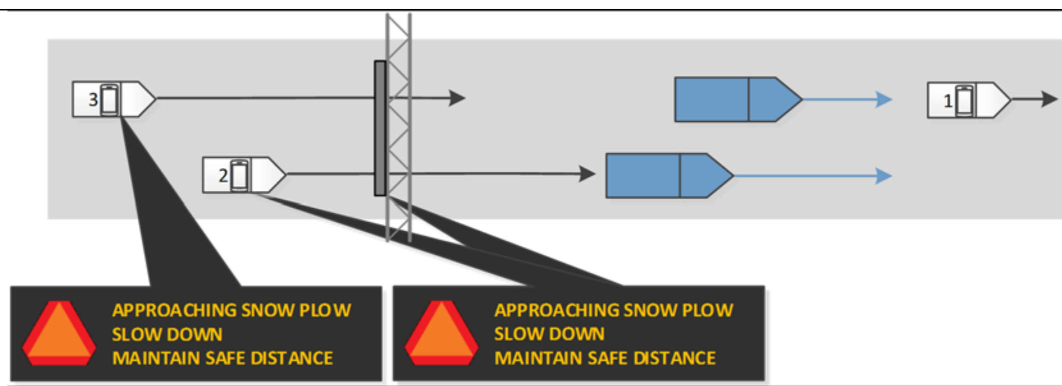


Note: The Over-The-Air-Message Security function is used for wireless communications within the CC System and wireless communications between the CC System and External Systems, such as the On-Board/Nomadic Device

Figure 10: Mobile Work Zone Warning System Functional Diagram

5.5.1 Use Case 6 Scenario 1: Normal Operating Conditions – Snow Plow Warning

Use Case	Mobile Work Zone Warning System
Scenario ID and Title	*UC6-S1: Normal Operating Conditions – Snow Plow Warning*
Scenario Objective	• Warn approaching drivers of snow plow operations ahead using dynamic message signs and optionally using a smart phone application

<table>
<tr><td>Operational Event(s)</td><td colspan="4">• The CC System determines the location of the snow plow and the operational status of the snow plow
• The CC System provides snow plow location and message information to the driver's on-board nomadic device
• The CC System provides a snow plow message to select DMS based on the snow plow location</td></tr>
<tr><td rowspan="4">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Snow Plow Driver</td><td colspan="2">Operate snow plow in normal manner</td></tr>
<tr><td colspan="2">General Equipped Vehicle Operator 1</td><td colspan="2">Drive vehicle in normal manner</td></tr>
<tr><td colspan="2">General Equipped Vehicle Operators 2 and 3, Unequipped Driver</td><td colspan="2">Properly respond to system warning of plow ahead</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• The system is properly configured, enabled and operational, including a smart phone application (optional) within Vehicle 1 (General Equipped Vehicle Operator 1), Vehicle 2 (General Equipped Vehicle Operator 2), and Vehicle 3 (General Equipped Vehicle Operator 3)
• A dynamic message is sign is operational on the route and direction the snow plow is plowing and is either blank or showing a lower priority message than the snow plow ahead message
• The snow plow is moving more slowly than surrounding traffic and 350 feet upstream from the dynamic message sign
• The snow plow operator provides input that they are actively involved in snow plow operations (may be automated based on snow plow blade position)
• General Equipped Vehicle Operator 1 is on the same road and direction as the snow plow, 300 feet ahead of the plow and moving faster than the plow
• General Equipped Vehicle Operator 2 is on the same road and direction as the plow, 500 feet behind the plow and moving faster than the plow
• General Equipped Vehicle Operator 3 is on the same road and direction as the plow, 2 miles behind the plow and moving faster than the plow</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">
</td></tr>
<tr><td rowspan="2">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>General Equipped Vehicle Operator 1</td><td>1</td><td>Receives no message, neither on the DMS nor on the smart phone app.</td><td>Continues to drive as he/she would without the system.</td></tr>
</table>

	Snow Plow Operator	2	Sees the snow plow ahead message begin to display on the DMS shortly before passing the DMS.	Operates the plow normally
	CC System	3	Broadcasts TIM (may be received by On-Board/Nomadic Device)	From roadside locations upstream of the snow plow (for predefined period)
	General Equipped Vehicle Operator 2	4a	Receives snow plow ahead message on smart phone app	Begins to look for the plow
	Unequipped Driver/ General Equipped Vehicle Operator 2	5a	Approaches the DMS	Sees the snow plow ahead message on the DMS.
	Unequipped Driver/ General Equipped Vehicle Operator 2	6a	Approaches the Snow Plow	
	Unequipped Driver/ General Equipped Vehicle Operator 2	7a	Slows down and stays behind the plow	Continuing to receive the snow plow ahead message on the smart phone app
	Unequipped Driver/ General Equipped Vehicle Operator 2	8a	Changes lanes and safely passes the plow	Upon which the snow plow ahead message on the smart phone app ceases
	General Equipped Vehicle Operator 3	5b	Initially receives no warning on the smart phone app	
	General Equipped Vehicle Operator 3	6b	Passes the DMS	The snow plow ahead message has already expired on the sign, which now is blank or showing a lower priority unrelated DMS message
	Unequipped Driver	7b	Passes the DMS	Does not receive snow plow notification at this DMS, may receive notification at next DMS.
	CC System	8b	Provides a snow plow ahead message to General Equipped Vehicle Operator 3	
	General Equipped Vehicle Operator 3	9b	Approaches the Snow Plow	

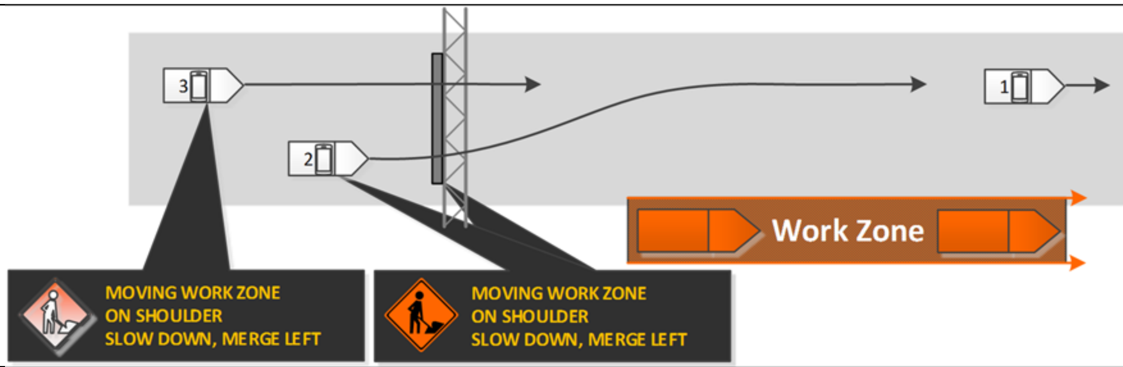
	General Equipped Vehicle Operator 3	10b	Slows down and stays behind the plow	Continuing to receive the snow plow ahead message on the smart phone app
	General Equipped Vehicle Operator 3	11b	Changes lanes and safely passes the plow	Upon which the snow plow ahead message on the smart phone app ceases
Post-Conditions	• All vehicle operators and drivers are able to use advance notification of snow plow to safety approach/pass the snow plow • The snow plow is more than 1 mile past the dynamic message sign • The dynamic message sign is no longer showing a snow plow ahead message			
Traceability	UN-CC-1.02-v01 Dynamic Roadway Maintenance Activity Awareness UN-CC-2.01-v01 – On-Board/Nomadic Device Data UN-CC-2.02-v01 – Unequipped Driver Dynamic Roadway Maintenance Activity Awareness UN-CC-3.03-v01 Snow Plow Operator Safety UN-CC-7.03-v01 Dynamic Rodway Maintenance Activity Information UN-CC-7.05-v01 – CC System Support			
CC System Inputs	• General Equipped Vehicle Location/Motion (from GNSS) • Snow Plow Location/Motion (from GNSS) • Snow Plow Operational Status (from Snow Plow Operator, may be automated) • Snow Plow Message Input (from Traffic Operations Manager)			
CC System Outputs	• Snow Plow Notification (to General Equipped Vehicle Operator) • TIM (to On-Board/Nomadic Device) • Snow Plow Message and applicable DMS (to IRIS)			

5.5.2 Use Case 6 Scenario 2: Normal Operating Conditions – Moving Work Zone on Shoulder Warning

Use Case	**Mobile Work Zone Warning System**	
Scenario ID and Title	*UC6-S2: Normal Operating Conditions – Moving Work Zone on Shoulder Warning*	
Scenario Objective	• Warn approaching drivers of shoulder work zone operations ahead using dynamic message signs and optionally using a smart phone application	
User(s)	User	Role
	Work Zone Worker	Engage in work zone activities in normal manner
	General Equipped Vehicle Operator 1	Drive vehicle in normal manner
	General Equipped Vehicle Operators 2 and 3, Unequipped Driver	Properly respond to system warning of work zone ahead
Initial Conditions	• The system is properly configured, enabled and operational, including a smart phone application (optional) within Vehicle 1 (General Equipped Vehicle Operator 1), Vehicle 2 (General Equipped Vehicle Operator 2), and Vehicle 3 (General Equipped Vehicle Operator 3) • A dynamic message is sign is operational on the route and direction of the work zone and is either blank or showing a lower priority message than the work zone ahead message	

	• The work zone is intermittently stopping/moving along the shoulder and 350 feet upstream from the dynamic message sign • The work zone operator provides input that they are actively involved in work zone operations (may be automated based on flashing arrow activation) • General Equipped Vehicle Operator 1 passes the work zone location before the work zone becomes active • General Equipped Vehicle Operator 2 is on the same road and direction as the work zone, 500 feet behind the work zone and moving faster than the work zone • General Equipped Vehicle Operator 3 is on the same road and direction as the work zone, but does not approach the work zone until the work zone is 1 mile beyond the DMS

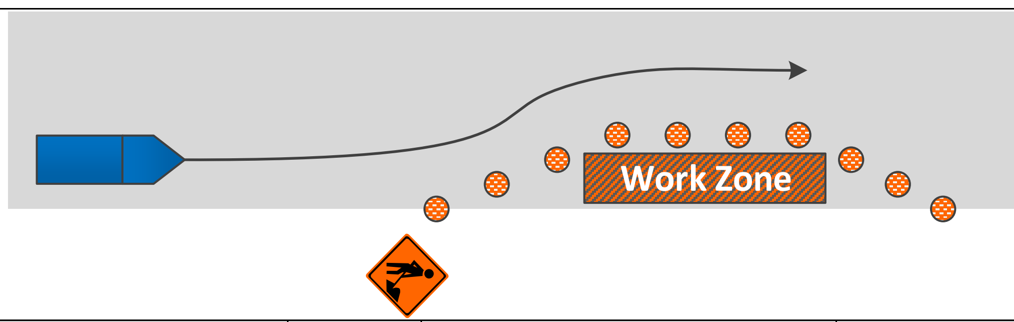
Scenario Diagram



Key Actions and Flow of Events	Source	Step	Key Action	Comments
	General Equipped Vehicle Operator 1	1	Receives no message, neither on the DMS nor on the smart phone app.	Continues to drive as he/she would without the system
	Work Zone Operator	2	Sees the work zone ahead message begin to display on the DMS shortly before passing the DMS.	Engages in work zone activities
	CC System	3	Broadcasts TIM (may be received by On-Board/Nomadic Device)	From roadside locations upstream of the snow plow (for predefined period)
	General Equipped Vehicle Operator 2	4a	Receives work zone ahead message on smart phone app	Begins to look for the work zone
	Unequipped Driver/ General Equipped Vehicle Operator 2	5a	Approaches the DMS	Sees the work zone ahead message on the DMS.
	Unequipped Driver/ General Equipped Vehicle Operator 2	6a	Approaches the Work Zone	

	Unequipped Driver/ General Equipped Vehicle Operator 2	7a	Slows down and safely passes the work zone or changes lanes and safely passes the work zone	Upon which the work zone ahead message on the smart phone app ceases
	General Equipped Vehicle Operator 3	4b	Initially receives no warning on the smart phone app.	
	General Equipped Vehicle Operator 3	5b	Passes the DMS	the work zone ahead message has already expired on the sign, which now is blank or showing a lower priority unrelated DMS message
	Unequipped Driver	6b	Passes the DMS	Does not receive work zone notification at this DMS, may receive notification at next DMS.
	CC System	7b	Provides a work zone ahead message to General Equipped Vehicle Operator 3	
	General Equipped Vehicle Operator 3	8b	Approaches the work zone	
	General Equipped Vehicle Operator 3	9b	Slows down and safely passes the work zone or changes lanes and safely passes the work zone	Upon which the work zone ahead message on the smart phone app ceases
Post-Conditions	• All vehicle operators and drivers are able to use advance notification of work zone to safety pass the work zone • The work zone is more than 1 mile past the dynamic message sign • The dynamic message sign is no longer showing a work zone ahead message			
Traceability	UN-CC-1.02-v01 – Dynamic Roadway Maintenance Activity Awareness UN-CC-2.01-v01 – On-Board/Nomadic Device Data UN-CC-2.02-v01 – Unequipped Driver Dynamic Roadway Maintenance Activity Awareness UN-CC-6.01-v01 Work Zone Worker Safety UN-CC-7.03-v01 Dynamic Rodway Maintenance Activity Information UN-CC-7.05-v01 – CC System Support			
CC System Inputs	• General Equipped Vehicle Location/Motion (from GNSS) • Work Zone Location/Motion (from GNSS) • Work Zone Operational Status (from Work Zone Worker, may be automated) • Work Zone Message Input (from Traffic Operations Manager)			
CC System Outputs	• Work Zone Notification (to General Vehicle Operator) • TIM (to On-Board/Nomadic Device) • Work Zone Message and applicable DMS (to IRIS)			

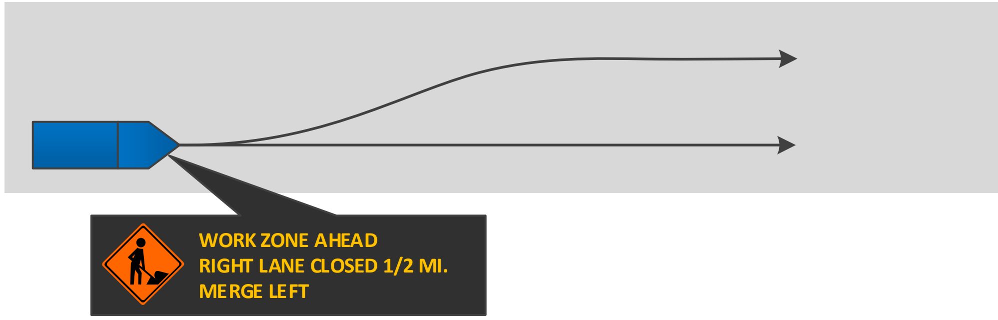
5.5.3 Use Case 6 Scenario 3: Degraded Conditions – Inaccurate Vehicle Positioning (False Negative Output)

<table>
<tr><th>Use Case</th><th colspan="4">Mobile Work Zone Warning System</th></tr>
<tr><td>Scenario ID and Title</td><td colspan="4">UC6-S3: Degraded Conditions – Inaccurate Vehicle Positioning</td></tr>
<tr><td>Scenario Objective</td><td colspan="4">• Demonstrate the fall back scenario if the detected path of the vehicle or private vehicle is inaccurate.</td></tr>
<tr><td>Operational Event(s)</td><td colspan="4">• The system falsely determines there is not a work zone in the vehicle’s path
• The system does not notify all Drivers and Vehicle Operators of the work zone ahead.</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Snow Plow Operator</td><td colspan="2">Engage in work zone activities in normal manner</td></tr>
<tr><td colspan="2">General Equipped Vehicle Operator</td><td colspan="2">Properly respond to system warning of plow ahead</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">• The system is properly configured, enabled and operational, including a smart phone application (optional) within the vehicle of the General Equipped Vehicle Operator
• A dynamic message is sign is operational on the route and direction of the work zone and is either blank or showing a lower priority message than the work zone ahead message
• The work zone operator provides input that they are actively involved in work zone operations (may be automated based on flashing arrow activation)
• The work zone is moving more slowly than surrounding traffic and 350 feet upstream from the dynamic message sign
• General Equipped Vehicle Operator is on the same road and direction as the work zone, 500 feet behind the work zone and moving faster than the work zone</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">
</td></tr>
<tr><td rowspan="4">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>General Equipped Vehicle Operator</td><td>1</td><td>Receives no message, neither on the DMS nor on the smart phone app.</td><td>Because the CC System is not able to position the vehicle on the same roadway as the work zone</td></tr>
<tr><td>General Equipped Vehicle Operator</td><td>2</td><td>Approaches the DMS</td><td>Does not sees the work zone ahead message on the DMS.</td></tr>
<tr><td>General Equipped Vehicle Operator</td><td>3</td><td>Approaches the Work Zone</td><td></td></tr>
</table>

	General Equipped Vehicle Operator	4	Slows down and passes the work zone or changes lanes and passes the work zone	Does not have as much time to react as if the CC system was working properly
Post-Conditions	• The General Equipped Vehicle Operator visually observes the work zone and passes the work zone • The General Equipped Vehicle Operator may lose trust in the notification system.			
Traceability	*N/A for Degraded Conditions due to Inaccuracies*			
CC System Inputs	• (inaccurate) General Equipped Vehicle Location/Motion (from GNSS) • Work Zone Location/Motion (from GNSS) • Work Zone Operational Status (from Work Zone Worker, may be automated) • Work Zone Message Input (from Traffic Operations Manager)			
CC System Outputs	• Work Zone Message and applicable DMS (to IRIS)			

5.5.4 Use Case 6 Scenario 4: Degraded Conditions – Inaccurate Vehicle Positioning (False Positive Output)

Use Case	**Mobile Work Zone Warning System**	
Scenario ID and Title	*UC6-S4: Degraded Conditions – Inaccurate Vehicle Positioning*	
Scenario Objective	• Demonstrate the fall back scenario if there is inaccurate positioning of the work zone	
Operational Event(s)	• The system cannot determine a work zone is in operation • The system is not able to notify the General Equipped Vehicle Operator that there is a work zone ahead • The system is not able to notify the Unequipped Drivers that there is a work zone ahead • The system is not able to output TIMs	
User(s)	User	Role
	Work Zone Worker	Engage in work zone activities in normal manner
	General Equipped Vehicle Operator, Unequipped Driver	Properly respond to system warning of plow ahead
Initial Conditions	• The system is properly configured, enabled and operational, including a smart phone application (optional) within the vehicle of the General Equipped Vehicle Operator • The work zone operator provides input that they are actively involved in work zone operations (may be automated based on flashing arrow activation) • General Equipped Vehicle Operator 2 is on the same road but traveling in the opposite direction of the work zone	

Scenario Diagram				
Key Actions and Flow of Events	**Source**	**Step**	**Key Action**	**Comments**
	General Equipped Vehicle Operator	1	Receives work zone ahead message	Begins to look for the work zone
	General Equipped Vehicle Operator	2	Never comes across the work zone	The vehicle position indicates there is a work zone ahead, but the actual path of the vehicle does not pass the work zone
	General Equipped Vehicle Operator	3	Slows down, and speeds up after not noticing a work zone	Message eventually ceases
Post-Conditions	• The General Equipped Vehicle Operator continues driving, unnecessarily decreasing speed • The driver may lose trust in the notification system, and may be less likely to respond to notifications in the future			
Traceability	*N/A for Degraded Conditions due to Inaccuracies*			
CC System Inputs	• (inaccurate) General Equipped Vehicle Location/Motion (from GNSS) • Work Zone Location/Motion (from GNSS) • Work Zone Operational Status (from Work Zone Worker, may be automated) • Work Zone Message Input (from Traffic Manager)			
CC System Outputs	• (false) Work Zone Notification (to General Equipped Vehicle Operator)			

5.5.5 Use Case 6 Scenario 5: Degraded Conditions – Communications Latency

Use Case	Mobile Work Zone Warning System
Scenario ID and Title	*UC6-S5: Degraded Conditions – Communications Latency*
Scenario Objective	• Demonstrate the fall back scenario if there is latency associated with system processes that are responsible for transforming inputs into actionable outputs
Operational Event(s)	• Latency in the system (processing, communication between CC System components, or communication between the CC System and external systems)

<table>
<tr><td></td><td>result in an output that is not received in time to be of practical use to the recipient.
The system is not able to notify the General Equipped Vehicle Operator that there is a work zone ahead in a timely manner
The system is not able to notify the Unequipped Drivers that there is a work zone ahead in a timely manner
The system is not able to output TIMs in a timely manner</td></tr>
<tr><td>User(s)</td><td><table><tr><th>User</th><th>Role</th></tr><tr><td>Work Zone Worker</td><td>Engage in work zone activities in normal manner</td></tr><tr><td>General Equipped Vehicle Operator, Unequipped Driver</td><td>Properly respond to system warning of plow ahead</td></tr></table></td></tr>
<tr><td>Initial Conditions</td><td>The system is properly configured, enabled and operational, including a smart phone application (optional) within the vehicle of the General Equipped Vehicle Operator
A dynamic message is sign is operational on the route and direction of the active work zone and is either blank or showing a lower priority message than the work zone ahead message
The work zone is moving more slowly than surrounding traffic and 350 feet upstream from the dynamic message sign
The work zone operator provides input that they are actively involved in work zone operations (may be automated based on flashing arrow activation)
General Equipped Vehicle Operator is on the same road and direction as the work zone, 500 feet ahead of the work zone and moving faster than the work zone
Limited system resources (processing, communications) adds latency to outputs compared to the normal operating condition.</td></tr>
<tr><td>Scenario Diagram</td><td>Same as Scenario 3</td></tr>
<tr><td>Key Actions and Flow of Events</td><td><table><tr><th>Source</th><th>Step</th><th>Key Action</th><th>Comments</th></tr><tr><td>Work Zone Operator</td><td>1</td><td>Does not sees the work zone ahead message begin to display on the DMS</td><td>Engages in work zone activities</td></tr><tr><td>CC System</td><td>2</td><td>Broadcasts TIM</td><td>Later than under Normal Operating Conditions</td></tr><tr><td>Unequipped Driver/ General Equipped Vehicle Operator 2</td><td>3</td><td>Approaches the DMS</td><td>DMS may not display work zone message before driver/operator pass</td></tr><tr><td>Unequipped Driver/ General Equipped</td><td>4</td><td>Approaches the Work Zone</td><td>Unequipped Driver has not seen work zone message</td></tr></table></td></tr>
</table>

	Vehicle Operator 2			
	Unequipped Driver	5a	Makes sudden movement in response to work zone and passes the work zone	
	CC System	5b	Issues Work Zone message to General Equipped Vehicle Operator	Later than under Normal Operating Conditions, immediately prior to entering work zone. The system may issue a latency advisory to the General Equipped Vehicle Operator and/or to the Traffic Operations Manager if latency is observed.
	General Equipped Vehicle Operator 2	6b	May have to make sudden movement in response to work zone and passes the work zone	Upon which the work zone ahead message on the smart phone app ceases
Post-Conditions	• The General Equipped Vehicle Operator receives delayed notification of work zone ahead, and may rapidly change speeds or rapidly change lanes in response. • The Unequipped Driver may not see the work zone message on the DMS. This is similar to the current operating condition.			
Traceability	UN-CC-7.06-v01 – Remote Diagnostic			
CC System Inputs	• General Equipped Vehicle Location/Motion (from GNSS) • Work Zone Location/Motion (from GNSS) • Work Zone Operational Status (from Work Zone Worker, may be automated) • Work Zone Message Input (from Traffic Operations Manager)			
CC System Outputs	• (late) Work Zone Notification (to General Equipped Vehicle Operator) • (late) TIM (to On-Board/Nomadic Device) • (late) Work Zone Message and applicable DMS (to IRIS)			

5.5.6 Use Case 6 Scenario 6: Degraded Conditions – Communications Failure

Use Case	**Mobile Work Zone Warning System**
Scenario ID and Title	*UC6-S6: Degraded Conditions – Communications Failure*
Scenario Objective	• Demonstrate the fall back scenario if failure of communication between CC System components, or communication between the CC System and external systems result in no output when output would have been given under normal operating conditions
Operational Event(s)	• Failure of communication between CC System components, or communication between the CC System and external systems result in an output that is never received

<table>
<tr><td></td><td colspan="4">The system is not able to notify the General Equipped Vehicle Operator that there is a work zone ahead
The system is not able to notify the Unequipped Drivers that there is a work zone ahead
The system is not able to output TIMs</td></tr>
<tr><td rowspan="3">User(s)</td><td colspan="2">User</td><td colspan="2">Role</td></tr>
<tr><td colspan="2">Work Zone Worker</td><td colspan="2">Engage in work zone activities in normal manner</td></tr>
<tr><td colspan="2">General Equipped Vehicle Operator, Unequipped Driver</td><td colspan="2">Properly respond to system warning of plow ahead</td></tr>
<tr><td>Initial Conditions</td><td colspan="4">A dynamic message is sign is operational on the route and direction of the active work zone and is either blank or showing a lower priority message than the work zone ahead message
The work zone is moving more slowly than surrounding traffic and 350 feet upstream from the dynamic message sign
The work zone operator provides input that they are actively involved in work zone operations (may be automated based on flashing arrow activation).
General Equipped Vehicle Operator is on the same road and direction as the work zone, 500 feet ahead of the work zone and moving faster than the work zone
A system processing/communications outage prevents the system from providing any output.</td></tr>
<tr><td>Scenario Diagram</td><td colspan="4">Same as Scenario 3</td></tr>
<tr><td rowspan="5">Key Actions and Flow of Events</td><td>Source</td><td>Step</td><td>Key Action</td><td>Comments</td></tr>
<tr><td>Work Zone Operator</td><td>1</td><td>Does not see the work zone ahead message begin to display on the DMS</td><td>Engages in work zone activities</td></tr>
<tr><td>CC System</td><td>2</td><td>Does not broadcasts TIM</td><td>The system may issue an advisory to the Traffic Operations Manager if internal failure conditions are observed.</td></tr>
<tr><td>Unequipped Driver/ General Equipped Vehicle Operator 2</td><td>3</td><td>Approaches the DMS</td><td>DMS does not display work zone message</td></tr>
<tr><td>Unequipped Driver/ General Equipped Vehicle Operator 2</td><td>4</td><td>Approaches the Work Zone</td><td>Have not seen work zone message</td></tr>
</table>

	Unequipped Driver/ General Equipped Vehicle Operator 2	5a	Makes sudden movement in response to work zone and passes the work zone	
Post-Conditions	• The General Equipped Vehicle Operator does not receive notification of the work zone ahead, and may rapidly change speeds or rapidly change lanes in response. • The Unequipped Driver will not see the work zone message on the DMS. This is similar to the current operating condition.			
Traceability	UN-CC-7.06-v01 – Remote Diagnostic			
CC System Inputs	• General Equipped Vehicle Location/Motion (from GNSS) • Work Zone Location/Motion (from GNSS) • Work Zone Operational Status (from Work Zone Worker, may be automated) • Work Zone Message Input (from Traffic Operations Manager)			
CC System Outputs	• *none*			

Appendix A – Stakeholder Meeting Attendance and Outcomes

The meeting started with an introduction and overview of CV technology, followed by interactive sessions where stakeholders could communicate their needs and collaborate as a group to determine which needs were most pressing along the TH-55 corridor. After a discussion about needs, stakeholders participated in a discussion to come up with concepts for the proposed system that would address the needs elicited during the previous session. For both needs and system concepts, stakeholders were given the opportunity to vote on which needs and concepts were most important to them. Each stakeholder could vote for up to five options. **Error! Reference source not found.** and **Error! Reference source not found.** in **Error! Reference source not found.** show the needs and concepts ranked according to the number of votes each concept received – only concepts that received one or more votes are shown. These needs and concepts served as the basis for the development of user needs and system concepts for this project. Ultimately, a group of agency leaders were consulted to develop the final use cases to be included in the CC System concept.

Table 9: Stakeholder Meeting Attendees

Name	Organization
RJ Kakach	City of Golden Valley
Scott Poska Steve Mosing	City of Minneapolis
Jeremy Koenen	City of Minnetonka
Jim Renneberg	City of Plymouth
Jim McCarthy	USDOT
Ken Levin	Hennepin County
Terri Johnson	HERE Technologies
Gary Nyberg Jason Podany Steve Rippey Curt Olson Hoki Tse Chad Loeffler	Metro Transit
Sue Stroinsk Ernie Zahradka	Metro Transit, Met Council
Victoria Hopwood Tim Johnson Russ Reilly Tom Wanamaker	State of Minnesota Information Technology (MN IT)

Name	Organization
Sue Zarling Jim Deans Mukhtar Thakur Mike Fairbanks Steve Misgen Derek Lehrke Kevin Schwartz Cory Johnson Ray Starr Peter Skweres John Bieniek Chris Wenzel Brian Kary	MnDOT
Farveh Makhssous	Sambatek*
Matt Fyten	Southwest Transit
Brian Scott Michael Janson	SRF*
Kiel Ova	TTS
Max Donath	University of Minnesota
Scott Shogan Chris Toth Tom Timcho	WSP*

*Indicates members of the project team

Table 10: Issues and Needs

Need	Votes
Accidents between buses and pedestrians/bicycles (esp. left/right turning)	24
Managing and sharing data	17
Spreading chemicals at signals	16
Over capacity issues	12
Lack of travel times along arterials	11
Sharing of incident data	11
Work zone crashes	10
High speed crashes with high severity	8
Crashes at Lyndale/I-94 (veh, ped, and bike)	7
Safety at non-signalized intersections	6
Delay for minor road traffic crossing TH-55	6
Rear-end crashes with plows and buses	6
Other (17)	0

Table 11: Concept Development

Concept	Votes
Snow plow signal priority	12
Work zone warning (short-term/moving zone) To avoid rear-end crashes into work convoys and to support route guidance	11
Use of CV data to support adaptive signal control/system-wide signal system support (adapt for priority calls, etc.)	10
Data-processing application to turn CV data into useful information and fuse with other data sources	9
Snow-plow “eco-approach” –recommended approach speed to avoid stopping at next signal and hit the green light	8
Recommended lane guidance on arterials (also speed recommendations)	8
Transit-Pedestrian warning system to warn drivers of pedestrians in conflicting crosswalk	7
Enhanced travel time data on arterials supported by CV/BSM data	7
Personal Mobile Devices connected with BLE tags	6
Providing data (traditional ITS + CV) to third parties for use in their applications	6
Red-light warning system	6
Warning to passing vehicle of pedestrian crossing in front of bus	6
Some sort of queue-jump for buses to join the HOT lane on 394 during congested periods	5
Tampa CV pilot pedestrian app	5
Improved real-time conditions to better predict bus arrival times enhanced by CV data – data from MnDOT TMC to MT TCC to AVL	4
Pedestrian assistance for visually-impaired along TH 55	3
Share ramp condition/wait data to support route guidance	3
Pedestrian in crosswalk warning at unsignalized crosswalks	2
Warning to trailing vehicles of bus stopping	1
Metropia–induced travel demand management app. Gamification app which uses points/credits to alleviate traffic at peak times	1
Other (5)	0

Appendix B – Acronyms

Acronym	Definition
4G LTE	Fourth Generation of Broadband Cellular Network Technology Long-Term Evolution
5G	Fifth Generation of Broadband Cellular Network Technology
AASHTO	American Association of State Highway Transportation Officials
ASC	Actuated Traffic Signal Controller
ATSPM	Arterial Traffic Signal Performance Measures
BSM	Basic Safety Message
CC	Connected Corridor
CV	Connected Vehicle
C-V2X	Cellular Vehicle-to-Everything
DMS	Dynamic Message Sign
DSRC	Dedicated Short Range Communications
GNSS	Global Navigation Satellite System
I-	Interstate
IOO	Transportation Infrastructure Owners And Operators
IRIS	Intelligent Roadway Information System
ITE	Institute of Traffic Engineers
ITIS	International Traveler Information Systems
ITS	Intelligent Transportation Systems
ITSA	ITS America
MAP	MapData Message
MLPS	Multi-Protocol Label Switching
MnCORS	Minnesota DOT Continuously Operating Reference Station
MnDOT	Minnesota Department of Transportation
NTCIP	National Transportation Communications for ITS Protocol
RSU	Roadside Unit
RTCM	Radio Technical Commission for Maritime Services Correction Message
RTMC	Regional Transportation Management Center
SAE	Society of Automotive Engineers
SPaT	Signal Phase and Timing Message
TH-	Trunk Highway
TIM	Traveler Information Message
V2I	Vehicle-to-Infrastructure
V2I DC	Vehicle to Infrastructure Deployment Coalition
V2V	Vehicle-to-Vehicle