MnDOT Connected Corridor Initiative

Concept of Operations Summary

Introduction

The Connected Corridor is a vision for two key regional arterials and a select number of vehicles to be outfitted with Connected Vehicle (CV) communications infrastructure. Vehicle-to-Infrastructure (V2I) technology, deployed at traffic signals, will allow the exchange of information between vehicles and equipment at intersections. This exchange of information enables CV applications, which (directly and indirectly) aim to improve the quality of life of roadway users along the selected arterials. These benefits are realized through improved safety and mobility.

MnDOT has selected the TH-55 corridor between downtown Minneapolis and I-494 as initial location to deploy this technology. In addition, ramp intersections along the parallel I-394 corridor may be outfitted with connected vehicle infrastructure to allow for additional applications related to integrated corridor management.

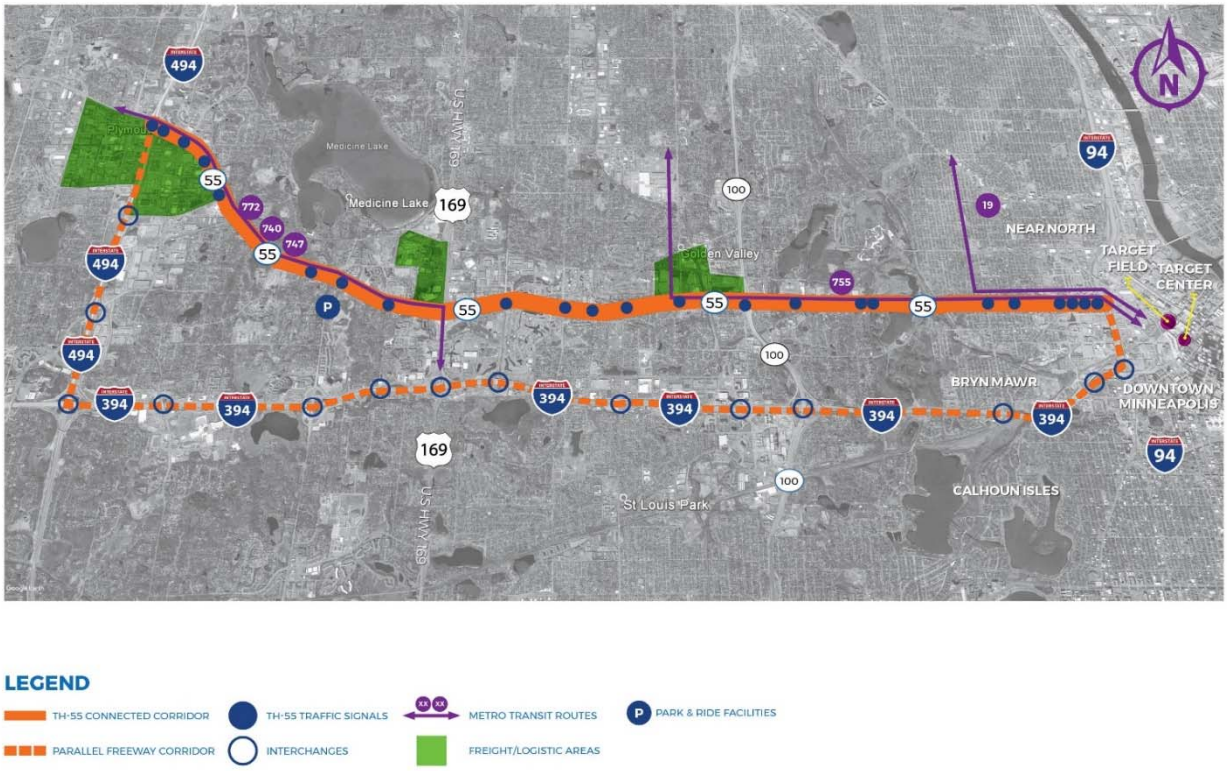


Figure 1: Connected Corridor Map

Challenges and Needs

A project stakeholder meeting designed to understand user needs and proposed solution concepts was held 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, University of Minnesota, and members of the project team involved in the systems engineering process.

The meeting included interactive sessions where stakeholders could communicate their challenges and 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. The challenges and associated needs developed are listed in Table 1 below.

Table 1: Challenges and User Needs

Challenge	Need
In-Vehicle equipment running applications need intersection data to support those applications	**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	**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	**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
CV Self-Equipped Drivers do not have direct, real-time access to data from roadside devices	**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	**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
Uneven application of snow removal chemicals from stopping and raising plow blade to accelerate from a stopped position at a signalized intersection	**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
Disruption of Gang Plow operations due to stopping at offramp/onramp signalized intersection	**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	**Improve Snow Plow Operator Safety.** A Snow Plow Operator needs a safe work environment
Not noticed by drivers when in a crosswalk	**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 Providers do not have direct, real-time access to SPaT data from traffic signal controllers	**Third-Party Data Services.** A Traveler Information Provider needs access to real-time SPaT data to provide traveler information services to its users.
Drivers may create unsafe operating conditions in mobile short-term work zones.	**Work Zone Worker Safety.** A Work Zone Worker needs a safe work environment
Obtaining more accurate data that represents roadway network operations	**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

Challenge	Need
Disseminating system data in real-time so that it can be used by drivers	**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	**Dynamic Roadway Maintenance Activity Information.** The Traffic Manager needs to be able to provide work zone information and dynamic maintenance activity information to travelers
Processing all roadway network operations data in a timely manner to support operations	**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	**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	**Remote Diagnostic.** The Traffic Operations Manager needs to be aware of and diagnose system malfunctions so that they can be quickly resolved
Lack of institutional experience with deploying CV systems	**DSRC Experience.** The Traffic Operations Manager 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

System Concept and Proposed Applications

The Connected Corridor will consist of the deployment of CV technology on the roadside and in select vehicles. The Connected Corridor system boundary includes 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. The figure below shows the system boundary and illustrates the relationship between the CC System, existing external systems, and system users. A summary of this system is provided below and is described in detail below.

Together, equipment deployed on the roadside and in vehicles, the transmission of messages, and the deployment of applications supports the needs of users. Roadside equipment consists of communications equipment, a traffic signal controller, and other ITS equipment such as pedestrian detection equipment. Wireless communications will enable the secure communication of various messages from roadside infrastructure to vehicles. The traffic signal controller provides signal data to the communications equipment. The traffic signal controller may need to be replaced, or may have to have its firmware updated to support the output of data used to populate the SPaT message.

Equipment deployed in select vehicles will receive messages sent from roadside equipment. In-Vehicle Equipment also broadcasts data 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 Basic Safety Messages (or another form of location and motion data) that can be captured by other in-vehicle equipment and roadside equipment.

Through IRIS, the 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 2), and will interface with GNSS to provide positioning and allow time synchronization between devices.

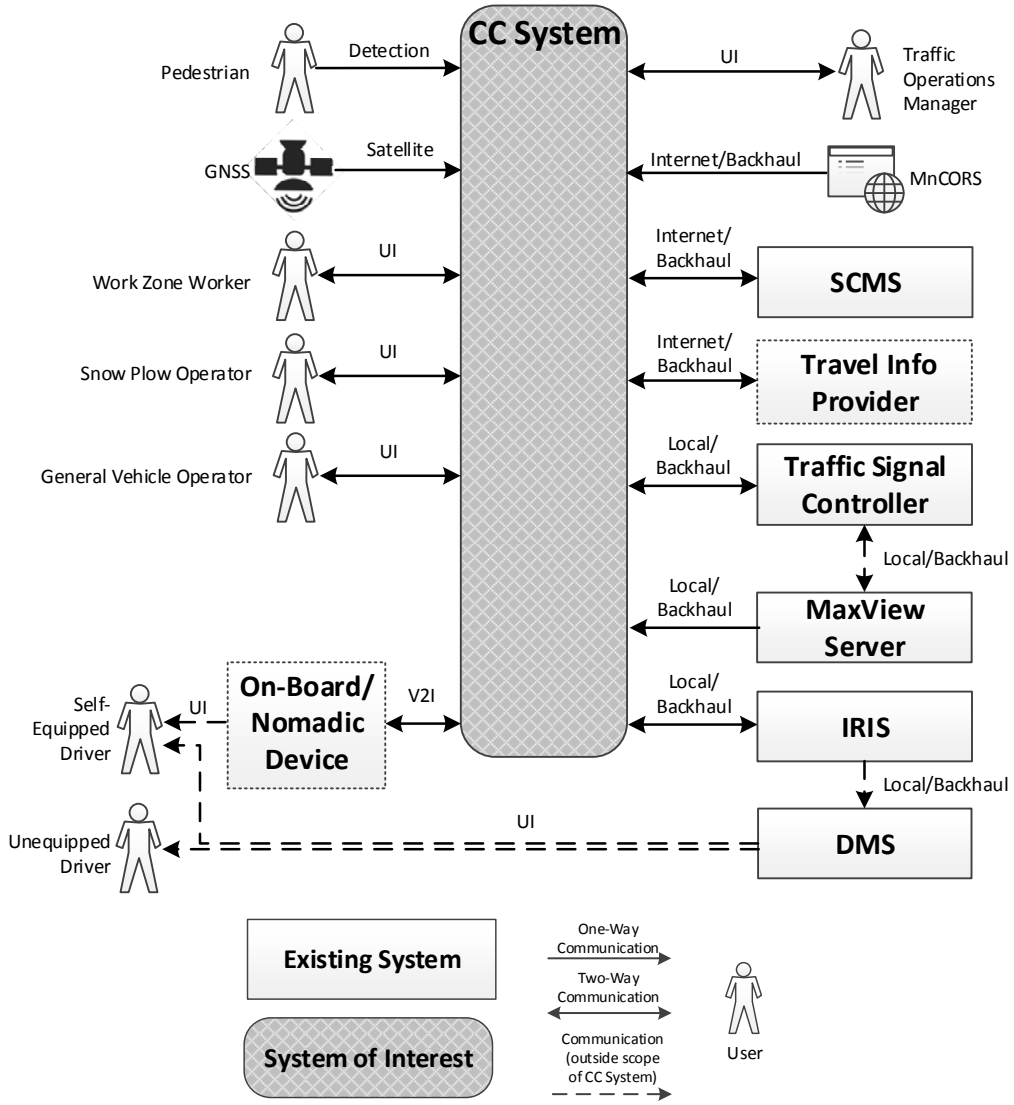
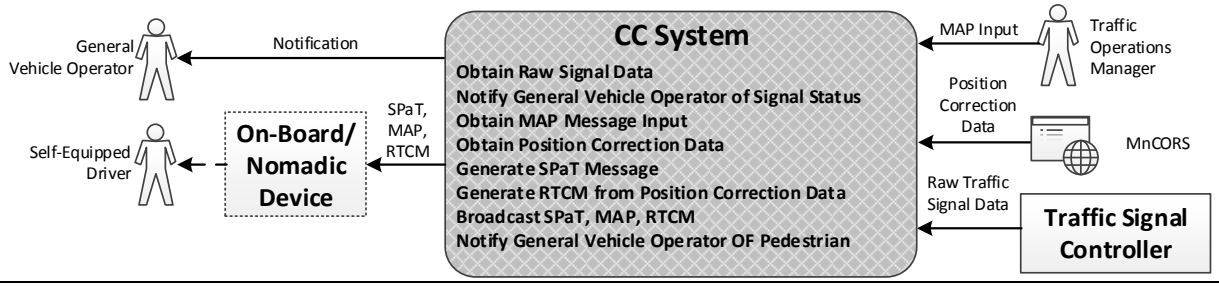


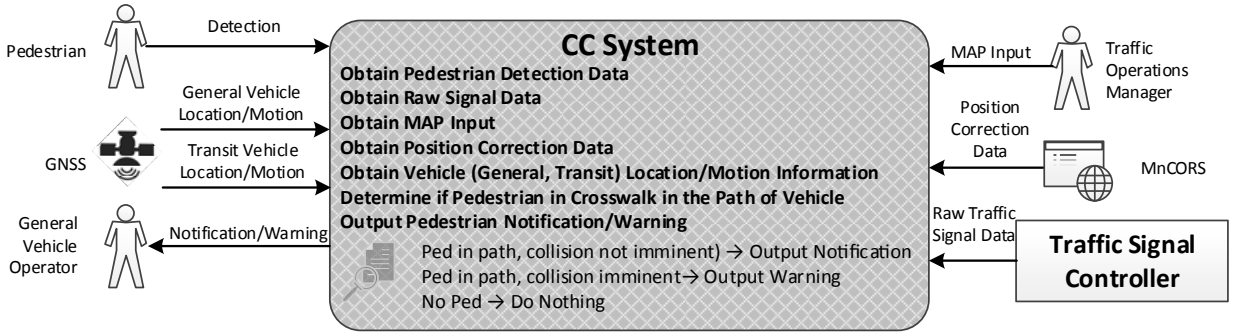
Figure 2: Connected Corridor High-Level System of Interest

As discussed previously, overarching challenges 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:

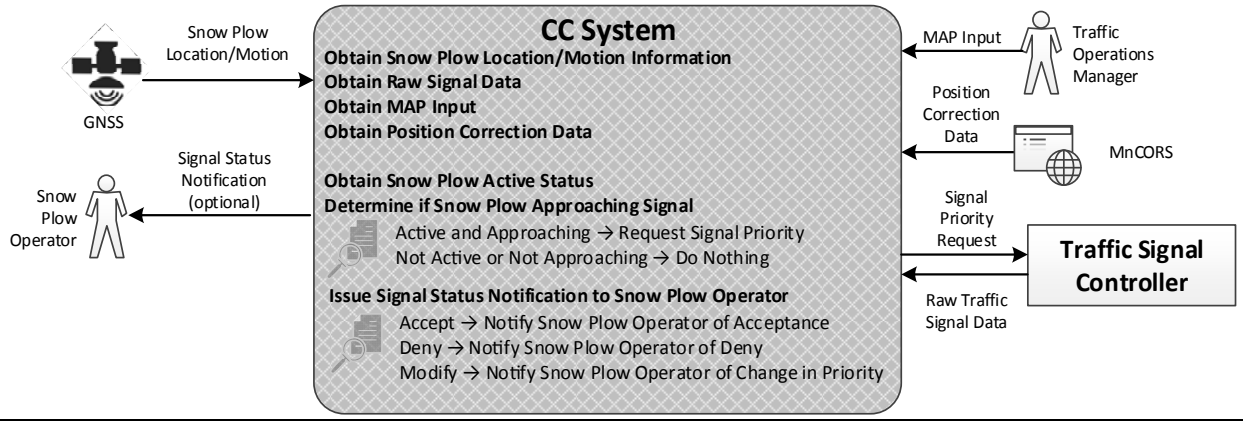
- Communicating SPaT data (along with other vehicle-based data, such as Basic Safety Messages (BSM)) in order to respond to the SPaT Challenge and gain experience with DSRC infrastructure and CV data management
- Reducing crashes between vehicles and pedestrians (esp. left/right turning)
- Improving 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

These system objectives are captured in use cases, which are detailed in the tables below. For each use case, the users involved are listed, a description is provided, a functional diagram is given, and anticipated benefits are listed.

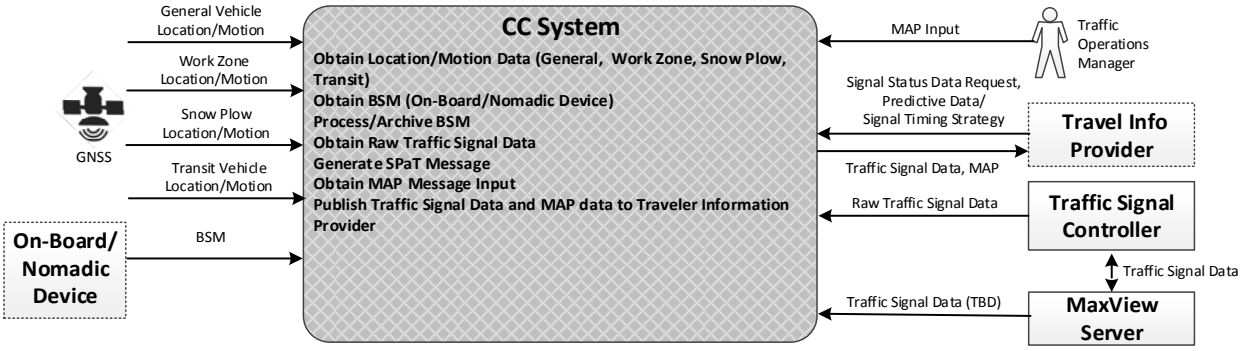
Use Case 1: SPaT and MAP	
Users	General Vehicle Operator, Self-Equipped Driver, Traffic Operations Manager
Description	The Signal Phase and Timing use case provides SPaT and other associated messages to properly equipped vehicles in order to provide information regarding the signal state and the amount 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.
Diagram	
Expected Benefit	• Improved vehicle operator awareness of traffic signal state and timing of subsequent phases • Drivers of vehicles with on-board/nomadic devices can utilize CV Data (SPaT, MAP, RTCM) made available by the CC System to enable safety, mobility, environmental application benefits of those devices.

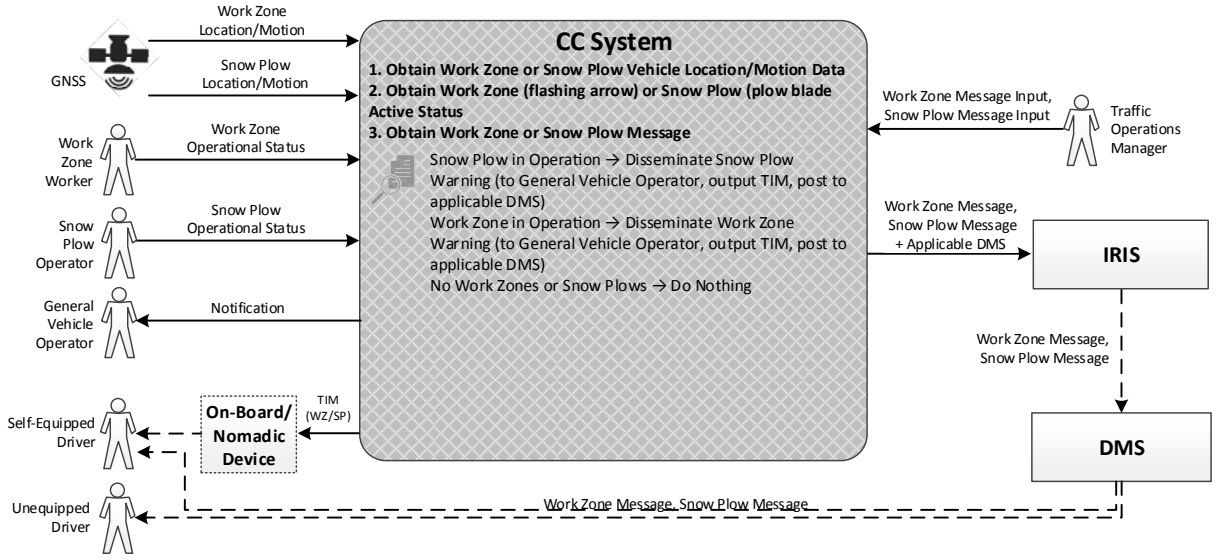
Use Case 2: Vehicle-Pedestrian Intersection Conflict Warning	
Users	General Vehicle Operator, Transit Vehicle Operator, Pedestrian
Description	The Vehicle-Pedestrian Intersection Conflict Warning use case alerts drivers when a pedestrian is in a crosswalk at a signalized intersection along the vehicle's 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.
Diagram	
Expected Benefit	• Improves driver awareness of pedestrians with an alert when a pedestrian is in a crosswalk • Provides an additional level of safety to pedestrians as they cross busy intersections

Use Case 3: Snow Plow Signal Priority

Users	Snow Plow Operator
Description	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.
Diagram	
Expected Benefit	• Allows prioritized treatment at traffic signals for plow clearing operations along and across TH-55 • Reduces the number of stops. This will allow operators to: o Reduce incomplete snow clearance and clear intersections in a single pass o Reduce total snow clearance time

Use Case 4 and 5: Basic Safety Message Management and Traffic Signal Data Dissemination (Connected Vehicle Data Exchange)

Users	System Operations Manager
Description	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. Furthermore, 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. The **Connected Vehicle Data Exchange** will serve as the foundation for the capture and storage of BSM and traffic signal data. 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. 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. 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).
Diagram	
Expected Benefit	• Allows partners to offer various third-party applications direct to consumers, through both integrated vehicle systems or mobile devices to improve mobility, or provide environmental benefits on the roadways and reduce driver stress. • As the presence of connected and automated vehicles on Minnesota's roads increases in the coming years, technology will become critical to supporting these advanced vehicles and creating opportunities for improved safety and mobility. • Prepares Minnesota to capture, process, and archive high-quality probe data from an ever-increasing number of these vehicles using its roadways.

Use Case 6: Mobile Work Zone Warning System	
Users	General Vehicle Operator, Transit Vehicle Operator, Self-Equipped Driver, Unequipped Driver, Snow Plow Operator, Work Zone Worker
Description	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. Because the dissemination of work zone and snow plow messages can be performed via DMS, the extent of this application is not limited to the I-394 and TH-55 corridors. Once developed and tested along the Connected Corridor, this system could be extended to other corridors to assist travelers throughout the Twin Cities region.
Diagram	
Expected Benefit	• Supports better traveler information to all motorists through dynamic signs, mobile applications, and direct radio messages, of road maintenance and short-term work zones. • Improves safety for both drivers and road workers