DEPARTMENT OF TRANSPORTATION

Highway 52 Connected and Automated Vehicles (CAV) Study

Final Report

September 2021

DESTINATION CAV

SRF

I. Project Overview

MnDOT's Office of Connected and Automated Vehicles (known as "CAV-X") was launched in 2018 to help the state plan and prepare for emerging technologies like connected and automated vehicles (CAV). These technologies have the potential to improve the lives of Minnesotans by advancing safety, reduce transportation barriers, and create a more efficient transportation system. MnDOT's CAV goals are to leverage CAV industry innovations to advance transportation safety, equity, accessibility, public health, and sustainability.

1. About CAV Technologies

CAV is a broad term that encompasses a wide range of technologies, including how vehicles interact with both other vehicles, transportation users, and the road. CAV technologies evolve and change quickly and offer a wide range of possible solutions. To help us understand how to plan and prepare for these technologies, The Federal Highway Administration (FHWA) describes four types of these technologies[1].

1. **Connected drivers** who bring their own communications devices such as smartphones into vehicles.
2. **Connected vehicles** that leverage in-vehicle devices like cellular connections and GPS to gather data, provide driver information, and send data outside the vehicle.
3. **Automated vehicles** use technologies like adaptive cruise control, lane keeping assistance, and active collision avoidance to support drivers with traditional driving tasks.
4. **Autonomous vehicles** incorporate many types of automation to program vehicles to operate without a human. Some autonomous vehicles do not rely on external communications or cellular connections like connected drivers and connected vehicles. Other autonomous vehicles use connected vehicle technology. States like Minnesota believe that to support our transportation safety goals, we must advance both connected and automated technologies, which some call "CAV".

Connected driver applications have been around since 2008. The popular rise of the smartphone enabled applications such as Google Maps to provide real-time guidance to drivers. Since then, other applications have entered the market such as Waze, enabling two-way data sharing.

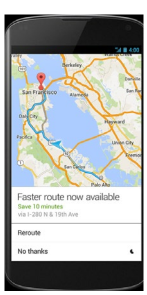


Figure 1 – Example Google Maps Application

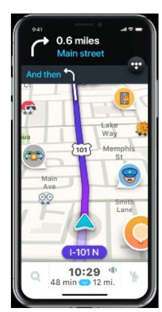


Figure 2 – Example Waze Application

[1] Leveraging the Promise of Connected and Autonomous Vehicles to Improve Integrated Corridor Management and Operations: A Primer (https://ops.fhwa.dot.gov/publications/fhwahop17001/index.htm)

Connected vehicles have been part of the landscape since 1997 with the introduction of the OnStar system by General Motors. Initially designed as an emergency assistance concierge service, connected vehicle applications have evolved. Now they provide dashboard or windshield infotainment, including your speed, lane position, travel information and some may even include road construction information, streaming music, or other connectivity functions.

Figure 3 – General Motors OnStar Logo

Figure 4 – Example Dashboard Safety Systems Display

Automated vehicle technologies vehicles also have a long history, going back to some of the early. 1992 driver warning systems on Mitsubishi vehicles, Mercedes Benz adaptive cruise control in 1999 to the Department of Defense 2004 “DARPA challenge” which challenged industry to create a fully self-driving vehicle. Today, adaptive cruise control is standard on all Toyota vehicles. Other Advanced Driver Assist Systems (ADAS) such as Radar, Lidar, and video processing systems are all now common on automated vehicles, however, these are intended to assist driver operation, rather than navigate the vehicle without driver interaction.

Fully autonomous vehicles are being research and tested by several companies, such as Waymo, Ford and Tesla. Passenger vehicle operation is a complex task, and progress toward fully autonomous vehicle will take many years. Currently, there are no fully autonomous vehicles that can operate in a public roadway environment, although some companies claim they have fully autonomous vehicles that are operating in controlled environments.

2. Why this Project?

Planning and preparing for future transportation technologies is a significant challenge for any region especially with the ever changing and evolving transportation technologies available. To better prepare, the Highway 52 CAV study, MnDOT facilitated conversations with regional transportation stakeholders to understand how CAV applications can benefit travelers and communities between the Twin Cities and Rochester. These applications may address winter weather driving challenges, work zone safety concerns, and other needs identified by the study. Identified and prioritized applications will allow MnDOT to strategically invest of new technologies based on stakeholder needs. This method of CAV corridor planning can also be used for corridors across the state.

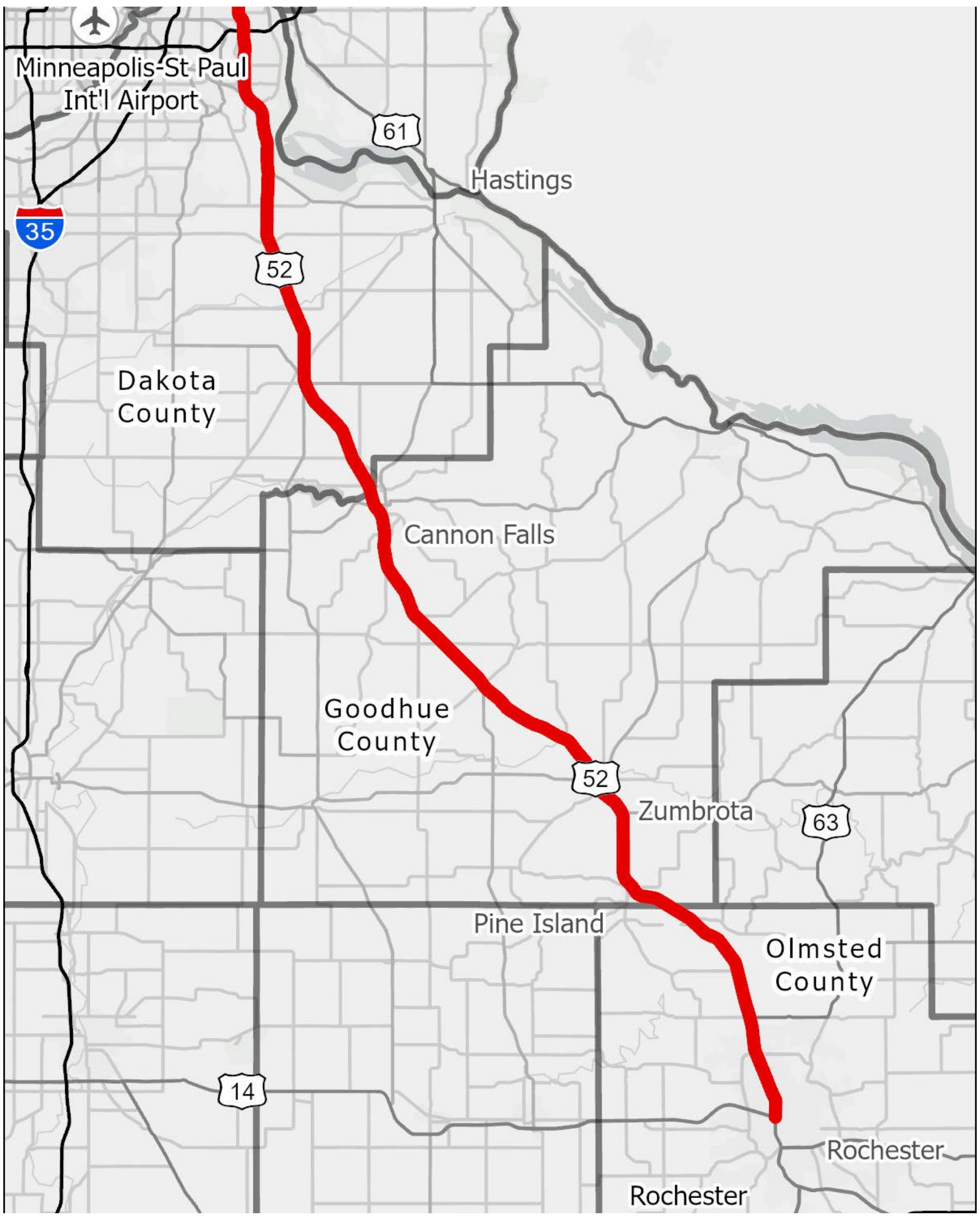
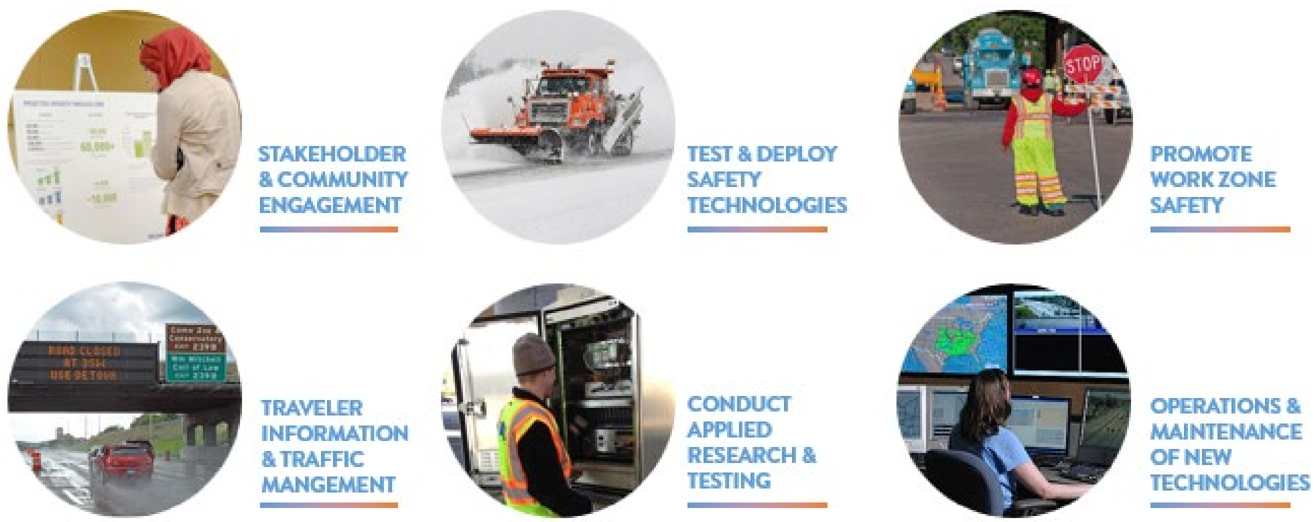


Figure 5 – Highway 52 Corridor Map

3. Highway 52 Corridor Goals

MnDOT has established the following goals for the Highway 52 Corridor:



4. Why the Highway 52 Corridor?

Highway 52 was identified for this CAV study for the following reasons:

- **Leverage past and upcoming projects –** Several projects to improve safety and mobility along the corridor have been completed over the last 20 years. For example, these include the Lafayette Bridge – Mississippi River Crossing, Highway 52 in Rochester (known as the "ROC52" project), Reduced Conflict Intersections in Dakota County (CSAH 66), and the "Cooperative Intersection Collision Avoidance Systems – Stop Sign Assist" project at Goodhue County Road 9. Four signification construction projects are scheduled along the corridor between 2021 and 2024.
- **Address increased travel demands –** Travel along the corridor continues to increase due to rapid growth in the Rochester area due to in part the Destination Medical Center and Mayo Clinic. Growth has averaged 2% per year compared to an average of 1.5% for other state trunk highways.
- **Promote partnerships –** Partnerships have been established and are encouraged to secure funding and build physical improvements on the corridor.
- **Use existing infrastructure investments –** Traffic Management System (TMS) upgrades, such as fiber optic communications, vehicle detection, and CCTV cameras, were recently completed along the corridor to allow advanced safety applications.
- **Manage congestion –** Significant congestion occurs along the corridor as traffic enters St. Paul as the corridor changes from more rural to urban with lower speeds.

Highway 52 History and Timeline

1934	1950s	1967	1958	1994
• Highway 52 first appeared. U.S. Highways were re-routed and re-designated redesignated to extend Highway 52 from Fowler, Indiana to Fargo, North Dakota. This approach led to different widths, geometries, and pavement types on the corridor.	• Before the interstate system was established in 1958, additional construction took place, creating interchanges in St. Paul and the four-lane expressway configuration in the 1950s.	• Majority of construction completed.	• The Lafayette Freeway section passing through Inver Grove Heights to downtown St. Paul first opened.	• The Lafayette Freeway completed to connect Highway 52 connected connection to Interstate 94

Highway 52 today passes through urban, suburban, rural, and agricultural areas. Access to the road varies from full, controlled interchanges to at-grade roadway crossings without traffic signals.

The study area includes 75 miles of Highway 52 from St. Paul to Rochester, MN, passes through four counties (Ramsey, Dakota, Goodhue, and Olmstead) and intersects two Interstates (I-94 and I-494). The wide variety of conditions makes the Highway 52 Corridor an ideal place to examine how CAV technologies can benefit travelers in Minnesota.

Traffic Characteristics

Just as the physical nature of Highway 52 varies greatly, so do its traffic patterns.

- **Commercial freight** - At the north section near St. Paul, Highway 52 carries approximately 80,000 vehicles per day. Heavy trucks and passenger vehicles experience weekday congestion in this urban area.
- **Agricultural use** - In the central section of the corridor, near Zumbrota, roughly 21,000 vehicle per day use the Highway. Agricultural traffic (tractors, and other slow-moving vehicles) crosses Highway 52 at at-grade intersections, or by driving along the highway shoulder.
- **Urban traffic** - Near Rochester, traffic shifts again to a more urban. Access is controlled with grade separated interchanges. Traffic includes heavy trucks and passenger vehicles. Typical daily traffic volumes range from 35,000 to 40,000 vehicles, with weekday congestion in Rochester.

II. Identifying Corridor Challenges and Opportunities

MnDOT met with corridor stakeholders to identify transportation challenges currently experienced along the corridor. Because CAV is a complex technology this project was intended to reach out to transportation professionals, law enforcement, regional planners, and leading experts to identify specific technology applications that can improve transportation along the Highway 52 Corridor. After some preliminary CAV opportunities are identified, MnDOT can reach out to communities to hear from them on whether these technologies may meet their identified transportation needs.

1. Engagement Methodology

The Highway 52 CAV study focused on reaching out to local, state, and federal government, regional planners, transportation professionals, law enforcement, engineers, and safety experts to identify the key challenges along the corridor. This started as a study in how CAV applications could advance safety, but quickly evolved to understand that this project could be expanded in future efforts to conduct broad engagement to address safety, equity, sustainability, mobility, and access. However, this study purposely did not reach out to broader community members because the stakeholders wanted to manage expectations on the limitations of the technology and what CAV applications can actually be used in Minnesota.

COVID-19 restrictions required participants to meet virtually. Three total workshops were held, with additional one-to-one virtual meetings, to gather feedback on project goals, challenges, recommendations, and outcomes. Each workshop hosted facilitated breakouts to grow relationships and have CAV expert facilitators help participants understand how CAV technologies could potentially help solve some of the regional transportation challenges.

- **Understanding CAV and Identifying Corridor Challenges** - Two initial workshops introduced the project and CAV technologies. Participants then brainstormed corridor challenges using online survey and real-time information tools like Mentimeter and live whiteboards.
- **Prioritizing Corridor Needs** - The second workshop prioritized the corridor challenges and opportunities and discussed potential CAV applications to address them.
- **Consensus on Potential Technology Applications** - The third workshop summarized the potential CAV and ITS applications into nine key opportunities and solicited feedback from participants on the applications.

Each workshop followed a common format of an initial presentation by the project team, followed by interactive discussions and polling tools to gather information. The complex nature of some transportation issues required follow up interviews where stakeholders could be engaged in detail. These meetings were also held virtually, with the results documented for inclusion into the issues summary and CAV applications recommendations of the study.

2. Project Stakeholders

A stakeholder list was developed by the project management team to focus on transportation professionals involved in traffic safety and regional planning to help CAV experts understand the regional challenges. This study was not intended to conduct public engagement because this was a technology study intended to identify technology opportunities that can eventually be shared with community members. Rather, transportation professionals from law enforcement, planners, DOT staff, multi-modal experts, engineers, city and county staff, federal officials, freight, and transit were asked to provide their technical and local knowledge.

Approximately forty stakeholders participated in a series of three virtual workshops facilitated by MnDOT and SRF. Subsequent one-to-one interviews were held with stakeholders. The following transportation and safety organizations were represented. A complete project roster can be found in Appendix A.

- Minnesota Department of Transportation: Connected and Automated Vehicle Office (CAV-X), Metro District (Twin Cities region), District 6 (Southeast Minnesota), Regional Traffic Management Center (RTMC), Office of Transportation System Management Planning, Office of Freight and Commercial Vehicle Operations, Transportation System Management and Operations (TSMO), Construction, Maintenance, and Communications
- Minnesota Department of Public Safety (DPS) and State Patrol
- Federal Highway Administration (FHWA) Division Office
- Dakota, Goodhue, and Olmstead County Engineers and Sheriffs
- Rochester-Olmsted Council of Governments (ROCOG)
- Destination Medical Center (DMC)
- Rochester City Lines

3. What did we Learn?

Corridor transportation challenges were categorized into four groups:

1. **Safety:** Issues that can arise from variations the flow of traffic, weather, or other environmental factors, or from characteristics of the roadway itself that result in injuries or property damage.
2. **Mobility and Access:** Issues arising from congestion and delay on the roadway, the ability to use Highway 52, and variability in travel time conditions.
3. **Transit and Multimodal:** Issues including safe access to different modes of transportation, not just passenger vehicles, including transit, ridesharing, walking, biking, micro-mobility, such as scooters, availability of alternative modes, transit reliability, and dedicated transit facilities.
4. **Equity**: Issues including economic, geographic, and other access barriers that may prevent individuals from having equal access to transportation along the corridor.

Specific CAV applications to address equity were not explored. Rather, possible CAV applications were examined through an “equity lens” to ensure that implementation of technological applications do not magnify or create new inequities in the transportation system and instead work to mitigate them. Each issue raised by stakeholders can be assessed from an equity perspective. In this way, when CAV applications are deployed in the future, the issues they address will have a traceable connection to equity concerns.

4. Issue Prioritization

Overall, 14 separate issues were identified by stakeholder input. Using an online engagement tool (Mentimeter), stakeholders were asked to rank their top five priorities, shown below: (1) improving safety during weather events; (2) improving work zone safety; (3) mitigating St. Paul congestion; (4) providing more traveler information including alternate routes; and (5) improving safety for first responders and maintenance on the shoulder issues.

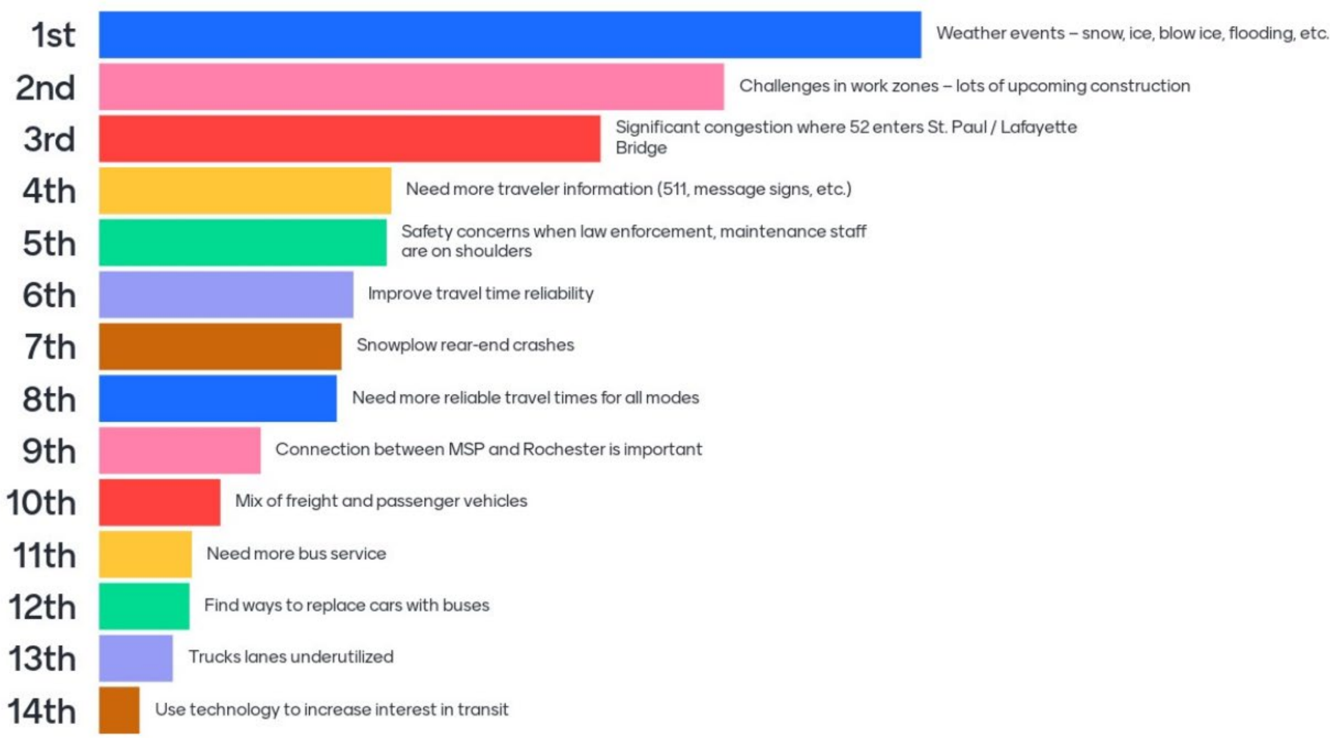


Figure 6 – Issue Prioritization Exercise Results

III. Opportunities Analysis

The project included an "opportunities analysis" task. The goal was to conduct a comprehensive research summary and literature review of published reports from other states to understand what other CAV research and projects have taken place. In addition, three states were selected for interviews to gain insight into their CAV experience. This information allowed the project team to identify CAV deployment opportunities for Highway 52 to leverage other regional work and avoiding duplicating previous efforts.

1. Research Review

MnDOT's library conducted a comprehensive literature review of state-level CAV activity, which was reviewed to determine any gaps in knowledge, experience, or deployments of CAV technologies. Many states have deployed some form of CAV application, while others have only studied the potential use of the technology.

The project team identified 15 common CAV applications used in the United States. A summary of these applications can be found in Appendix B. The team also reviewed state-level policy documents, planning activities, roadmaps, and data management policies. This effort identified national research so that work done in other states would not be duplicated in Minnesota. Some commonalities and differences were identified, including those noted below.

- **Most state Departments of Transportation report some level of connected or automated vehicle activity**, although in some cases it may only be at the study or planning level. For automated vehicle systems, 23 states have some deployment or demonstration activity.

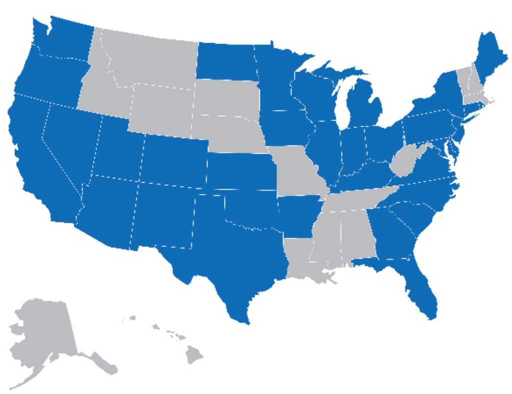


Figure 7 – States with AV Activities

- **The diversity of climates in the U.S. adds a complex challenge to CAV deployments** as seasonal weather conditions can have significant effects on the system performance of CAVs. For example, delivery and passenger vehicle activities are more common in warmer areas without snow whereas autonomous vehicle activities in harsh climates tend to focus on shuttles or limited-route buses.

Figure 8 - Automated Shuttle Operating in Snow

- **Connected vehicle systems** are primarily focused on dedicated short-range communication (DSRC) based vehicle to infrastructure applications. Of these, signal phase and timing activities are the most common. In-vehicle warnings of vehicle proximity, pedestrian presence, and critical areas (such as work zones) have also been demonstrated in various states.
- States are working with CAVs at the program level, through **dedicated offices and staff**, or as a function within an existing DOT office. Twenty-one states have **published strategic plans** for CAV deployment. There are also several **regional and national pooled fund studies and coordinating coalitions**, such as the Mid America Association of State Transportation Officials (MAASTO) and the Transportation Research Board (TRB) who are organizing CAV efforts.

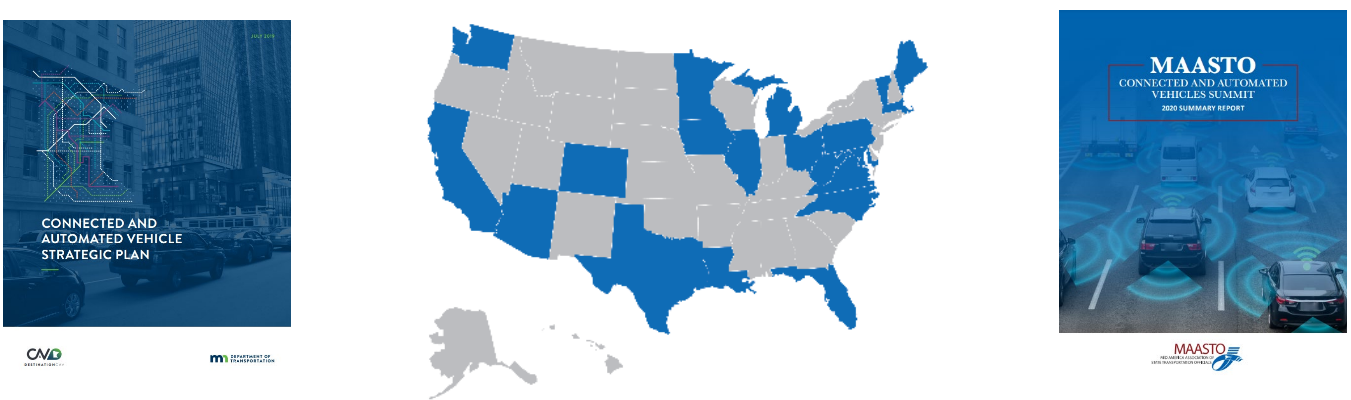


Figure 9 - States with CAV Plans and Example Documents

2. Lessons and Input from Other Agencies

As a part of the opportunities analysis, three state DOTs were interviewed to gather information about their specific experience in deploying connected vehicle systems. The states were chosen for their unique experiences or insights with CAV deployments.

- **Wyoming** is a participant in the USDOT Connected Vehicle Pilot Deployment. Their deployment is operational and includes over 400 instrumented vehicles and 75 roadside devices enabling two-way communications on the largely rural Interstate 80 corridor. Wyoming's focus on collecting information from and delivering information to travelers in a CAV context is highly relevant to potential applications on the Highway 52 corridor.

- **Florida** is also a participant in the Connected Vehicle Pilot Deployment program. In contrast to Wyoming, Florida's deployment focuses on the urban environment in Tampa, FL. Applications include wrong-way warnings, pedestrian safety, and intersection movement assistance, which may be useful to consider for at-grade intersections on Highway 52.

- **California** is the hub for many of the companies developing CAV technologies. Caltrans operates a research facility (Connected Vehicle Test Bed) where these technologies are tested and evaluated.

All interviews were conducted remotely using teleconferencing. Each interviewed agency had one or more participants and the project team conducting the interview had a minimum of three representatives. Interviews began with a short presentation by the project team describing the CAV study and framing the interview topics. The interview then proceeded as a guided discussion.

The interviews help identify suitable opportunities for deployment efforts in Minnesota, by describing some of the equipment and technology challenges and limitations in providing in-vehicle information.

Lesson Learned

1. Equipment Choice Challenges

All three states indicated difficulty with integrating and supporting equipment chosen for pilots. Pre-purchase demonstrations frequently showed optimistic results that could not be replicated in 'real world' deployments. Contracting mechanisms such as performance-based or milestone payment terms may reduce the risks associated with CAV deployments. The evolution of standards and changes in technology – such as the changes in Federal Communications Commission (FCC)FCC regulations of the DSRC safety spectrum - were cited by states as factors that complicate CAV deployments.

2. Information Delivery Limitations

All three states have limited deployments of in-vehicle hardware to provide information to drivers, but all acknowledged the cost and support requirements of units in private vehicles limit the appeal of that approach. As a result, states are looking into partnering with providers that already have a presence in the vehicle though navigation applications, such as Google, Apple, and Waze. Alternately, engaging directly with manufacturers to integrate data into the vehicle's infotainment systems is a viable path, but has had limited success due to a lack of partnerships with vehicle manufacturers.

IV. Potential CAV Applications

Based on the challenges identified by stakeholders and lessons learned from other states, a list of recommended CAV applications for the Highway 52 Corridor was developed. Recommended CAV applications were selected by identifying technologies that could readily address the corridor challenges within the next five years. MnDOT staff were also consulted to identify opportunities to collaborate on planned MnDOT projects.

1. Related MnDOT Projects

MnDOT has been actively engaged in researching, testing, and deploying CAV systems. Several existing and planned MnDOT projects were identified as aligning with the goals of this study.

1. Connected Vehicle Traveler Alert

MnDOT snowplows are already equipped with automatic vehicle location (AVL) systems to monitor their real-time location. This information is being used to publish messages to dynamic message signs when snowplows are in the area to increase driver awareness. This information could be further integrated to provide this information through MnDOT's 511 app, Google, Waze, etc.

Figure 10 – Connected Vehicle Traveler Alert System Diagram

2. Lafayette Bridge Queue Warning System

MnDOT is currently adding a "Stopped Traffic Ahead" message system for the roadside message signs near the Highway 52 Lafayette Bridge area that alerts drivers when there is stopped or queued traffic on the highways. These messages will be automatically displayed based on detected vehicle speeds.

3. Intelligent Work Zones

MnDOT is now evaluating opportunities to implement Intelligent Work Zones (IWZs) technologies for all construction projects. Queue warning systems, a specific IWZ application, detect the flow of traffic through work zones and provide travelers with real-time estimates of travel times, variable speed limits and lane closures. Due to the number of construction projects along Highway 52 in the coming years, MnDOT will be equipping the corridor with radar vehicle detectors and portable changeable message signs to support IWZ applications.

4. CAV Standard Pavement Markings

MnDOT is testing new permanent pavement markings that are wider, more densely spaced, and more contrasting through the state, including on Interstate 94 in the central part of the state. These enhanced pavement marking are easier to see by human operators and automated vehicles alike.

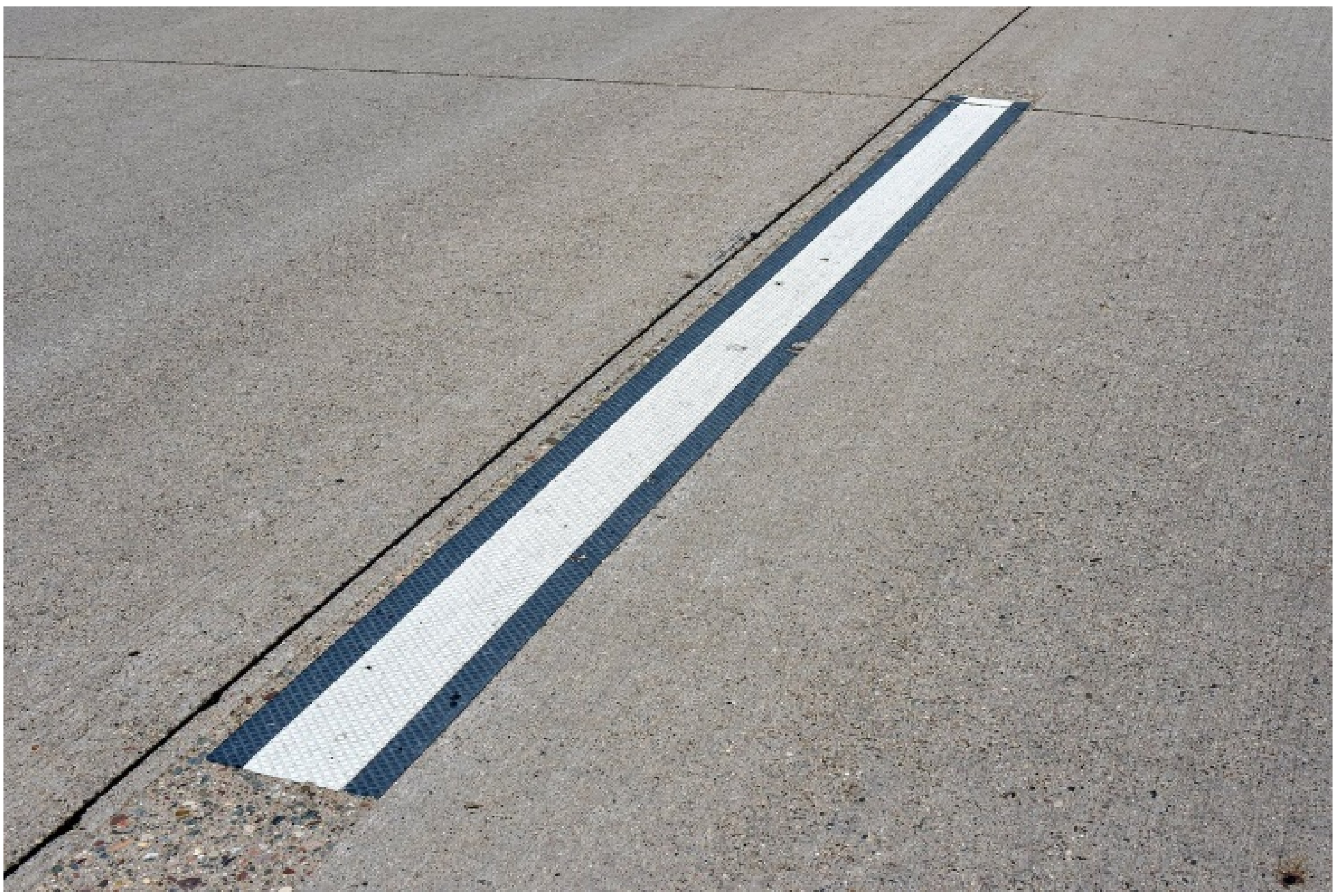


Figure 11 – Enhanced Pavement Marking

2. Recommended CAV Applications

After stakeholders prioritized potential CAV opportunities, the project team interviewed representatives from the AV technology industry and CAV vendors to discuss potential applications for Minnesota. Representatives included Silicon Valley traveler information artificial intelligent startups, a large transportation infrastructure product manufacturer, and a local AV technology company.

Interviews introduced the characteristics of the corridor and the specific issues identified by stakeholders. With this background, interviewees recommended CAV solutions based on their understanding of industry readiness, and scalability of CAV technologies. After discussing the potential CAV applications with MnDOT and industry, the following CAV applications were recommended for the Highway 52 Corridor.

General Considerations for CAV Applications

1. Technology Continues to Evolve

Many CAV technologies have evolved from their original concepts. For example, portions of the radio frequency spectrum dedicated to CAV applications have been re-assigned. These changes have made the Dedicated Short-Range Communication (DSRC) standard envisioned for CAV applications impractical to implement. For this reason, the applications considered in this section can be implemented using the newer "Cellular Vehicle to Anything" (C-V2X) technology.

2. Safety is Paramount

For any CAV application, safe operation is a design priority. Delivering information to drivers has commonly used either an application on a cellular phone or in-dash display. Phone applications must be carefully designed to minimize driver distraction.

3. Challenges with In-Vehicle Information Delivery

In-dash displays are closely controlled by auto manufacturers, and currently there are few opportunities to deliver "live" content from DOTs using these displays. Development of data products and relationships with manufacturers will be needed before CAV applications can be delivered using the existing displays. Near term CAV applications that deliver information to drivers will likely leverage MnDOT's existing 511 app or existing connections into the vehicle such as Google, Apple, or Waze.

Intelligent Work Zones

With several upcoming construction projects along Highway 52, MnDOT will deploy Intelligent Work Zones (IWZs) to improve safety along the corridor. With MnDOT already planning to deploy roadside equipment to support IWZ applications, the additional deployments described below can provide more real-time information while minimizing the need for roadside infrastructure.

1. **Real-Time Information Sharing:** MnDOT is currently updating its work zone data systems under the Federal Highway Administration Work Zone Data Exchange. This effort seeks to standardize work zone data across agencies to facilitate the exchange of data as well as to encourage third parties (navigation applications, vehicle manufactures, etc.) to integrate work zone data into their platforms. Most work zone data is currently static and based on planned work zone activities. Real-time work zone information would improve safety because travelers would have more reliable and updated information during construction.

   Specifically, **smart arrow boards** that automatically report their location and arrow display direction provide the exact location and timing of lane closures in work zones. Recent work by the Iowa DOT to standardize the communications protocols and adoption of this standard by manufacturers is simplifying the adoption of smart arrow board systems. Processing of this data can provide accurate, high-resolution information about the current land configurations and locations of work zones. An operational test of these devices can provide data to populate the Work Zone Data Exchange with accurate and up-to-date information while minimizing additional staff workload.

2. **Queue Warning System Enhancements:** Queue warning systems typically consist of roadside ITS devices, like non-intrusive detection and portable changeable message signs (PCMS). These devices are often placed in construction work zones. Now that many more tech companies provide data from connected vehicles there is an opportunity to detect upcoming queues or backups. This data makes it possible to identify traffic congestion by analyzing speed data from vehicles with built-in or cellular connections via third party providers. This lets users know of upcoming delays anywhere along a corridor where connected vehicle data is available, without the need to deploy expensive roadside sensors.

Figure 12 – Queue Warning System

Hazard Warning Systems

Several of the transportation challenges along the corridor stem from roadside hazards, including slow-moving equipment or vehicles pulled over on the shoulder. These hazards may be caused by weather events, traffic incidents, or routine maintenance. Several types of hazard warning system can mitigate these issues.

3. **Freeway Incident Response Safety Team (FIRST) Patrol**: Similar to snowplows with the Connected Vehicle Traveler Alert project, FIRST vehicles are equipped with AVL systems. FIRST vehicles frequently assist in moving disabled vehicles off the roadway, help State Patrol manage crash scenes, move debris off the roadway, and help with emergency vehicle repairs. This requires FIRST vehicles to stop in traffic or on road shoulders. Locations of stopped FIRST vehicles can be used from their vehicle sensors using existing technology developed for smart work zones. This information can then be shared via 511, including web sites, smartphone apps, DMS, and in-vehicle infotainment systems with connected data feeds. This helps warn drivers of nearby obstructions and lane closures.

Figure 13 – FIRST Truck

4. **Law Enforcement:** Building off the FIRST application above, travelers can be warned of stopped law enforcement vehicles. While publicly sharing the real-time location of law enforcement poses some challenges, there may be times when it makes sense for law enforcement to "activate" the ability to share their location to warn nearby drivers of unsafe conditions. For example, this could be used to notify drivers that there is a law enforcement vehicle on the shoulder ahead, reminding them to move over. Preliminary discussions with Minnesota State Patrol have indicated that they are interested in this application, but further details would need to be discussed.

Figure 14 – Law Enforcement Vehicle on Shoulder

5. **Weather:** MnDOT operates and maintains several road weather information systems (RWIS) sites through the state. These sites require capital investment and ongoing operations and maintenance costs. Third party data vendors collect data such as hard braking and anti-lock brake activation from connected vehicles through partnerships with auto manufacturers. This information can indicate the presence of slippery or poor road conditions due to weather or other incidents. The availability of the information depends on the number of connected vehicles, which varies by vehicle manufacturer and type. This information could be used to trigger hazard warnings via dynamic message signs or mobile applications. More information is needed on the number of vehicles that have this capability (known as "market penetration") before a project like this can be successful. An analysis of the actual number of vehicles that have this capability should be included in potential projects.
6. **Vehicles on Shoulder:** Third party data vendors can provide information about the presence of vehicles on the shoulder. For example, connected vehicle data can show the location and speed of a vehicle, which may show a vehicle stopped on the shoulder. Unlike the FIRST and law enforcement systems, vehicles driving along Highway 52 would use in-vehicle camera systems to detect stopped vehicles or other hazards. Detected vehicles can then be reported via cellular connections to a central database to be distributed to other connected warning systems. These systems could be used to provide hazard warnings to motorists, similar to the snowplow warning system. Warnings have previously been delivered via roadside message signs and indicate to drivers that a slow-moving vehicle is ahead. Additional information such as "slow down" or "move left" could be delivered depending on the specific context of the warning. If in-vehicle displays are used, the nature of the message may be purely graphical (hazard ahead icon, etc.) or may take a specific form based on the vehicle systems.

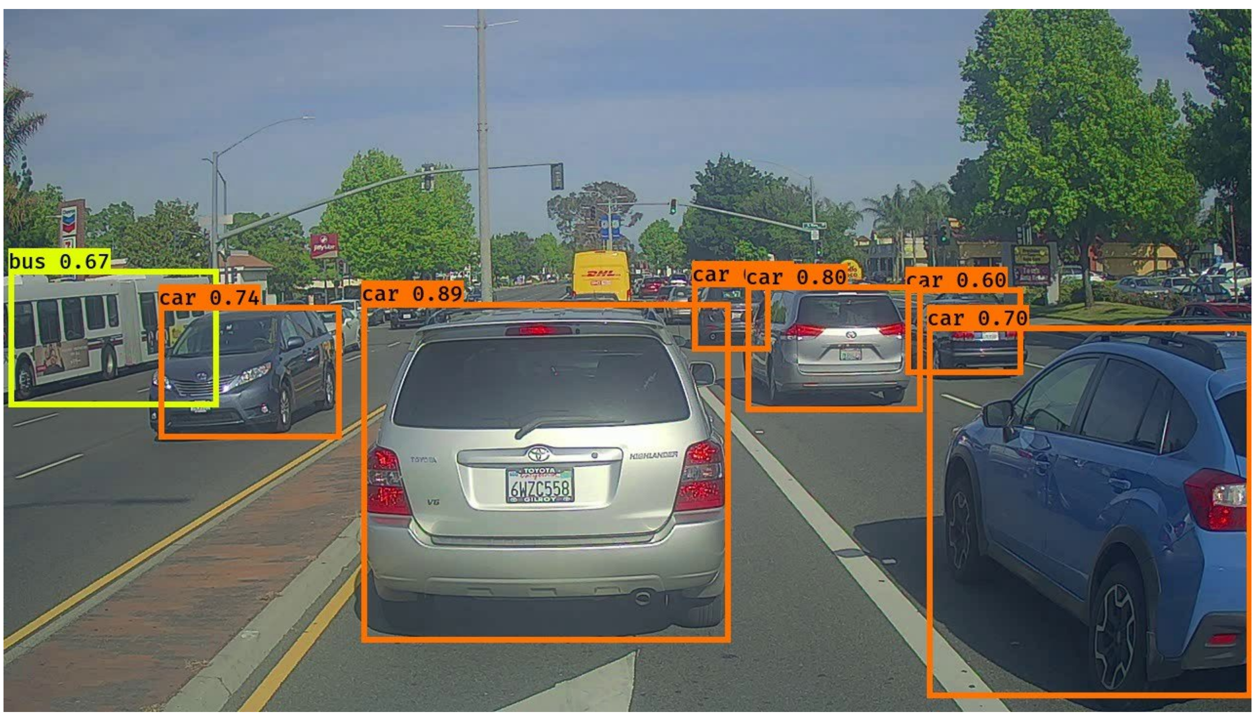


Figure 15 – Vehicle Detection using In-Vehicle Camera Systems

Traveler Information

While MnDOT already operates and maintains an extensive traffic management and traveler information system. More detailed traveler information could be provided by leveraging CAV technologies without the need to deploy additional infrastructure. The existing 511/Next Generation 511 systems can provide a basis for these applications. 511 currently offers traffic, road closure, and construction information. By using existing mobile apps, web sites, and other interfaces, a consistent "look and feel" can be created, while minimizing the need to develop new systems and software.

7. **Alternate Routes Advisories:** Connected vehicle data from fleets of "probe" vehicles from vendors including Wejo, INRIX, or HERE can increase the ability for travelers to understand road conditions and learn about safe alternate routes, particularly important during construction or weather events. Connected vehicle data can provide travel speeds and information on road conditions. More complete alternate route data allows drivers to make better, earlier, more-informed decisions for their trips. This could be helpful for the Highway 52 region because travelers will likely use this route during nearby Highway 14 construction.

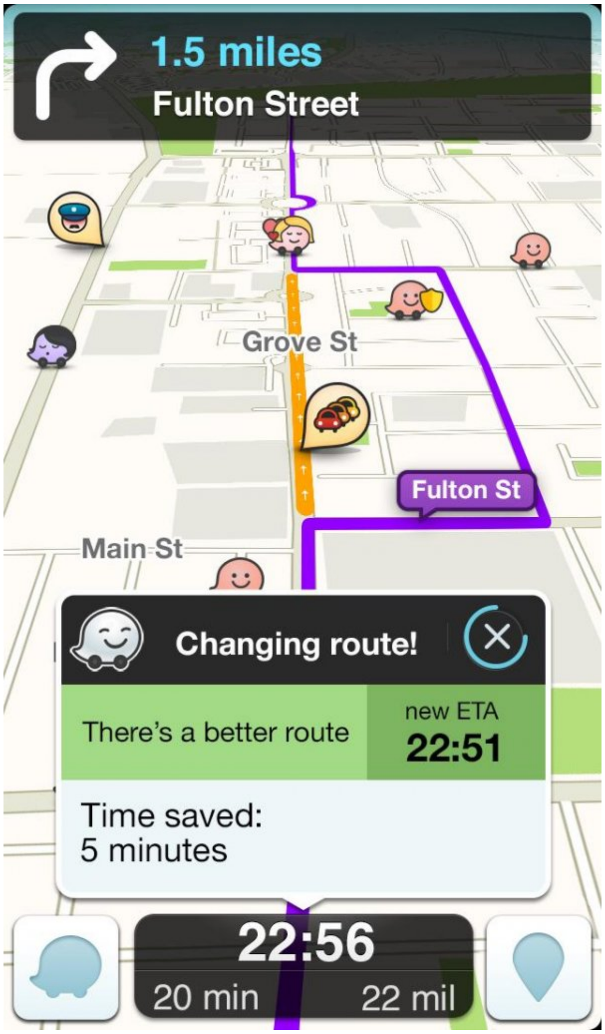


Figure 16 – Example Alternate Route Advisory from Waze

8. **Data Fusion and Integration:** The ability to process and visualize large amounts of data has become more feasible for agencies with connected vehicle data. Data fusion, data storage, and analytic tools help to identify the location, nature, and severity of previously difficult-to-identify safety concerns. For example, near-collisions are known safety challenges, but it is difficult to track where and when these occur. However, with connected vehicle acceleration and braking data, locations with high crash rates or congestion can be identified and addressed before crashes occur. Additional studies should be conducted to assess the amount of connected vehicle data available.

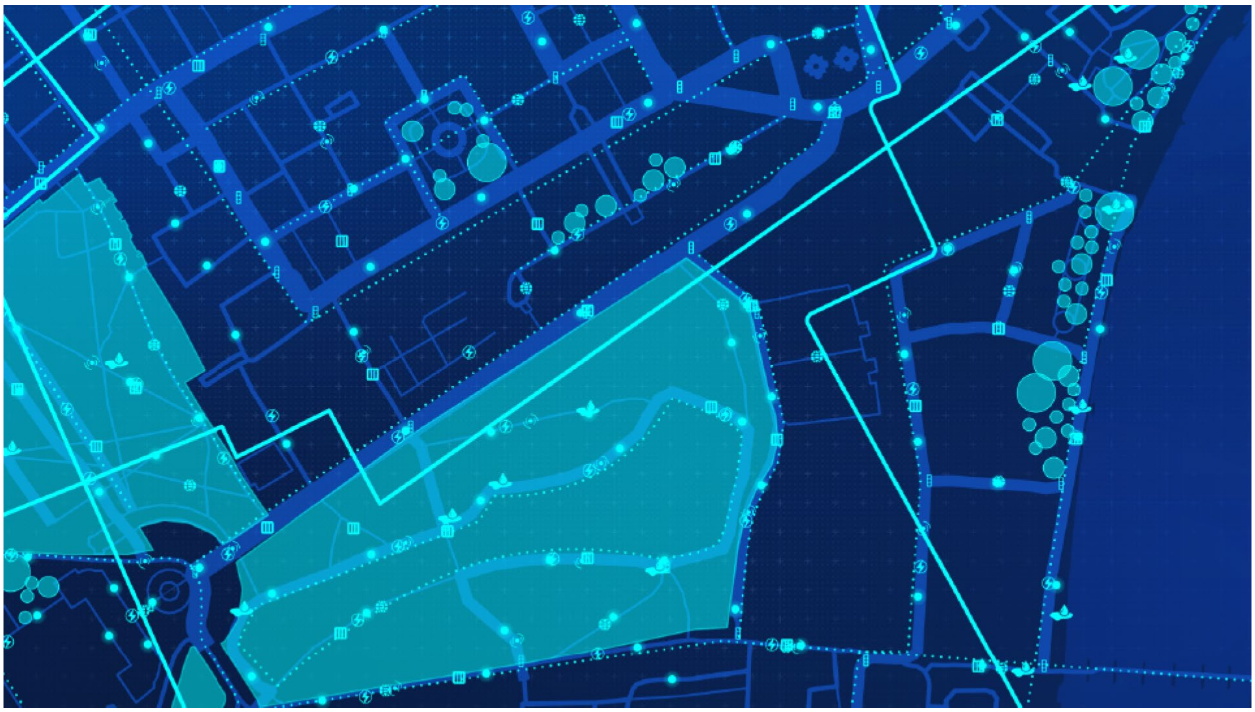


Figure 17 – Map of Near-Miss Locations based on Connected Vehicle Data

9. **Special Purpose Data Portals:** The Wyoming DOT has a web-based data portal for commercial vehicle dispatching which the state and industry highly value. This approach takes a traditional website and populates it with data collected from connected winter maintenance (plow) vehicles and roadside sensors to provide highly accurate, timely road condition data. MnDOT could use a similar portal for freight or transit vehicles as a dedicated web site or an extension to the existing 511 app and web site.

V. Next Steps

These CAV applications were selected because they have the potential to address safety challenges that meet needs identified by transportation stakeholders. MnDOT will use the findings from this study to guide future CAV research, planning, investments, and deployments along Highway 52 over the coming years.

MnDOT plans to move forward to implement these recommendations in four key ways: (1) industry engagement; (2) continued planning for CAV deployment; (3) CAV model deployments, and (4) soliciting partners through the CAV Challenge program. Lastly, this method for CAV corridor planning will be shared with other statewide communities to ensure this process can be used across the state.

1. Industry Engagement

Many CAV applications rely on vehicles supplying data to central databases or directly to other vehicles. Displaying data using existing infotainment systems in vehicles also requires the systems to retrieve and process data. Enabling these applications will require engagement with vehicle manufacturers and equipment suppliers on several fronts, including:

- Understanding the data types and market penetration available from third-party suppliers. This can include vehicle location, braking/acceleration data, and other vehicle attributes.
- Establishing a working relationship with system “gatekeepers” that make decisions on what information will be allowed into vehicle systems. For example, vehicle manufacturers will need to come to agreements with third party data vendors and DOTs regarding the type of information (real-time traffic or construction, for example) they will accept and provide through infotainment systems in vehicles.
- Defining and promoting the benefits to vehicle manufactures of including connected vehicle applications in their products.
- Assessing the manufacturer’s needs and concerns for displaying data to drivers. Accessing external data from multiple departments of transportation and integrating into vehicle displays may be technically challenging for manufacturers. Opportunities for standardization should be explored to minimize risk and maximize the ease of adoption.
- The Iowa DOT successfully engaged with manufacturers to standardize smart arrow board data formats. MnDOT may take a similar approach with other work zone data, stalled/stopped vehicle reporting, and road hazard warnings. Successful development and implementation of standard data formats relies on industry adoption.

2. Deployment Planning

CAV deployment should follow a clear framework established by a planning process. There are several key items that should be addressed in a deployment plan:

- Key stakeholder needs and challenges that will be addressed by deployments.
- Identification of and approaches to addressing equity issues in the Highway 52 corridor.
- Specific functional areas and segments of the corridor that will have a deployment focus.

- Standards and guides for the level of market penetration, coverage, resolution, and quality for various types of data to meet project objectives.
- Safeguards for data security and protection of private (personally identifiable) data.
- Roles and responsibilities for system managers, stewards, and users.
- Operations and maintenance roles and budgeting.
- Deployment timelines and system interdependency identification.

The planning documentation should be “living” documents that provide guidance but can be revised and updated as necessary. With the rapidly evolving technology landscape for CAV applications, continuous monitoring of the industry and updates to deployment plans will be an important risk management strategy. The planning document may be reviewed annually, or as technological and regulatory changes warrant.

3. CAV Model Deployments

Model deployments typically focus on projects that are intended to provide an on-going benefit and provide an example for similar deployments in the state. A greater emphasis is placed on sustainability in terms of operations and maintenance responsibilities and initial functionality.

The recommended CAV applications have several possibilities for model deployments as they **extend or enhance existing systems.** As a result, the benefits and operational requirements are better understood than with other projects.

Potential model deployment candidates include:

- FIRST stopped vehicle warning
- Smart work zone/smart arrow board deployment
- Alternate route advisories
- Special purpose data portals

4. CAV Challenge Projects & RFPs

MnDOT’s CAV Challenge offers a unique way to quickly deploy innovative solutions that originate in the industry. By allowing private partners to propose ideas, MnDOT can access the latest developments in CAV technology and gain insight early in the development process for upcoming solutions. The CAV Challenge is an open, rolling solicitation where anyone– industry, researchers, or community members – can propose an idea to advance transportation safety, equity, and sustainability via CAV technologies.

Several of the CAV solutions are areas in which the industry is actively developing products. Through continual industry engagement, suppliers of CAV solutions could be encouraged to offer proposals for CAV Challenge project. These include:

- Stalled vehicle detection and warnings
- Queue detection (using third party data) and warning
- Weather condition detection and warnings

The leading-edge nature of these projects makes them suitable candidates for the CAV Challenge partnership program. If MnDOT doesn't hear ideas on these opportunities through the Minnesota CAV Challenge, it will likely issue requests for proposals on the recommended applications.

5. Lessons Learned

Over the course of the project several lessons were learned regarding the CAV planning process:

- **Listen -** Everyone (DOT staff, local agencies, law enforcement, etc.) has a unique perspective on CAVs. Lots of time should be spent listening.
- **Embrace local expertise** - Stakeholders are great a conveying corridor issues, particularly local knowledge.
- **Continued CAV education is critical** - Stakeholder have difficulty making connections between transportation challenges and CAV/technology solutions. Continue to educate and inform people on CAV technology, benefits, and challenges.

This project took place during the COVID-19 pandemic, requiring all meetings to take place virtually. Specific lessons learned from this process include:

- **Use virtual engagement tools** such as Zoom, Mentimeter, and Miro to increase stakeholder engagement. Breakout rooms in particular were found to be useful to encourage stakeholders to provide their input during large workshops. Be sure to seek out ideas from virtual participate to keep them engaged throughout virtual meetings.
- **Multiple opportunities to participate** - Offer the same stakeholder workshop multiple times to ensure everyone can participate.
- **Individual interviews** - Follow-up individually/personally with stakeholders who are unable to attend a workshop to ensure their input is heard.
- **Scrap meetings minutes for more succinct fact sheets** - Traditional meeting minutes are useful but focused one-pagers serving as project updates are more effective.

6. Conclusion

The Highway 52 CAV study facilitated conversations with regional transportation stakeholders to understand how CAV applications can benefit travelers and communities between the Twin Cities and Rochester. As part of this process, MnDOT engaged a team of transportation professionals involved in traffic safety and regional planning to help CAV experts understand the challenges along Highway 52. Corridor transportation challenges were categorized into four groups: safety, mobility and access, transit and multimodal, and equity. The top five transportation issues were identified as:

1. Improving safety during weather events
2. Improving work zone safety
3. Mitigating St. Paul congestion

4. Providing more traveler information including alternate routes
5. Improving safety for first responders and maintenance on the shoulder issues.

The project team then worked with key MnDOT staff, national CAV leaders, and industry representatives to develop potential CAV applications for the Highway 52 Corridor. In addition to the expansion of existing MnDOT CAV efforts, the following CAV applications were recommended:

1. Real-time Information Sharing
2. Queue Warning System Enhancements
3. FIRST Patrol Hazard Warning System
4. Law Enforcement Warning System
5. Weather Detection and Warning System
6. Vehicle on Shoulder Detection and Warning System
7. Alternate Route Advisories
8. Data Fusion and Integration
9. Special Purpose Data Portals

MnDOT's CAV Office will continue to hear and consider new concepts and proposals that align with these recommendations through the CAV Challenge. MnDOT will also look at deploying additional CAV technologies along the corridor as part of future projects. A standalone RFP for CAV deployments along Highway 52 is also being considered.

As part of future CAV projects along Highway 52, MnDOT will continue to understand how the state can operate and maintain new technologies and validate what technologies can be safely used in Minnesota to advance safety, equity, accessibility, mobility, and sustainability. The CAV corridor planning framework piloted in this study will be used in other regions to understand which CAV technologies can help improve the lives of Minnesotans by advancing safety, reducing transportation barriers, and creating a more efficient transportation system to plan for tomorrow, today.

Appendix A: Project Roster

Table 1. Project Management Team

Name	Agency	Role
Kristin White	MnDOT CAV-X	Project Champion
Tara Olds	MnDOT CAV-X	Project Co-Champion
Cory Johnson	MnDOT CAV-X	MnDOT Project Manager
Marthand Nookala	SRF	SRF Project Manager
Jacob Folkeringa	SRF	SRF Deputy Project Manager

Table 2. Project Team

Name	Agency	Role
Cathy Huebsch	MnDOT CAV-X	CAV-X Project Coordination
Brian Kary	MnDOT RTMC	RTMC Director
Ray Starr	MnDOT Traffic Engineering	Assistant State Traffic Engineer
Steve Misgen	MnDOT Metro	Metro Traffic Engineer
Mike Schweyen	MnDOT D6	D6 Traffic Engineer
Philip Schaffner	MnDOT Planning	Planning
Heather Lukes	MnDOT D6	D6 Planning
Kurt Wayne	MnDOT D6	D6 Planning
Jon Solberg	MnDOT Metro	Director of Planning, Program Management & Transit
Ted Coulianos	MnDOT	Freight & Commercial Vehicle Operations
Praveena Pidaparthi	MnDOT	Director of Freight & Commercial Vehicle Operations
Jed Falgren	MnDOT TSMO	TSMO Engineer
Kevin Kosobud	MnDOT Construction	Project Development Manager
Jai Kalsy	MnDOT D6	D6 Construction
Steve Lund	MnDOT Maintenance	State Maintenance Engineer
Mark Schoenfelder	MnDOT D6	D6 Engineer
Ryan Wilson	MnDOT Metro	South Area Manager
Molly Kline	MnDOT Metro	South Area Engineer

Name	Agency	Role
Melissa Barnes	MnDOT Metro	North Area Manager
Tony Wotzka	MnDOT Metro	North Area Coordinator
Anne Meyer	MnDOT	Public Affairs
Chris Krueger	MNDOT Metro	Metro Communications
Mike Dougherty	MnDOT D6	D6 Communications

Table 3. Advisory Committee

Name	Agency	Role
Mike Hanson	DPS	DPS Director
Captain Jeff Schroepfer	DPS	D6 Captain
Jim McCarthy	FHWA	FHWA
Andrew Emanuele	FHWA	FHWA
Mark Krebsbach	Dakota County	Dakota County Engineer
Kaye Bieniek	Olmsted County	Olmsted County Engineer
Greg Isakson	Goodhue County	Goodhue County Engineer
Tim Leslie	Dakota County	Dakota County Sheriff
Kevin Torgerson	Olmsted County	Olmsted County Sheriff
Marty Kelly	Goodhue County	Goodhue County Sheriff
Josh Hanson	Goodhue County	Goodhue County Sheriff
Ben Griffith	ROCOG	MPO
Bryan Law	ROCOG	MPO
Patrick Seeb	DMC	Destination Medical Center
Christian Holter	Rochester City Lines	Transit/Shuttle industry

Appendix B: National CAV Activities

Table 4. Identified CAV Activities by State

	Automated Vehicle Systems or Infrastructure					Connected Vehicle Systems					Administrative/ Programmatic				
State	Autonomous Shuttle/Bus	Autonomous Delivery/Freight	Autonomous Passenger	Autonomous TMA	Pavement Markings	DSRC - Signals	DSRC - Other RSU	DSRC – V2V	Ped Detection	Intrusion Detection	Roadway/ Infrastructure	Fiber Deployment	CAV Program	Research Facility	Studies/Plans
Alabama						X				X		X			
Alaska															
Arizona		X	X										X		X
Arkansas		X													
California	X	X	X												
Colorado				X			X					X	X		X
Connecticut	X														
Delaware	X														
Florida	X		X			X	X	X	X				X	X	
Georgia					X	X	X							X	
Hawaii						X	X	X	X						
Idaho													X		
Illinois		X													X
Indiana		X												X	
Iowa			X												X
Kansas															
Kentucky															
Louisiana															X
Maine			X										X		X
Maryland															X

	Automated Vehicle Systems or Infrastructure					Connected Vehicle Systems					Administrative/ Programmatic				
State	**Autonomous Shuttle/Bus**	**Autonomous Delivery/Freight**	**Autonomous Passenger**	**Autonomous TMA**	**Pavement Markings**	**DSRC - Signals**	**DSRC - Other RSU**	**DSRC – V2V**	**Ped Detection**	**Intrusion Detection**	**Roadway/ Infrastructure**	**Fiber Deployment**	**CAV Program**	**Research Facility**	**Studies/Plans**
Massachusetts															X
Michigan	X					X	X				X			X	
Mississippi															
Missouri															
Montana															
Nebraska														X	
Nevada															
New Hampshire															
New Jersey	X														
New Mexico		X													
New York	X	X				X	X								
North Carolina	X	X													X
North Dakota				X											
Ohio	X	X				X	X					X			X
Oklahoma		X													
Oregon															
Pennsylvania			X											X	X
Rhode Island	X														
South Carolina			X												
South Dakota															
Tennessee						X			X						
Texas		X													X
Utah						X	X					X			

	Automated Vehicle Systems or Infrastructure					Connected Vehicle Systems					Administrative/ Programmatic				
State	**Autonomous Shuttle/Bus**	**Autonomous Delivery/Freight**	**Autonomous Passenger**	**Autonomous TMA**	**Pavement Markings**	**DSRC - Signals**	**DSRC - Other RSU**	**DSRC – V2V**	**Ped Detection**	**Intrusion Detection**	**Roadway/ Infrastructure**	**Fiber Deployment**	**CAV Program**	**Research Facility**	**Studies/Plans**
Vermont															X
Virginia	X	X	X			X	X			X			X	X	X
Washington			X										X		X
West Virginia															X
Wisconsin													X	X	
Wyoming							X	X							