DEPARTMENT OF TRANSPORTATION

Model Systems Engineering Document

ITS Application: Reduced Visibility Warning

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Contents

Acronyms

ARC-IT	• National Architecture Reference for Cooperative and Intelligent Transportation
ATMS	• Advanced Traffic Management Software
BSM	• Basic Safety Message
CARS	• Condition Acquisition Reporting System
CAV	• Connected and Automated Vehicle
DMS	• Dynamic Message Signs
EDCM	• Event Driven Configurable Messages
FAT	• Factory Acceptance Test
IRIS	• Intelligent Roadway Information System
ITS	• Intelligent Transportation System
LAN	• Local Area Network
MUTCD	• Manual on Uniform Traffic Control Devices (MUTCD)
MnDOT	• Minnesota Department of Transportation
NTCIP	• National Transportation Communications for ITS Protocol
NWS	• National Weather Service
RSU	• Roadside Unit
RSM	• Road Safety Messages
RTMC	• Regional Transportation Management Center
SEA	• Systems Engineering Analysis
TAMS	• Transportation Asset Management System
TTC	• Temporary Traffic Control
VPN	• Virtual Private Network
WAN	• Wide Area Network

Purpose and Description of Application

Document Purpose

This document is intended to support the Systems Engineering Analysis (SEA) activities for the Minnesota Department of Transportation (MnDOT) and other local transportation agencies within Minnesota as they consider, plan, develop, design, implement, and operate reduced visibility warning systems. The content of this document will be a systems engineering analysis resource to support project compliance as set forth in Federal Regulation 23 CFR Section 940 (Rule 940: Intelligent Transportation Systems (ITS) Architecture and Standards). This document can be used in conjunction with the MnDOT Statewide Regional ITS Architecture and related resources to complete an ITS Systems Engineering project-specific checklist as part of the initial analysis of applications considered for implementation. To access the available checklists for ITS-related deployments, visit the MnDOT Systems Engineering web page at: https://www.dot.state.mn.us/its/systemsengineering.html. In situations where projects are not consistent with this systems engineering document, the contents of this document may be used as a base to support the development of project specific systems engineering documents, including a concept of operations, functional requirements, and test plans specific to the project.

Description of Application –Reduced Visibility Warning

Transportation agencies sometimes deploy reduced visibility warning systems at roadway sections that are prone to recurring reduced visibility conditions, such as dense fog, and cause more than typical crashes to occur. These systems detect reduced visibility conditions and activate advanced warning signs to alert drivers of the reduced visibility ahead. As operations of Connected and Automated Vehicles (CAVs) expand, several data exchanges between CAV management systems and CAVs are anticipated, some of which will utilize reduced visibility warning systems and related road weather data. Functions of reduced visibility warning systems may be completed by field devices as a stand-alone system or in conjunction with a supporting operator using Advanced Traffic Management Software (ATMS), if a communications connection to the ATMS is available.

Guidance Criteria for Deploying Reduced Visibility Warning

The following criteria provide guidance to help agencies make an initial decision about whether to deploy reduced visibility warning systems. Locations that meet these criteria may be suitable for deployment of reduced visibility warning. However, these criteria are provided for guidance only; reduced visibility warning is not required at all locations that meet these criteria.

1a. The location has been identified to have a high probability for crashes, using one or more agency accepted crash analyses (e.g. on a list of areas most prone to crashes, higher than typical frequency of crashes);

Or

1b. The critical crash rate for the segment is higher than expected for similar segments within the state, based upon the judgment of local engineers;

Or

1c. Crashes or Crash Rate within the segment are higher than expected over a 5-year period for a region, with agency-accepted analyses and thresholds.

And

2. Other strategies to reduce crashes related to reduced visibility, such as lower or non-technology solutions have been tried at this location (e.g. geometric improvement, operational improvements, static warning signs, manually activated signs, etc.) and have not had a positive impact on reducing crashes.

And

3. The location is prone to reduced visibility conditions (e.g. dense fog, nearby smoke or steam generating facility) at locations that are unexpected to drivers. For example, locations that are prone to dense fog or in locations where the roadway geometry is such that conditions ahead (such as dense fog or slowing traffic queues in advance of the dense fog) are not easily seen by drivers approaching the reduced visibility area.

Reduced Visibility Warning Environment/Components

Table 1 presents core components and optional components that would comprise the environment for a reduced visibility warning system, along with corresponding functions of each.

Table 1: Reduced Visibility Warning Environment/Components with Corresponding Function

Environment/Component	Function
Core Components of Reduced Visibility Warning System	
1. Visibility Sensors	Sensing equipment located near the roadway to detect reduced visibility conditions at an elevation where the driver's ability to view approaching conditions is impacted. Visibility sensors may consist of devices that detect atmospheric conditions that result in reduced visibility.
2. Processing and/or Communications	The processing and communications component could be a stand-alone unit or could be incorporated into the warning signs or visibility sensors, depending upon local design. For stand-alone reduced visibility warning systems, this is the connection between the visibility sensors and the warning sign(s). In situations where there is connectivity to ATMS, this component processes data from the visibility sensors and sends it to the ATMS. In situations where operators use the ATMS to enter information about reduced visibility conditions, this component would receive this information from the ATMS to activate the warning signs. In situations where a Road Weather Information System (RWIS) station is nearby, this component could also communicate data from visibility sensors to the RWIS station.
3. Warning Signs	Visual indicators to travelers that reduced visibility conditions ahead are likely. Warning signs could include static signs with flashing beacons, blank-out signs that display one message when activated or no message when not activated, or

Environment/Component	Function
	dynamic message signs. Warning signs will activate when reduced visibility conditions are detected, or as the signs are manually operated. The number of signs, sign locations, and sign types may vary for each system deployment, based on local conditions. (See Table 2 for examples of warning signs.)
Optional Components of Reduced Visibility Warning System	
4. Video for Monitoring	Cameras placed to enable operators to view visibility conditions and/or operability of warning signs. Cameras may convey still images or live video. *(See MnDOT Model Systems Engineering Document, ITS Application: Video).*
5. Video for Analytics	Cameras equipped with analytics to detect reduced visibility conditions and send alerts to operators through the ATMS.
6. Traffic Detection	Field detection sensors or third-party sources that collect traffic data such as speed, volume, lane occupancy, and other related data. (See *MnDOT Model Systems Engineering Document, ITS Application: Traffic Detection*). Speed data from traffic detection in advance of warning signs could be used to assess driver behavior in reaction to sign activations. Traffic detection data could also be used to detect vehicle speeds approaching areas of reduced visibility and trigger activation of warning signs that alert drivers of slow traffic ahead or advisory speed limits.
7. RWIS Stations	Environmental sensor stations in the field that are used to collect and distribute road weather data such as atmospheric parameters, pavement conditions, and visibility. Nearby RWIS stations could receive data from visibility sensors, or in-place RWIS sensors could be used for reduced visibility warning system detection.
8. Communications to ATMS	The communications infrastructure to allow data communications between the local reduced visibility warning system and the ATMS. Note that communications to the ATMS is optional and that there are situations where reduced visibility warning systems exist as stand-alone systems.
9. ATMS	The software that is used by traffic operations personnel to monitor traffic and control infrastructure systems. For example, the ATMS may enable viewing of video at the site of the reduced visibility warning system, generate notifications to be sent when warning signs are activated or de-activated, or allow remote control of the reduced visibility warning systems.
10. Traveler Information Systems	Agency traveler information systems that may access information about reduced visibility conditions from the ATMS, in order to provide road condition information to the traveling public, or to external entities such as the media or third-party information providers.

Environment/Component	Function
11. Electrical Current Sensing Device	A device that detects the flow of electrical current to the reduced visibility system's field devices (e.g. visibility sensors, warning signs) to assist with monitoring operability of the warning system. Electrical current sensing devices may connect to the ATMS to assess system activations from a remote location.
12. Roadside Unit (RSU)	A field device used to communicate with CAVs. RSUs may be used to broadcast messages to CAVs about reduced visibility condition and/or may receive messages broadcast from vehicles (e.g. Basic Safety Message (BSM)) to receive data from vehicles that may describe reduced visibility conditions. RSUs may assemble needed security credentials for messages, if required.
13. CAV Infrastructure Systems	The systems deployed by the DOTs to communicate with on-board units within CAVs. Reduced visibility warning systems (or the ATMS) may communicate reduced visibility warning information to CAV Infrastructure Systems to pass on to CAVs. Similarly, CAVs may detect conditions such as reduced visibility and communicate it to the CAV Infrastructure Systems. CAV Infrastructure Systems may include communications to onboard units in vehicles using RSUs, internet cloud connectivity, or network cellular connection.
14. CAVs	The vehicles and on-board applications that communicate with CAV Infrastructure Systems and other CAVs. As noted in this document, situations may exist where CAVs may receive reduced visibility warning notices and alert drivers. CAVs may also be a source of information for reduced visibility conditions.

A reduced visibility warning system could be either a stand-alone system that operates locally in in the field (with no communication connection to the ATMS) or could be connected to the ATMS for additional monitoring and control capabilities. The provision of a communications connection from a reduced visibility warning system to the ATMS is a local decision to be addressed during the design process. This decision is expected to be based on a variety of factors that determine whether local conditions warrant remote automated system notifications or operator influence on the system. These factors include the location of the roadway within the larger transportation network, potential impact of the recurring reduced visibility conditions, number of travelers impacted, and availability and cost to provide communications to the ATMS.

Figure 1 illustrates the connections between components and related systems/users of a stand-alone reduced visibility warning system. Figure 2 illustrates a reduced visibility warning system that is connected to the ATMS.

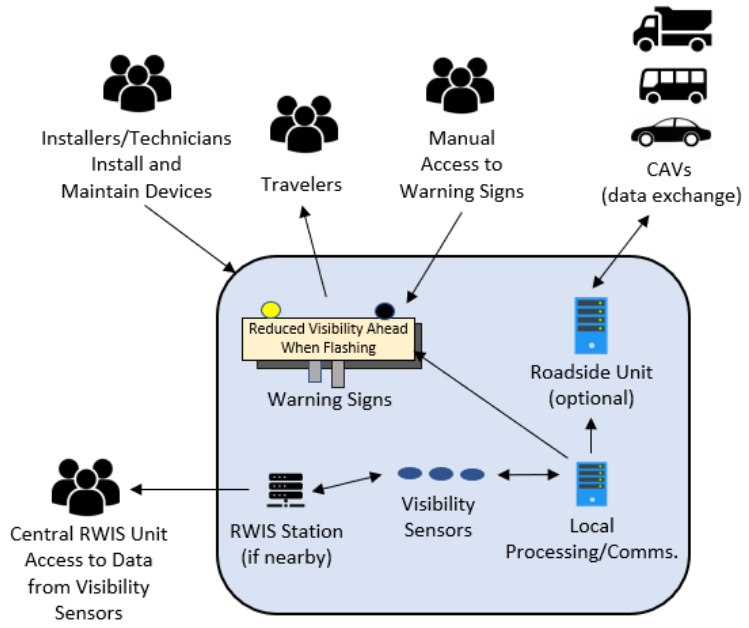


Figure 1: Illustration of Stand-Alone Reduced Visibility Warning System - Components and Related Systems/Users

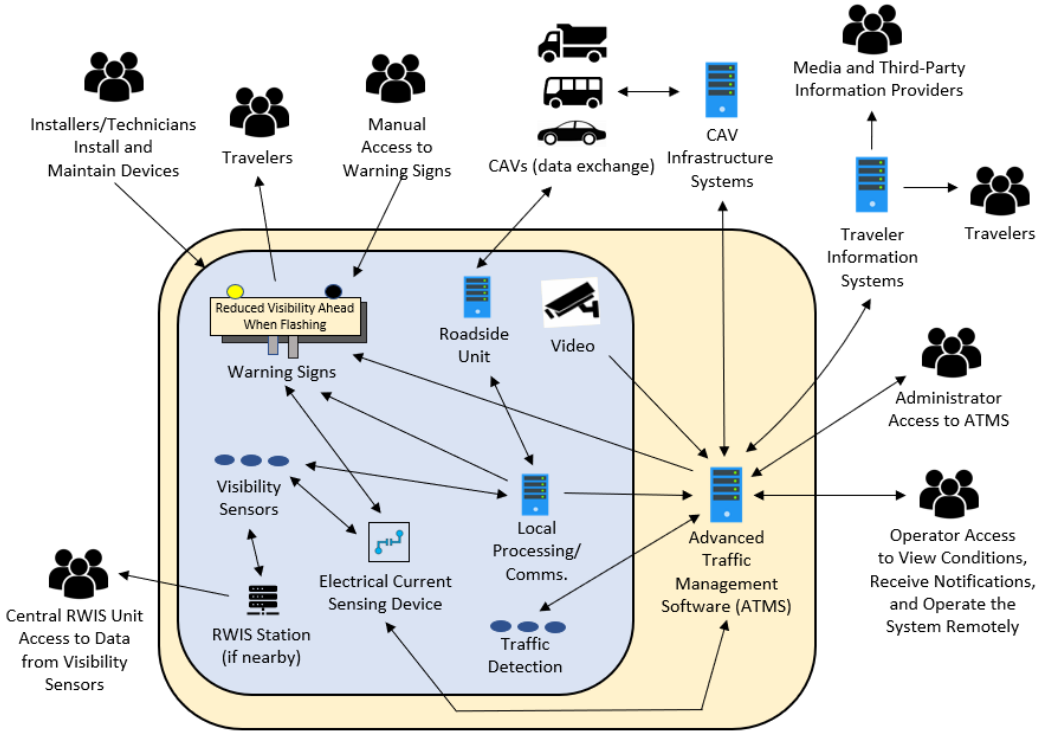


Figure 2: Illustration of Reduced Visibility Warning System Connected to ATMS - Components and Related Systems/Users

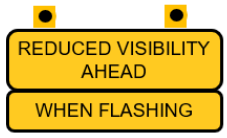
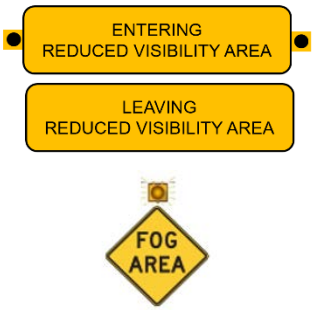
Examples of Warning Signs for Reduced Visibility Warning

As noted in Table 1, the number of signs, sign locations, and sign types could vary for each reduced visibility warning system deployment. The system could include one sign in each direction approaching the reduced visibility condition or multiple signs, each with their own messages, sensor placements, and

activation thresholds. While local reduced visibility warning systems typically consist of static signs with flashing beacons located in advance of the recurring reduced visibility condition, some reduced visibility warning systems may include other types of warning signs.

Table 2 provides examples of warning signs that may be included in reduced visibility warning system deployments.

Table 2: Examples of Warning Signs for Reduced Visibility Warning

Warning Sign Type	*Description*	*Example Graphics*[1]
Static Signs with Flashing Beacons	Static signs with attached beacons that begin to flash when visibility sensors indciate that visibility at a typical driver viewing elevation has dropped below a pre-determined threshold. The beacons stop flashing when the visibilty level returns to higher than the pre-determined threshold.	
Dynamic Message Signs (DMS)	DMS that display advisory messages based on current conditions. Pre-determined messages are posted automatically to "blank-out" signs located upstream of the reduced visibility area, based on pre-determined thresholds, or messages could be posted to DMS using the ATMS. Messages may or may not include advisory speeds. (See *MnDOT Model Systems Engineering Document, ITS Application: Dynamic Message Signs*.)	
Signs for Entering or Leaving a Reduced Visibility Area	Signs that advise drivers at the start and end of areas with recurring reduced visibility conditions (such as fog) that could affect driving conditions. Static signs for advanced warning may include flashing beacons that activate when reduced visibility conditions are present.	

[1] *The example graphics shown in this table are for illustrative purposes only, to help demonstrate the system concept described in this document. Sign types and messages will be determined during design of the reduced visibility warning system.*

Role of Asset Management Systems

Components of reduced visibility warning systems and the data produced by these systems could be utilized with asset management systems, such as MnDOT's Transportation Asset Management System (TAMS). For example, components (i.e. field devices and related systems) may be entered into an asset management system to track installation dates, maintenance schedules, repairs conducted, and other information to assist agencies in managing assets. In some cases, data from reduced visibility warning field devices (e.g. data from visibility sensors or traffic detection) may be communicated to asset management systems for long-term storage and access by administrators, technicians, or other stakeholders. Data communications to asset management systems are typically managed through optional components of a

reduced visibility warning system (e.g. via the ATMS or RWIS), and as such are secondary to local reduced visibility warning systems. Any specific functions of asset management systems related to reduced visibility warning will be addressed during final design of the reduced visibility warning system, as applicable.

Examples of Communications Technologies Supporting Reduced Visibility Warning

The reduced visibility warning application relies upon a number of communications technologies (detailed in a separate document - *Model System Engineering Document, ITS Application: Communications*) to transfer the reduced visibility warning information from field devices to eventual end users. The following table summarizes examples of communications technologies used today.

Table 3: Example of Current Communications Supporting Reduced Visibility Warning

Reduced Visibility Warning Application Communications	Communications Technologies Supporting Reduced Visibility Warning Applications
Visibility sensors to warning signs	• **Short-range wireline or wireless communications** – Ethernet or serial connections using fiber or copper mediums or WiFi, microwave, or FM radio, depending on local conditions, to support communications over short distances between the visibility sensors and warning signs.
Reduced visibility warning field systems to ATMS	• **Long-range communications** – Ethernet connections using fiber or copper mediums to communicate visibility information from reduced visibility warning field systems to the ATMS. • **DOT operated Local Area Network (LAN) or Wide Area Network (WAN)** – Private communications network that allows a connection between reduced visibility warning field systems and the ATMS with standard security concerns. • **Commercial wireless communications** – Services provided by third party providers over commercial networks, such as cellular, allow wireless communications of visibility information from reduced visibility warning field systems to the ATMS. • **Virtual Private Network (VPN) over public internet** – Secure and encrypted communications over less secure networks and the public internet allow communication of visibility data from reduced visibility warning field systems to the ATMS in locations where agency owned communications are not practical.
ATMS to CAVs (reduced visibility warnings)	• **Public internet** – Use of the public internet allows information (e.g. reduced visibility warning information) to be shared with CAVs. • **Commercial wireless communications** – Services provided by third party providers over commercial networks, such as cellular, allow wireless communications of reduced visibility warning information from the ATMS to CAVs.

Stakeholders and Needs

Stakeholders

Table 4 identifies the stakeholder groups that interface with one or more aspects of reduced visibility warning system deployment and operations.

Table 4: Reduced Visibility Warning Stakeholders/Users

Stakeholder	Description
Travelers	Vehicle drivers operating traditional vehicles and CAVs.
Operators	Operators responsible for performing freeway or arterial operations and entry of road conditions and alerts. This includes field staff who may interact with the reduced visibility warning system to manually activate or de-activate the system in the field. Where a communications connection is warranted and available, operators may enter reduced visibility conditions (not detected by field devices) or may view reduced visibility conditions that are detected by field devices and communicated to the ATMS.
Administrators	A combination of operators and technical staff responsible for configuring, updating, troubleshooting, and verifying reduced visibility warning system field equipment or the ATMS capable of supporting reduced visibility warnings.
Technicians and Installers	Technical staff responsible for installing, maintaining, and troubleshooting field equipment that detects reduced visibility conditions, processes and communicates the reduced visibility notices, and the warning signs that display related messages to travelers.
Central RWIS Unit	Staff responsible for management of statewide road weather data collected by RWIS field sites and other weather information sources. The Central RWIS Unit gathers and distributes this data, including atmospheric and visibility conditions, for statewide road weather management purposes.
CAV Infrastructure Systems and CAVs	External systems that include both CAV infrastructure systems (systems operated by MnDOT) and CAVs (vehicles and on-board units in the vehicles) that support connected and automated vehicle operations. CAVs may receive reduced visibility notices and alert drivers. CAVs may also be a source for reduced visibility conditions detected by sensors on vehicles.

Stakeholder Needs

Table 5 identifies a series of problems or challenges and the related needs for each stakeholder identified above. Note that some needs are listed as optional needs (e.g. “may need…” or “when a communications connection to the ATMS is present…”) depending on various situations, such as whether the local reduced visibility warning system has a communications connection to the ATMS or whether the reduced visibility warning system is connected to a nearby RWIS station.

Table 5: Challenges/Needs

Problem/Challenge	Needs (As a Result of the Problem/Challenge)
Travelers Needs	
- Travelers en-route to their destination are unaware that they are approaching a reduced visibility condition.	***Need 1: Real-time, En-route, Local Reduced Visibility Notification*** Travelers need to view information in advance of locations where reduced visibility is occurring, with enough time to adjust their speed accordingly prior to reaching the reduced visibility condition.
- Without advanced notice, travelers may not be prepared to encounter reduced visibility conditions along their planned route.	***Need 2: Advanced Reduced Visibility Information*** Travelers need a mechanism for viewing locations where reduced visibility conditions are occurring, in advance of their trip.
Operators Needs	
- Reduced visibility can occur at unexpected locations and can be encountered by drivers suddenly due to changes in roadway elevations or as atmospheric conditions change.	***Need 3: Automated Activation of Local Reduced Visibility Warning Displays*** In locations prone to recurring reduced visibility conditions, operators need the presence of reduced visibility conditions at typical driver viewing elevation to be detected and local warning signs to be activated or de-activated, without requiring or waiting for operator involvement.
- Field equipment may not always detect reduced visibility conditions, and operators can benefit from understanding when these conditions are occurring, in order to monitor traffic conditions at impacted areas.	***Need 4: Operator Interaction with Reduced Visibility Warning Systems*** When local conditions warrant operator influence, operators need a mechanism to interact with reduced visibility warning systems to view and monitor visibility conditions at typical driver viewing elevations, view warning displays from a remote location, activate or de-activate the warning sign displays as needed, or to receive notifications of system activations and de-activations.
Administrators Needs	
- It is important to identify issues with devices as early as possible, to implement repairs or replacements and minimize disruption in reduced visibility warning system operations.	***Need 5: Reduced Visibility Warning System Assessment*** Administrators need the ability to query and understand the operational status of reduced visibility warning system field devices. Depending on whether or not the reduced visibility warning system field equipment has a communications connection to the ATMS, this assessment may occur in the field or remotely.
- The locations of recurring reduced visibility conditions and the locations of reduced visibility warning field equipment are important for maintaining an understanding of conditions and assets in the field.	***Need 6: Local Reduced Visibility Warning System Configuration*** When a communications connection to the ATMS is present, administrators need to be able to configure the local reduced visibility warning systems by establishing the locations of the impacted road sections and the reduced visibility warning system devices (e.g. detection, signage) in the ATMS.

Problem/Challenge	Needs (As a Result of the Problem/Challenge)
- It is important to understand whether drivers reduce their speeds in response to reduced visibility warning displays, to understand the effectiveness of reduced visibility warning systems.	***Need 7: Traffic Data to Assess Driver Response to Reduced Visibility Warning Displays*** When a communications connection to the ATMS is present, administrators need speed data from traffic detection, to assess vehicle speeds approaching activated reduced visibility warning signs, in order to determine whether the displays lead to drivers to reduce their speed in reaction to the activated warning signs.
- Administrators could benefit from historical data, to understand the timing and extent of recurring reduced visibility and overall system operations.	***Need 8: Access to Historical Data from Reduced Visibility Warning Systems*** When a communications connection to the ATMS is present, operators need a mechanism to access historical data from reduced visibility warning systems, such as reports of system activations and data from visibility sensors, to help them understand the frequency of activations and impacts to the road segment when recurring reduced visibility conditions occur.
Technicians and Installers Needs	
- Proper use of field equipment to detect and disseminate reduced visibility warnings require communications, power, and installation at the deployment sites.	***Need 9: Field Device Supporting infrastructure*** Technicians and installers need power, communications, and support structures to be available at locations where field equipment for reduced visibility warning systems is deployed. Note: power may be locally generated (e.g. solar, wind); local communications may not be able to provide a connection to the ATMS.
- Equipment deployed in the field must not harm technicians, installers, or anyone in vicinity of the equipment.	***Need 10: Safety Standards*** Technicians and installers need the field devices to adhere to appropriate safety standards, specifications, and protocols.
- Devices that are not compatible with existing equipment or systems may not be able to be installed or could require significant staff effort during installation.	***Need 11: Equipment Consistency*** Technicians and installers need consistency and compatibility in the reduced visibility warning equipment to achieve efficiencies in procurement, maintenance, and training.
Central RWIS Unit Needs	
- The Central RWIS Unit seeks road weather data information from several sources, in order to understand current road weather conditions and historical trends.	***Need 12: Road Condition Data from Reduced Visibility Warning Systems*** When a reduced visibility warning system is connected to an RWIS station, the Central RWIS Unit needs data from the visibility sensors, to increase their understanding of road weather conditions.
CAV Infrastructure Systems and CAVs Needs	
- CAVs will benefit from data from nearby vehicles.	***Need 13: Vehicle to Vehicle Data Exchange***

Problem/Challenge	Needs (As a Result of the Problem/Challenge)
	CAVs need real-time, low latency data from other CAVs to exchange data that could describe locations where reduced visibility is detected.
- Vehicle data (e.g. visibility sensors) can offer insight into reduced visibility conditions.	***Need 14: Vehicle to Infrastructure Data Exchange*** DOTs need to benefit from the data broadcast by public and private CAVs to assist in detection of reduced visibility conditions whenever possible.
- CAVs will benefit from reduced visibility alerts and notices provided by DOT-owned infrastructure, as additional automated driving systems and capabilities are integrated into vehicles.	***Need 15: Vehicle Use of Infrastructure-generated Reduced Visibility Warnings*** CAVs need to receive infrastructure-generated reduced visibility warnings as they approach these conditions.

Operational Concepts

The operational concepts below are presented for reduced visibility warning systems that may or may not have a communications connection to the ATMS. The provision of a communications connection to the ATMS is expected to be a local design decision based on factors that would determine whether local conditions warrant operator influence on the reduced visibility warning system. These factors include the location of the roadway within the larger transportation network, potential impact to travelers, and availability and cost to provide communications.

Travelers' Perspective

Table 6 describes the reduced visibility warning operational concepts from the travelers' perspective, and relates each concept to a need, as defined in the previous section.

Table 6: Reduced Visibility Warning Operational Concepts – Travelers' Perspective

Need (Travelers' Perspective)	Operational Concept
Travelers' Perspective related to ***Need 1: Real-Time, En-route, Local Reduced Visibility Notification***	1.1 Travelers driving on selected routes that are prone to recurring reduced visibility conditions may observe static signs and/or a DMS with a message such as "Reduced Visibility When Flashing" or "Fog Ahead." 1.2 Travelers will view warning signs in advance of the reduced visibility condition, with enough time to reduce their speed prior to reaching the reduced visibility condition. 1.3 Static signs will have attached beacons that flash when the system is activated and do not flash when the system is not activated. 1.4 At times when reduced visibility at the typical driver viewing elevation is detected, the flashing beacons will be activated or the DMS message will be displayed, and travelers will be alerted to the reduced visibility condition downstream of their position. 1.5 Upon seeing the activated warning sign, it is anticipated that travelers will slow down and proceed with caution as they approach the section of reduced visibility.
Travelers' Perspective related to ***Need 2: Advanced Reduced Visibility Information***	2.1 Prior to departing on their trips, travelers may access traveler information systems, such as websites or mobile apps operated by MnDOT or other third-party providers, to view current alerts and notices. While they may not be seeking information about reduced visibility conditions, travelers may see locations where these conditions are occurring. 2.2 Travelers accessing local news media broadcasts may view or hear notices of reduced visibility conditions. 2.3 Travelers will likely receive more consistent and current notices of reduced visibility impacts if the reduced visibility warning system has a communications connection to the ATMS to automate reporting based on real-time conditions.

Operators' Perspective

Table 7 describes the reduced visibility warning operational concepts from the operators' perspective, including local MnDOT field staff, in situations where a local reduced visibility warning system is manually activated in the field and/or is connected to the ATMS for remote viewing of the site or automated reduced visibility warning system notifications. Each concept is related to a need, as defined in the previous section.

Table 7: Reduced Visibility Warning Operational Concepts – Operators' Perspective

Need (Operators' Perspective)	Operational Concept
Operators' perspectives related to: ***Need 3: Automated Activation of Local Reduced Visibility Warning Displays***	3.1 In locations prone to recurring reduced visibility conditions, there may be local reduced visibility warning systems installed to automatically detect reduced visibility conditions at typical driver viewing elevations. 3.2 The detection of reduced visibility conditions will be an automatic function and not require consistent operator monitoring or input. 3.3 The activation of local displays for the travelers upstream of the location (e.g. static signs with flashing beacons or dynamic signs) will not require operator input. 3.4 As visibility conditions return to a normal level, the activation displays will turn off automatically, without operator input. 3.5 Visibility sensors for reduced visibility warning systems may include visibility sensors deployed as part of an existing nearby RWIS station.
Operators' perspectives related to ***Need 4: Operator Interaction with Reduced Visibility Warning Systems***	4.1 When a communications connection to the ATMS is present, notices of local reduced visibility warning system activations and de-activations will be sent to the ATMS, allowing operators to be aware of the conditions and take action as appropriate. 4.2 When a communications connection to the ATMS is present, operators may receive automated notifications from the ATMS (via email, text message, or other mechanisms) when the reduced visibility warning system has been activated and de-activated. 4.3 Operators with access to the ATMS (e.g. Intelligent Roadway Information System (IRIS)) or a condition reporting system (e.g. Condition Acquisition Reporting System (CARS)) will have a mechanism to examine the reduced visibility warning systems configured in the system to view if reduced visibility conditions have been detected, when a communications connection to the reduced visibility warning system is present.

Need (Operators' Perspective)	Operational Concept
	4.4 When a communications connection to the ATMS is present, operators may use the ATMS and video to verify and monitor reduced visibility conditions or the current status of the local warning signs using video (cameras) mounted at a typical driver viewing elevation in the field, as available. 4.5 When on-site video (cameras) mounted at typical driver viewing elevations are equipped with analytics to detect reduced visibility conditions, the cameras may automatically send alerts to operators when the reduced visibility condition is detected and when the visibility returns to a normal level, if cameras are deployed. 4.6 When a communications connection to the ATMS is present, operators will use the ATMS to manually activate the reduced visibility warning system remotely, in the event that reduced visibility conditions are identified that local visibility sensors do not detect. The supporting systems will cause the local warning signs to activate as they would if the field devices had detected the occurrence of reduced visibility conditions. 4.7 When a communications connection to the ATMS is present, the reduced visibility warning system signs that operate as DMS will follow the National Transportation Communications for ITS Protocol (NTCIP) as appropriate, and therefore may operate timeout features as required by NTCIP. Outside of these situations where NTCIP timeouts occur, the operations of reduced visibility warning systems will not rely on automated timeout of messages. 4.8 Operators, i.e. field staff, will sometimes manually activate the reduced visibility warning sign locally in the field in the event reduced visibility conditions are identified that local visibility sensors do not detect. The supporting systems will cause the local warning signs to activate as they would if the visibility sensors had detected the reduced visibility condition. In these situations, the warning signs would need to be manually de-activated.

Administrators' Perspective

Table 8 describes the reduced visibility warning operational concepts from the administrators' perspective, and relates each concept to a need, as defined in the previous section.

Table 8: Reduced Visibility Warning Operational Concepts - Administrators' Perspective

Need (Administrators' Perspective)	Operational Concept
Administrators' perspective related to ***Need 5: Reduced Visibility Warning System Assessment***	5.1 Administrators will query and understand the operational status of reduced visibility warning system field devices, using tools such as electrical current sensing devices, as available. 5.2 If a communications connection to the ATMS is present, administrators may use the ATMS to connect to electrical current sensing devices remotely, to test the operability of reduced visibility warning system field devices. 5.3 If a communications connection to the ATMS is present, the ATMS may include functionality to identify faulty visibility sensors at the site of the reduced visibility warning system. When the ATMS generates message identifying the faulty sensor within the ATMS, administrators will initiate maintenance activities to repair or replace the faulty sensor.
Administrators' perspective related to ***Need 6: Local Reduced Visibility Warning System Configuration***	6.1 Administrators will configure the local reduced visibility warning systems once they are installed, if a communications connection to the ATMS is present. Configuration will link the local reduced visibility warning system to the ATMS to establish its location in order to process alerts received and assign them properly to roads in the ATMS. 6.2 In situations where a communications connection to the ATMS is present and either the reduced visibility warning system is modified or upgraded or the ATMS is upgraded, configuration may be required to maintain compatibility. 6.3 Administrators may perform portions of the reduced visibility warning system configuration in the field or remotely when a communications connection to the ATMS is present. 6.4 Administrators may connect the local reduced visibility warning system to related systems and devices such as a nearby RWIS station, traffic detection, or video field devices, when these components are present in the deployment.
Administrators' perspective related to ***Need 7: Traffic Data to Assess Driver Response to Reduced Visibility Warning Displays***	7.1 When traffic detection is available via a communications connection to the ATMS, administrators will access vehicle speed data from the ATMS to assess driver response to reduced visibility warning displays. 7.2 Administrators will utilize the vehicle speed data from locations approaching the warning signs, along with system activation timestamps, to determine whether vehicles adjust their speeds in response to warning sign activations, in order

Need (Administrators' Perspective)	Operational Concept
	to help determine effectiveness of the reduced visibility warning system.
Operators' perspectives related to ***Need 8: Access to Historical Data from Reduced Visibility Warning Systems***	8.1 Administrators will view historical data from visibility sensors and past instances of reduced visibility warning system activations and de-activations, to help debrief from incidents or to understand the frequency and timing of reduced visibility conditions.

Technicians/Installers' Perspective

Table 9 describes the reduced visibility warning operational concepts from the perspective of the technicians and installers of reduced visibility warning system field devices, and relates each concept to a need, as defined in the previous section.

Table 9: Reduced Visibility Warning Operational Concepts - Technicians/Installers' Perspective

Need (Technicians/Installers' Perspective)	Operational Concept
Technicians and Installers' Perspectives related to ***Need 9: Field Device Supporting Infrastructure***	9.1 Reduced visibility warning system field devices will be deployed at locations where that they are accessible to communications and power, which may be locally generated by solar or wind. 9.2 Reduced visibility warning system field devices will be deployed such that communications and power will not be negatively impacted by any anticipated adverse conditions such as flooding or snow build-up. 9.3 Reduced visibility warning system field devices will be deployed such that technicians and installers can access the devices to perform maintenance. 9.4 Reduced visibility warning system field devices will be mounted on appropriate support structures, as needed. 9.5 Visibility sensors will be calibrated to activate reduced visibility warning systems when visibility at typical driver viewing elevation is reduced to a level that poses a potential risk to drivers' ability to see conditions ahead of them.
Technicians and Installers' Perspectives related to ***Need 10: Safety Standards***	10.1 Technicians and installers need the reduced visibility warning system field devices to adhere to appropriate safety standards, specifications, and protocols. Equipment deployed in the field must not harm technicians, installers, or anyone in vicinity of the equipment. 10.2 Technicians and installers will be responsible for performing appropriate temporary traffic control (TTC) in compliance

Need (Technicians/Installers' Perspective)	Operational Concept
	with the Minnesota Manual on Uniform Traffic Control Devices (MUTCD) when installing or performing field work on reduced visibility warning systems.
Technicians and Installers' Perspectives related to ***Need 11: Equipment Consistency***	11.1 Legacy field devices for reduced visibility warning systems will continue to be used. 11.2 Procurement of new field devices for reduced visibility warning systems will be consistent with in-place devices to the extent possible, so that installers and technicians will be well-trained to install and repair new devices and can interchange parts. 11.3 New field devices for reduced visibility warning systems will be compatible with existing equipment and systems such as communications (fiber, etc.) and data management systems (e.g. IRIS), even if there are no current plans for a communications connection to the ATMS. 11.4 Consistency and compatibility needs will not prevent or inhibit the testing and eventual production use of new products or services. MnDOT will continue to benefit from advances in technology. 11.5 Selection of new equipment or software tools will be done in a way that ensures interoperability and consistency with latest standards and technologies.

Central RWIS Unit's Perspective

Table 10 describes the reduced visibility warning operational concepts from the perspective of the Central RWIS Unit. Each operational concept relates to a need, as defined in the previous section.

Table 10: Reduced Visibility Warning Operational Concepts – Central RWIS Unit's Perspective

Need (Central RWIS Unit's Perspective)	Operational Concept
Central RWIS Unit perspective related to ***Need 12: Road Weather Data from Reduced Visibility Warning Systems***	12.1 When an RWIS station is nearby the reduced visibility warning system site, the visibility sensors will communicate visibility data to the RWIS station in in real-time. 12.2 The Central RWIS Unit will access the reduced visibility warning system's visibility sensor data from the RWIS station, to supplement their overall road weather condition datasets. 12.3 In situations where a nearby RWIS station is not present, the Central RWIS Unit may access reduced visibility warning system data through the ATMS, if a communications connection to the ATMS is present. (Note that this situation

	and deployment interaction(s) would be covered under a separate systems engineering effort.)

CAV Infrastructure Systems and CAVs' Perspective

Table 11 describes the reduced visibility warning operational concepts from the perspective of CAV infrastructure systems and CAVs, and relates each concept to a need, as defined in the previous section.

Table 11: Reduced Visibility Warning Operational Concepts - CAV Infrastructure Systems and CAVs' Perspective

Need (CAV Infrastructure Systems and CAVs)	Operational Concept
CAV Infrastructure Systems and CAVs' Perspectives related to ***Need 13: Vehicle to Vehicle Data Exchange***	13.1 CAVs (including agency owned CAVs) are expected to broadcast the Basic Safety Message (BSM) continuously as they drive the Minnesota roadways. Vehicles may also be equipped with supplemental messages identified in BSM Part 2, these may include atmospheric visibility status outside of the vehicle. 13.2 Agency or privately owned CAVs may receive and process BSM Part 2 messages from other vehicles and use this information to support such applications as spot weather information warning.
CAV Infrastructure Systems and CAVs' Perspectives related to ***Need 14: Vehicle to Infrastructure Data Exchange***	14.1 As a mechanism to avoid continuously processing data from CAVs, MnDOT may employ the use of Event Driven Configurable Messages (EDCM) to request data at times when reduced visibility condition reports from vehicles would be most useful. 14.2 MnDOT may locate CAV infrastructure systems on the roadside to receive and process BSM messages from CAVs at key locations to gather information to help identify reduced visibility conditions, such as atmospheric visibility status outside of the vehicle. 14.3 MnDOT may generate Road Safety Messages (RSMs) and broadcast them to CAVs, reporting reduced visibility detections. 14.4 MnDOT will develop data retention policies for CAV related data and regularly review these as the CAV industry matures and the amount of data generated is better understood.
CAV Infrastructure Systems and CAVs' Perspectives related to ***Need 15: Vehicle Use of Infrastructure-generated Reduced Visibility Warnings***	15.1 MnDOT may connect roadside units (RSUs) to the reduced visibility warning system's field devices to broadcast messages describing detections of reduced visibility conditions to CAVs. 15.2 The RSU broadcast will require creation of standardized messages (typically the road safety message RSM) and supporting location references and security credentials. This message assembly may be performed by the reduced visibility warning system or the RSU, depending on local design. 15.3 MnDOT technicians may use hand-held or vehicle-based detection devices to receive messages broadcast by RSUs and determine if the RSUs are broadcasting reduced visibility condition messages appropriately.

	15.4 CAV infrastructure systems operated by MnDOT may receive reduced visibility condition reports from the ATMS (that originally were detected by reduced visibility warning systems), for communication to CAVs in or around the detected conditions.

Operational Scenarios/Roles and Responsibilities

Roles and Responsibilities

During planning and design of reduced visibility warning systems, it is important for deploying agencies to determine agency-level roles for ownership, operation, and maintenance of system components, which will be carried out after such systems are deployed. Specifically, during planning and design, agencies will determine:

- ***System Ownership:*** Define the agency that will own the reduced visibility warning system after it is deployed;
- ***System Operation:*** Designate the agency (or unit within the agency) that will be responsible for operating the system on an ongoing basis; and
- ***System Maintenance:*** Designate the agency (or unit within the agency) that will be responsible for performing routine and long-term maintenance of the system, including preventative maintenance, any needed repairs, and replacement of failing or obsolete field equipment.

The table below provides a high-level summary of the roles and responsibilities of the stakeholder groups for reduced visibility waring.

Table 12: Operation and Maintenance Roles and Responsibilities

User Group	Role/Responsibility
Travelers	• View messages on reduced visibility warning signs to make decisions about reducing vehicle speeds in anticipation of potentially reduced visibility conditions.
Operators	• Monitor the status of reduced visibility warning systems, through notifications from field staff, by viewing the status in the ATMS, or by receiving automated notifications from the ATMS (if connected to the ATMS). • View cameras mounted at typical driver viewing elevations to assess visibility conditions or warning sign display statuses. • Add or edit reduced visibility events in CARS (when they are informed of these conditions). • Activate and de-activate reduced visibility warning systems as needed, locally in the field and remotely via the ATMS (if connected to ATMS).
Administrators	• Work with system designers (e.g. traffic engineers, system vendors) to determine design details including warning sign types, sign placements, and messages that will be displayed to travelers. • Configure new reduced visibility warning systems to the ATMS (if connected to the ATMS). • Connect new reduced visibility warning system's visibility sensors to nearby RWIS stations, as needed. • Query the operational status of reduced visibility warning system equipment using the ATMS, to identify operational issues. • Receive automatic notifications about operational issues (if connected to the ATMS).

User Group	Role/Responsibility
	• Notify technicians and installers of operational issues, to initiate repairs as needed. • Access vehicle speed data and reduced visibility warning system activation history (if connected to the ATMS) to evaluate the effectiveness of reduced visibility warning systems.
Technicians/Installers	• Prepare needed designs for reduced visibility warning system supporting infrastructure and support structures. • Install reduced visibility warning systems (including needed traffic control). • Troubleshoot technical issues with the reduced visibility warning systems in the field and ATMS software (if connected to ATMS) and make repairs. • Perform routine maintenance in accordance with MnDOT ITS field device guidance. • Participate in configuring reduced visibility warning systems with the ATMS (if connected to ATMS). • Participate in connecting visibility sensors to nearby RWIS, as needed.
Central RWIS Unit	• Define formats needed for data to be collected by visibility sensors, if these devices will communicate visibility data to a nearby RWIS station. • Access visibility data (e.g. reduced visibility detections) generated by local reduced visibility warning systems and communicated to nearby RWIS stations (if RWIS stations are nearby the reduced visibility warning system site.)

Operational Scenarios

Scenarios are intended to describe examples of how users would interact with the reduced visibility warning systems in various situations and specifically to provide a temporal description of the sequence of events. The following scenarios briefly describe how users would be impacted and how they are expected to respond.

- Scenario A: Deploying a Reduced Visibility Warning System
- Scenario B: Automated Activation of a Reduced Visibility Warning System
- Scenario C: Reduced Visibility Warning System Monitoring and Control with ATMS
- Scenario D: Manual Activation of a Reduced Visibility Warning Sign at the Site
- Scenario E: Maintenance and Repair of Reduced Visibility Warning Systems
- Scenario F: Reduced Visibility Warning System Visibility Sensors Connected to RWIS Station
- Scenario G: CAV Use of Messages from RSUs at Reduced Visibility Warning Systems
- Scenario H: CAV Use of Messages from Wide Area Communications Reporting Reduced Visibility Warning Systems

Scenario A: Deploying a Reduced Visibility Warning System

MnDOT District 1 staff identify a stretch of rural roadway that is prone to recurring dense fog in a lower elevation area. The area approaching this recurring dense fog area tends to have good visibility until the roadway elevation drops; therefore, drivers often don't expect to experience the problematic reduced visibility condition. Due to a history of crashes as vehicles reduce their speeds when they enter the dense fog area, District staff determine that this area would benefit from a reduced visibility warning system and work with Regional Transportation Management Center (RTMC) staff to determine it will be connected to ATMS. There is an RWIS station nearby, but this area is not currently instrumented with visibility sensors. During deployment, installers work with administrators and operators to configure the reduced visibility warning system to the ATMS such that it can be recognized and controlled by operators using the ATMS. The system is also connected to the nearby RWIS station during installation, so the newly installed visibility sensors can communicate visibility data to RWIS. The reduced visibility warning system is not near a local power connection, so it is powered using a combination of battery and solar power.

Scenario B: Automated Activation of a Reduced Visibility Warning System

MnDOT identifies a section of roadway that is prone to recurring reduced visibility conditions and has decided to install a reduced visibility warning system. The recurring reduced visibility site is in a rural area and does not have long-distance communications infrastructure nearby. During the planning phase, MnDOT determines that it would be cost probative to install long-distance communications infrastructure to the site, and therefore the reduced visibility warning system will not communicate with the ATMS. The reduced visibility warning system is installed and operates only with local processing and communications at the site. When the area experiences dense fog, the visibility sensors detect the reduced visibility condition when the visibility reaches a pre-determined threshold. The visibility sensors then activate flashing beacons on static warning signs that indicate "Reduced Visibility Ahead When Flashing," located upstream of the reduced visibility section in both directions. An approaching motorist sees a warning sign and reduces the vehicle's speed prior to reaching the reduced visibility area. A few hours later the fog slowly dissipates. The warning sign's beacons continue to flash until the visibility sensors detect that the visibility has returned to a pre-determined normal level, at which time the beacons stop flashing.

Scenario C: Reduced Visibility Warning System Monitoring and Control with ATMS

A reduced visibility warning system deployed in central Minnesota is connected to the ATMS. As visibility at the site of the system drops below a pre-determined level, the visibility sensors detect the condition and trigger activation of the warning signs. Because the reduced visibility warning system is connected to the ATMS, operators view the system activation in the ATMS as it occurs. The ATMS feature to send automated notifications to selected individuals when the reduced visibility warning system has been activated or de-activated is enabled. This notification feature is configured in the ATMS to send text messages to district field staff and selected TMC operators, for all activations and de-activations. Therefore, at the time of activation, the ATMS sends an automated text message to the pre-identified individuals, alerting them that the reduced visibility warning system has been activated. Operators view cameras mounted at typical driver height relative to the roadway elevation, to assess the visibility condition and view the operational status of the warning sign. After visibility has returned to a pre-determined normal level, the field staff and operators receive a notification that the reduced visibility warning system has been de-activated. Operators view the cameras again and see that the beacons on the warning sign are still flashing, though it appears the visibility has returned to a clear condition. Field

staff visit the site to confirm clear visibility, then operators use the ATMS to de-activate the warning sign remotely.

Scenario D: Manual Activation of a Reduced Visibility Warning Sign at the Site

A member of MnDOT's district field staff monitors the weather forecast and sees a dense fog advisory in the area where recurring dense fog occurs, and a reduced visibility warning system is deployed. As he drives by the warning system and sees that the sign is not activated (beacons on the sign are not flashing) even though the area is experiencing dense fog with very low visibility. The reduced visibility warning system is not connected to the ATMS. The district field staff manually activates the beacons on the sign at the site of the warning system. After a few hours, the district field staff returns to the site, observes that the dense fog has diminished, and de-activates the sign. A few weeks later, the same district field staff drives by the warning sign during another dense fog event and sees that the reduced visibility warning system appears to be functioning properly, as it has activated automatically with low visibility.

Scenario E: Maintenance and Repair of Reduced Visibility Warning Systems

Over the course of a few weeks during the spring thaw, MnDOT district field staff periodically drive by a reduced visibility warning system and notice that it is consistently not activating when the area downstream is experiencing dense fog. The district field staff contact administrators and technicians to inform them that the reduced visibility warning system may not be operating properly. A technician travels to the site to trouble-shoot the issue. The technician determines that many of the visibility sensors are not working properly and replaces the faulty devices. Several miles away in the same district, a reduced visibility warning system is connected to the ATMS. At this site, one of the visibility sensors is not operating properly. The ATMS includes functionality (i.e. algorithms) to assess the operability of the visibility sensors on a regular basis to identify faulty sensors. When this visibility sensor at the site fails, the ATMS recognizes the failure and generates a message in the ATMS indicating the location of the faulty sensor. Upon viewing the message in the ATMS, operators contact administrators and technicians to inform them of the faulty sensor. Technicians replace the faulty sensor at the site of the reduced visibility warning system and operations are not impacted.

Scenario F: Reduced Visibility Warning System Visibility Sensors Connected to RWIS Station

A new reduced visibility warning system is being deployed at a rural section of roadway in southeast Minnesota. There is an RWIS station nearby, but the impacted area does not yet have visibility sensors in place. During design of the reduced visibility warning system, designers work with the Central RWIS Unit to ensure that the new visibility sensors will produce data in a format that can be received by the nearby RWIS station. During installation of the reduced visibility warning system, installers work with administrators to connect the new visibility sensors to the nearby RWIS station, and the visibility data from the newly installed visibility sensors is communicated to the nearby RWIS station through local communications at the site. The Central RWIS Unit uses in-place mechanisms to access the newly available visibility data from the RWIS station, and uses the data to inform road weather management practices on an ongoing basis.

Scenario G: CAV Use of Messages from RSUs at Reduced Visibility Warning Systems

MnDOT is operating a reduced visibility warning system with a roadside unit (RSU) that broadcasts messages describing reduced visibility detections at the site of the warning system. As visibility sensors detect visibility levels that drop below a pre-determined threshold, the RSU sends periodic messages indicating the reduced visibility detection. A nearby vehicle equipped with CAV technology is approaching

the reduced visibility area. The CAV receives and processes the reduced visibility messages from the RSU and determines whether to provide an alert within the vehicle. The CAV-equipped vehicle provides an alert to the driver inside the vehicle, at which time the driver decreases the vehicle's speed prior to reaching the reduced visibility area.

Scenario H: CAV Use of Messages from Wide Area Communications Reporting Reduced Visibility Warning Systems

MnDOT is operating multiple reduced visibility warning systems that are connected to the ATMS. Recognizing that an increasing percentage of production vehicles are equipped with on-board applications capable of receiving and processing the Road Safety Message (RSM) from network cellular communications, MnDOT broadcasts the location and current warning messages for areas where visibility sensors have determined reduced visibility conditions. The vehicles receive and process the broadcasts and determine when to warn or alert drivers based on the vehicles' positions.

System Requirements

System requirements are verifiable details that define what a system will do, but not how the system will do it. Requirements can describe the functional, performance, interface, communications, operational, and maintenance conditions of what a system will do.

Requirements for reduced visibility warning systems are listed in the table below, first by needs (column 1). These represent the needs of all the stakeholders described in the *Stakeholder Needs and Typical Conditions* section. Based on each need and on the operational concepts presented in the *Operational Concepts* section, one or more system requirements (column 2) are described. Requirements are all numbered to facilitate traceability back to the original needs and further traceability through design and validation.

The core system requirements in Table 13, below, are necessary for a reduced visibility warning system to perform local system activations and de-activations at the site of the deployment. In for various optional components and systems to integrate with the reduced visibility warning system, some requirements will have dependencies and are noted with a "dependency" designation following the requirement. As such, some requirements would need to be met by other systems (separate from the reduced visibility warning system) in order to perform the functions as described. In particular, deployments where the reduced visibility warning system is connected to an ATMS, requirements noted as "ATMS dependency" indicate requirements that the ATMS would need to meet in order for the system to be fully integrated with the reduced visibility warning system and perform the functions described.

Table 13: Reduced Visibility Warning System Requirements by Need

Need	System Requirement
Travelers	
1. Travelers need to view information in advance of locations where reduced visibility is occurring, with enough time to adjust their speed accordingly prior to reaching the reduced visibility condition.	1.1. In locations that experience recurring reduced visibility conditions, reduced visibility warning system deployments shall be considered, to advise travelers of locations where reduced visibility conditions may impact the driver's ability of to see the approaching roadway environment. 1.2. Reduced visibility warning systems shall activate visual alerts to drivers when reduced visibility conditions are detected downstream. 1.3. Warning signs for reduced visibility warning systems shall be located such that the sign displays are visible to approaching drivers. 1.4. Warning signs (types, placements, etc.) shall comply with the Minnesota MUTCD or be approved through the appropriate design exemption processes. 1.5. Warning signs shall be placed in advance of the reduced visibility condition, at a distance such that the signs provide adequate perception-response time for the driver. (See Minnesota MUTCD, Section 2C, to view Guidance for Advance Placement of Warning Signs.)

Need	System Requirement
2. Travelers need a mechanism for viewing locations where reduced visibility conditions are occurring, in advance of their trip.	2.1. When a communications connection to the ATMS is present, the reduced visibility warning system shall communicate activation and de-activation alerts to the ATMS, to enable widespread dissemination using established traveler information system applications.
Operators	
3. In locations prone to recurring reduced visibility conditions, operators need the presence of reduced visibility conditions at typical driver viewing elevation to be detected and local warning signs to be activated or de-activated, without requiring or waiting for operator involvement.	3.1. The detection of a reduced visibility condition by visibility sensors shall automatically activate the warning sign displays to alert travelers of reduced visibility condition ahead. 3.2. The reduced visibility warning activations shall turn off automatically as visibility sensors detect that the reduced visibility condition has diminished. 3.3. If in-place visibility sensors that are part of a nearby RWIS station are used for a reduced visibility warning system, these visibility sensors shall be capable of detecting reduced visibility such that the reduced visibility warning system can utilize the visibility sensor data to activate and de-activate the warning signs. 3.4. To the extent practical, reduced visibility warning system components (i.e. field devices) shall be compliant with National Transportation Communications for ITS Protocol (NTCIP) standards.
4. When local conditions warrant operator influence, operators need a mechanism to interact with reduced visibility warning systems to view and monitor visibility conditions at typical driver viewing elevations, view warning displays from a remote location, activate or de-activate the warning sign displays as needed, or to receive notifications of system activations and de-activations.	4.1. When a communications connection to the ATMS is present, the reduced visibility warning system shall communicate reduced visibility detections to the ATMS, allowing operators to be aware of the condition. (Note that the provision of a communications connection is a local design decision.) 4.2. When a communications connection to the ATMS is present, the ATMS shall be able to send notifications (e.g. email or text message) of system activations and de-activations. (ATMS dependency) 4.3. When a communications connection to the ATMS is present, the ATMS shall have a mechanism to view the reduced visibility warning systems configured in the ATMS, to view the activation statuses of the reduced visibility warning systems. (ATMS dependency) 4.4. When a communications connection to the ATMS is present, the ATMS shall have a mechanism to manually activate and de-activate the reduced visibility warning system remotely. (ATMS dependency)

Need	System Requirement
	4.5. Reduced visibility warning systems shall have a mechanism to manually activate and de-activate the warning signs locally at the device in the field. 4.6. When a communications connection to the ATMS is present and video is deployed at the reduced visibility warning system site, video field devices shall be positioned such that users can view the status of the warning signs and the visibility conditions at typical driver viewing elevations via the ATMS. 4.7. Cameras that are equipped with analytics to detect reduced visibility conditions, as deployed, may be capable of providing automatic alerts to operators when a reduced visibility condition has been detected and when the visibility has returned to a normal level. 4.8. Warning signs may be capable of receiving and processing NTCIP compliant communications describing messages to be displayed on the sign and display or remove the appropriate messages. In situations where flashing beacons or blank-out signs are deployed (option is either display of one message or no message) the communications would be to activate or de-activate. 4.9. Warning signs may be capable of sending an NTCIP compliant message to the ATMS confirming when messages are displayed or removed from the sign.
Administrators	
5. Administrators need the ability to query and understand the operational status of reduced visibility warning system field devices. Depending on whether or not the reduced visibility warning system field equipment has a communications connection to the ATMS, this assessment may occur in the field or remotely.	5.1. The reduced visibility warning system field devices shall be capable of being queried locally in the field, to understand their operational status. 5.2. When a communications connection to the ATMS is present and electrical current sensing devices are available, these devices shall be capable of being polled through the ATMS, to remotely query the operational status of field devices. 5.3. When a communications connection to the ATMS is present and electrical current sensing devices are available, the reduced visibility warning system shall provide automatic notifications to the ATMS, regarding operational issues with field devices. 5.4. If a communications connection to the ATMS is present, the ATMS may be capable of identifying faulty visibility sensors at the site of the reduced visibility warning system and generating a message in the ATMS that shows the location of the faulty sensor. (ATMS dependency)

Need	System Requirement
6. When a communications connection to the ATMS is present, administrators need to be able to configure the local reduced visibility warning systems by establishing the locations of the impacted road sections and the reduced visibility warning system devices (e.g. detection, signage) in the ATMS.	6.1. When a communications connection to the ATMS is present, the ATMS shall allow users to add and delete reduced visibility warning systems in the ATMS once they are installed. (ATMS dependency) 6.2. When a communications connection to the ATMS is present, the ATMS shall allow users to establish the reduced visibility warning system location in the ATMS, in order to process reduced visibility alerts received and assign them properly to roads. (ATMS dependency) 6.3. When a communications connection to the ATMS is present, the reduced visibility warning system shall support local on-site configuration of the field devices to the ATMS.
7. When a communications connection to the ATMS is present, administrators need speed data from traffic detection, to assess vehicle speeds approaching activated reduced visibility warning signs, in order to determine whether the displays lead to drivers to reduce their speed in reaction to the activated warning signs.	7.1. When a communications connection to the ATMS is present, the ATMS shall allow users to access speed data from traffic detection approaching reduced visibility warning signs (when traffic detection is present), with corresponding timestamps of system activations and de-activations. (ATMS dependency) 7.2. When a communications connection to the ATMS is present, the ATMS shall allow users to query and access reduced visibility warning system data and corresponding speed data (when traffic detection is present) and create customized reports suitable for data analysis. (ATMS dependency)
8. When a communications connection to the ATMS is present, operators need a mechanism to access historical data from reduced visibility warning systems, such as reports of system activations and data from visibility sensors, to help them understand the frequency of activations and impacts to the road segment when recurring reduced visibility conditions occur.	8.1. When a communications connection to the ATMS is present, the ATMS may have a mechanism for users to view and create reports of past reduced visibility warning system activations and de-activations, including corresponding timestamps. (ATMS dependency) 8.2. When a communications connection to the ATMS is present, the ATMS may have a mechanism for users to view and create reports showing data from visibility sensors, with corresponding timestamps. (ATMS dependency)
Technicians and Installers	
9. Technicians and installers need power,	9.1. Reduced visibility warning system field devices shall be designed and installed in accordance with requirements for

Need	System Requirement
communications, and support structures to be available at locations where field equipment for reduced visibility warning systems is deployed. Note: power may be locally generated (e.g. solar, wind); local communications may not be able to provide a connection to the ATMS.	roadway clearance and crashworthiness (e.g. breakaway structures or protection.) 9.2. Reduced visibility warning system design shall include the approach to mounting the field devices. 9.3. Reduced visibility warning system design shall include power connections. 9.4. Reduced visibility warning system design shall include components to support local communications. 9.5. When a communications connection to the ATMS is present, the reduced visibility warning system design shall include components to support remote, long-distance communications. 9.6. Reduced visibility warning system design shall include adequate visibility of warning signs. 9.7. Reduced visibility warning system design shall include accessibility to field devices for maintenance and repairs.
10. Technicians and installers need the field devices to adhere to appropriate safety standards, specifications, and protocols.	10.1. A professional engineer registered in the State of Minnesota shall review and approve all design details of the complete reduced visibility warning system field deployment. The detection mechanisms, communications, traveler displays, and CAV dissemination components should all be considered in the design. 10.2. Reduced visibility warning system field devices shall include components to support safe lifting, transport, and installation of the devices. 10.3. Reduced visibility warning system field devices shall meet current specifications as approved by MnDOT or the agency/owner that is deploying and operating the reduced visibility warning system. 10.4. Reduced visibility warning system design shall include TTC plans for installing or performing field work on reduced visibility warning system field devices.

Need	System Requirement
11. Technicians and installers need consistency and compatibility in the reduced visibility warning equipment to achieve efficiencies in procurement, maintenance, and training.	11.1. Reduced visibility warning system field devices shall be compatible with existing equipment and systems such as communications (e.g. fiber, etc.) and related systems and devices (e.g. ATMS, RWIS stations, etc.) 11.2. Newly procured reduced visibility warning system field devices shall be consistent with similar in-place devices to the extent possible, as technicians and installers are well-trained to install and repair these devices and can interchange parts. 11.3. Reduced visibility warning system field devices shall utilize MnDOT standardized components, as available. 11.4. Reduced visibility warning system field devices, equipment, and software shall be procured to ensure interoperability and consistency with the latest standards and technologies. 11.5. Consistency and compatibility needs shall not prevent or inhibit testing or eventual production use of new products or services.
Central RWIS Unit	
12. When a reduced visibility warning system is connected to an RWIS station, the Central RWIS Unit needs data from the visibility sensors, to increase their understanding of road weather conditions.	12.1. Visibility sensors installed as part of reduced visibility warning systems shall produce visibility data in a format that is consistent with data from RWIS stations.
CAV Infrastructure Systems and CAVs	
13. CAVs need real-time, low latency data from other CAVs to exchange data that could describe locations where reduced visibility is detected.	13.1. Agency or privately owned CAVs may receive and process BSMs from other vehicles and use this information to support such applications as spot weather information warning. 13.2. Agency or privately owned CAVs may receive and process BSM Part 2 messages (such as atmospheric visibility status outside of the vehicle) from other vehicles and use this information to support such applications as spot weather information warning.
14. DOTs need to benefit from the data broadcast by public and private CAVs to assist in detection of reduced visibility conditions whenever possible.	14.1. DOTs may locate roadside units to receive and process BSM and BSM Part 2 messages at key locations, to gather information about vehicle performance such as atmospheric visibility status outside of the vehicle, to help identify reduced visibility conditions. 14.2. As the number of CAVs increases, DOTs shall consider deploying CAV infrastructure systems that are capable of

Need	System Requirement
	requesting and receiving EDCM as a means to receive visibility data from CAVs. 14.3. DOTs shall develop data retention policies for CAV related data and regularly review these as the CAV industry matures and the amount of data generated is better understood.
15. CAVs need to receive infrastructure-generated reduced visibility warnings as they approach these conditions.	15.1. DOTs may locate roadside units to broadcast information such as reduced visibility conditions (detected by visibility sensors) that will be received by CAVs. 15.2. Roadside units may receive reduced visibility warning alerts from the ATMS, local warning signs, or other data information systems, for use by CAVs. 15.3. When local RSUs are connected to reduced visibility warning systems, either the warning systems or the RSU shall generate standards compliant messages (e.g. Road Safety Message (RSM) or other message formats used by the agency) for broadcast by the RSU. 15.4. When local RSUs are connected to reduced visibility warning systems, either the warning systems or the RSU shall assign security credentials to the messages according to the agency approach and requirements for secure connections. 15.5. When local RSUs are connected to reduced visibility warning systems, either the warning systems or the RSU shall attach either low-fidelity or high-fidelity location reference (MAP) messages to accompany the warnings that are broadcast. 15.6. DOTs may use network cellular communications to broadcast messages describing reduced visibility conditions, including the geographic boundaries of the warnings. 15.7. CAVs may ingest the messages describing reduced visibility conditions from the roadside units or cellular communications, to support on-board applications or automated driving system features.

Relationship to the National ARC-IT and Minnesota ITS Architecture

The Minnesota Statewide Regional ITS Architecture presents a vision for how ITS systems work together, share resources, and share information. The 2018 update to the ITS Architecture represents the latest status of Minnesota, as captured through outreach meetings and input from stakeholders statewide. As such, the Minnesota ITS Architecture was a valuable input to the development of this documents, supporting:

- Identification of stakeholders;
- Definition of needs for reduced visibility warning;
- Concepts for the use of reduced visibility warning; and
- Overall input to the requirements.

The Minnesota ITS Architecture enabled the Project Team to build upon the content of the architecture and clarify specifics for this document.

In addition to the role of supporting the development of this document, the Minnesota Statewide Regional ITS Architecture and the National Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) will continue to serve as a resource for the agencies that utilize this document as they prepare for deployment. Table 14 below identifies the needs/potential solutions included in the Minnesota ITS Architecture that are addressed through concepts for the use of reduced visibility warning systems described in this document, as well as references to service packages and processes as defined in the ARC-IT. Finally, the far-right column identifies the reduced visibility warning system stakeholder need(s) that were influenced or derived based on each service package.

Table 14: Summary of Local and National ITS and CAV Architecture References Mapped to Reduced Visibility Warning Needs

MN Statewide Regional ITS Architecture: Need/Potential Solutions	ARC-IT: Service Packages	ARC-IT: Processes	Reduced Visibility Warning Stakeholder Needs Influenced by each Service Package
• ATIS04 Provide current and forecast road and weather condition information	• TM12 Dynamic Roadway Warning	• Control Roadway Warning System	• Need 1: Real-time, En-route, Local Reduced Visibility Notification • Need 2: Advanced Reduced Visibility Information • Need 3: Automated Activation of Local Reduced Visibility Warning Displays • Need 15: Vehicle Use of Infrastructure-generated Reduced Visibility Warnings
• ATIS04 Provide current and forecast road and weather condition information	• TM12 Dynamic Roadway Warning	• Manage Roadway Warning System	• Need 4: Operator Interaction with Reduced Visibility Warning Systems • Need 5: Reduced Visibility Warning System Assessment • Need 6: Local Reduced Visibility Warning System Configuration
• ATIS04 Provide current and forecast road and weather condition information	• TM12 Dynamic Roadway Warning	• Provide Traffic Operations Personnel Traffic Data Interface	• Need 4: Operator Interaction with Reduced Visibility Warning Systems • Need 8: Access to Historical Data from Reduced Visibility Warning Systems
• ATIS04 Provide current and forecast road and weather condition information	• TM12 Dynamic Roadway Warning	• Monitor Roadside Equipment Operation	• Need 5: Reduced Visibility Warning System Assessment
• ATIS04 Provide current and forecast road and weather condition information	• TM12 Dynamic Roadway Warning	• Provide Device Interface to Other Roadway Devices	• Need 12: Road Condition Data from Reduced Visibility Warning Systems

MN Statewide Regional ITS Architecture: Need/Potential Solutions	ARC-IT: Service Packages	ARC-IT: Processes	Reduced Visibility Warning Stakeholder Needs Influenced by each Service Package
• ATIS04 Provide current and forecast road and weather condition information	• TM12 Dynamic Roadway Warning	• Collect Traffic Field Equipment Fault Data	• Need 5: Reduced Visibility Warning System Assessment
• ATIS04 Provide current and forecast road and weather condition information	• MC09 Infrastructure Monitoring	• Collect Vehicle Roadside Safety Data • Process Collected Vehicle Safety Data	• Need 7: Traffic Data to Assess Driver Response to Reduced Visibility Warning Displays
• ATIS04 Provide current and forecast road and weather condition information	• MC09 Infrastructure Monitoring	• Collect Infrastructure Sensor Data	• Need 5: Reduced Visibility Warning System Assessment
• ATIS04 Provide current and forecast road and weather condition information	• WX01 Weather Data Collection	• Collect Vehicle Roadside Safety Data	• Need 13: Vehicle to Vehicle Data Exchange • Need 14: Vehicle to Infrastructure Data Exchange
• ATIS04 Provide current and forecast road and weather condition information	• TI07 In-Vehicle Signage	• Process In-vehicle Signage Data	• Need 15: Vehicle Use of Infrastructure-generated Reduced Visibility Warnings
• ATIS04 Provide current and forecast road and weather condition information	• TI07 In-Vehicle Signage	• Provide Short Range Traveler Information	• Need 15: Vehicle Use of Infrastructure-generated Reduced Visibility Warnings
• ATIS04 Provide current and forecast road and weather condition information	• WX03 Spot Weather Impact Warning	• Collect Connected Vehicle Field Equipment Status • Process Environmental Sensor Data	• Need 14: Vehicle to Infrastructure Data Exchange

MN Statewide Regional ITS Architecture: Need/Potential Solutions	ARC-IT: Service Packages	ARC-IT: Processes	Reduced Visibility Warning Stakeholder Needs Influenced by each Service Package
• ATIS04 Provide current and forecast road and weather condition information	• WX03 Spot Weather Impact Warning	• Process Environmental Sensor Data	• Need 1: Real-time, En-route, Local Reduced Visibility Notification
• WTR01 Provide automated monitoring of road weather conditions	• WX02 Weather Information Processing and Distribution	• Collect Environmental Data	• Need 12: Road Condition Data from Reduced Visibility Warning Systems
• WTR01 Provide automated monitoring of road weather conditions	• WX02 Weather Information Processing and Distribution	• Exchange Data with Other Traffic Centers	• Need 12: Road Condition Data from Reduced Visibility Warning Systems
• WTR01 Provide automated monitoring of road weather conditions	• WX02 Weather Information Processing and Distribution	• Disseminate Environmental Information	• Need 3: Automated Activation of Local Reduced Visibility Warning Displays
• WTR01 Provide automated monitoring of road weather conditions	• WX02 Weather Information Processing and Distribution	• Process Roadway Environmental Data	• Need 12: Road Condition Data from Reduced Visibility Warning Systems
• WTR01 Provide automated monitoring of road weather conditions	• WX02 Weather Information Processing and Distribution	• Retrieve Traffic Data	• Need 7: Traffic Data to Assess Driver Response to Reduced Visibility Warning Displays

Model Test Plan

This section presents a model test plan to support testing and validation activities during the integration and deployment stages of reduced visibility warning to confirm that the system is developed, installed, and operating as specified by the system requirements.

Each reduced visibility warning deployment will be different, and the testing and validation performed will likely vary depending upon the complexity of the system and the familiarity with the vendor products.

The table below provides a series of testing instructions related to the requirements presented above. The intent is that agencies using this model systems engineering document will incorporate these tests into their overall testing and validation plans, adapting them as needed.

Column 3 in the table below describes 'testing instructions' for each requirement. The reduced visibility warning requirements include a range of requirement types and therefore the testing instructions vary. The following bullet list explains the approach to different testing instructions:

- *Advisory requirement – no testing required:* This is noted for requirements that are primarily operational advice (e.g. the locating and use of reduced visibility warning) and therefore no formal testing is required;
- *Design:* These test instructions are used to describe testing in the form of design reviews or documentation reviews describing the reduced visibility warning. These are typically not physical tests, but rather reviews of processes or documents;
- *Factory Acceptance Test (FAT):* These represent recommendations for FATs to allow the agency deploying the reduced visibility warning to verify the quality assurance/quality control and reduced visibility warning operational parameters at the site of manufacturing and assembly. This can involve the procuring agency on-site at the vendor factory testing the actual equipment to be delivered or the reports of previous tests of components, software, or features;
- *Field:* These represent recommendations for tests to be conducted in MnDOT offices or in the field to test the actual deployment and functionality of the reduced visibility warning.

Table 15: Model Test Plan for Reduced Visibility Warning

System Requirement		Testing Instructions	Type of Result	Comments / Notes
1.1	In locations that experience recurring reduced visibility conditions, reduced visibility warning system deployments shall be considered, to advise travelers of locations where reduced visibility conditions may impact the driver's ability of to see the approaching roadway environment.	Advisory requirement – no testing required	N/A	
1.2	Reduced visibility warning systems shall activate visual alerts to drivers when reduced visibility conditions are detected downstream.	Field – Conduct test to confirm all supporting infrastructure is installed and operational (e.g. detection, power, communications) so the reduced visibility warning system activates the visual alerts when the reduced visibility condition is detected.	Pass/Fail	
1.3	Warning signs for reduced visibility warning systems shall be located such that the sign displays are visible to approaching drivers.	Field – Conduct tests to confirm that warning signs and any associated visual indicators (e.g. flashing beacons) are visible and legible to drivers at posted speeds.	Pass/Fail	
1.4	Warning signs (types, placements, etc.) shall comply with the Minnesota MUTCD or be approved through the appropriate design exemption processes.	Design – Confirm that the warning signs comply with the Minnesota MUTCD or have been approved through design exemption as needed. Field – Confirm that the installed warning signs are consistent with the approved design.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field – Pass/Fail	
1.5	Warning signs shall be placed in advance of the reduced visibility condition, at a distance such that the signs provide adequate perception-	Design – Confirm that the warning sign placements in the design plans are appropriate per Minnesota MUTCD guidance and engineering judgement.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	

	System Requirement	Testing Instructions	Type of Result	Comments / Notes
	response time for the driver. (See Minnesota MUTCD, Section 2C, to view Guidance for Advance Placement of Warning Signs.)	Field – Confirm that the placement of installed warning signs is consistent with the approved design. Confirm that warning signs are placed such that field conditions (roadway geometry, sight obstructions) do not impact the drivers' ability to view the signs and reduce vehicle speeds accordingly.	Field – Pass/Fail	
2.1	When a communications connection to the ATMS is present, the reduced visibility warning system shall communicate activation and de-activation alerts to the ATMS, to enable widespread dissemination using established traveler information system applications.	Design – Confirm that the reduced visibility warning system is designed to send alerts to the ATMS for system activations and de-activations. Field - Conduct test to confirm that the reduced visibility warning system communicates alerts to the ATMS when the system is activated and when the system is de-activated.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field – Pass/Fail	
3.1	The detection of a reduced visibility condition by visibility sensors shall automatically activate the warning sign displays to alert travelers of reduced visibility condition ahead.	Design – Confirm that the reduced visibility warning system display is designed to automatically activate when reduced visibility is detected. Field – Conduct test to confirm that the reduced visibility warning system will activate when reduced visibility is detected.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field – Pass/Fail	
3.2	The reduced visibility warning activations shall turn off automatically as visibility sensors detect that the reduced visibility condition has diminished.	Design – Confirm that the reduced visibility warning system display is designed to automatically de-activate when the reduced visibility condition has diminished.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
		Field – Conduct test to confirm that the reduced visibility warning system will de-activate when the reduced visibility condition has diminished.	Field – Pass/Fail	
3.3	If in-place visibility sensors that are part of a nearby RWIS station are used for a reduced visibility warning system, these visibility sensors shall be capable of detecting reduced visibility such that the reduced visibility warning system can utilize the visibility sensor data to activate and de-activate the warning signs.	Design – Confirm that the in-place visibility sensors are capable of detecting reduced visibility levels in accordance with the reduced visibility system design, to activate and de-activate warning signs. Field – After the in-place visibility sensors have been connected to communicate with the reduced visibility warning system, conduct a test to confirm that the signs activate with reduced visibility levels and de-activate when reduced visibility conditions have diminished, in accordance with design parameters.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field – Pass/Fail	
3.4	To the extent practical, reduced visibility warning system components (i.e. field devices) shall be compliant with National Transportation Communications for ITS Protocol (NTCIP) standards.	Design – Confirm NTCIP compliance for reduced visibility warning field devices, to the extent practical.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	
4.1	When a communications connection to the ATMS is present, the reduced visibility warning system shall communicate reduced visibility detections to the ATMS, allowing operators to be aware of the condition. (Note that the provision of a	Design – Confirm that the design allows field devices to communicate reduced visibility detections to the ATMS. Field – Confirm that the ATMS receive notices of reduced visibility detections.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
	communications connection is a local design decision.)			
4.2	When a communications connection to the ATMS is present, the ATMS shall be able to send notifications (e.g. email or text message) of system activations and de-activations. (ATMS dependency)	Field – Confirm that the ATMS sends notifications of system activations and de-activations as detections of activations/de-activations are received from the reduced visibility system or as activations/de-activations are entered by ATMS users.	Field - Pass/Fail	ATMS dependency
4.3	When a communications connection to the ATMS is present, the ATMS shall have a mechanism to view the reduced visibility warning systems configured in the ATMS, to view the activation statuses of the reduced visibility warning systems. (ATMS dependency)	Field – Confirm that the ATMS displays the reduced visibility warning systems configured in the ATMS. Field – Confirm that the ATMS is configured to display instances when reduced visibility conditions have been detected by the reduced visibility warning system. Field – Confirm that the ATMS is configured to display instances when reduced visibility conditions have diminished, as detected by the reduced visibility warning system. Field – Confirm that the ATMS is receiving data communications from the reduced visibility warning system describing the system activations. Field – Confirm that the ATMS is receiving data communications from the reduced visibility warning system describing the system de-activations.	Field - Pass/Fail	ATMS dependency

	System Requirement	Testing Instructions	Type of Result	Comments / Notes
4.4	When a communications connection to the ATMS is present, the ATMS shall have a mechanism to manually activate and de-activate the reduced visibility warning system remotely. (ATMS dependency)	Design – Confirm that the design allows the reduced visibility warning system displays to be manually activated remotely using the ATMS, per local design choice. Field – Confirm that the reduced visibility warning system display can be manually activated remotely using the ATMS. Field – Confirm that the reduced visibility warning system display can be manually de-activated remotely using the ATMS.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	ATMS dependency
4.5	Reduced visibility warning systems shall have a mechanism to manually activate and de-activate the warning signs locally at the device in the field.	Design – Confirm that the design allows the reduced visibility warning system display to be manually activated and de-activated locally at the device. Field – Confirm that the reduced visibility warning system display can be manually activated and de-activated locally at the device.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	
4.6	When a communications connection to the ATMS is present and video is deployed at the reduced visibility warning system site, video field devices shall be positioned such that users can view the status of the warning signs and the visibility conditions at typical driver viewing elevations via the ATMS.	Design – Confirm that the design shows video field devices positioned to enable adequate viewing of reduced visibility conditions at typical driver viewing elevations via the ATMS, with field device features such as pan-tilt-zoom as needed. Design – Confirm that the design shows video field devices position to enable adequate viewing of warning signs via the	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
		ATMS, with field device features such as pan-tilt-zoom as needed. Field – Confirm the location position of video field devices at the site, to view reduced visibility conditions at typical driver viewing elevations by using the ATMS to access video field devices and view the site. Field – Confirm adequate viewing warning signs by using the ATMS to access video field devices and view the site.	Field - Pass/Fail	
4.7	Cameras that are equipped with analytics to detect reduced visibility conditions, as deployed, may be capable of providing automatic alerts to operators when a reduced visibility condition has been detected and when the visibility has returned to a normal level.	Design – Confirm that the design shows that cameras equipped with analytics will communicate automatic alerts when a reduced visibility condition has been detected and when the visibility has returned to a normal level. Field – Conduct a test to confirm that the analytics-equipped cameras are detecting reduced visibility conditions. Field – Conduct a test to confirm that the analytics-equipped cameras communicate reduced visibility detections to operators.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	
4.8	Warning signs may be capable of receiving and processing NTCIP compliant communications describing messages to be displayed on the sign and display or remove the appropriate messages. In situations where flashing	FAT – Confirm the software used in the warning signs has passed NTCIP testing. Field – Conduct test displays of messages to confirm the proper posting and removal of messages.	FAT - Pass/Fail Field - Pass/Fail	

	System Requirement	Testing Instructions	Type of Result	Comments / Notes
	beacons or blank-out signs are deployed (option is either display of one message or no message) the communications would be to activate or de-activate.			
4.9	Warning signs may be capable of sending an NTCIP compliant message to the ATMS confirming when messages are displayed or removed from the sign.	Design – Confirm the software used in the warning signs generates messages confirming the current sign display. FAT – Confirm the software used in the warning signs has passed NTCIP testing. Field – Confirm that the ATMS is receiving corresponding messages when messages that are posted/removed from the sign are executed.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. FAT - Pass/Fail Field - Pass/Fail	
5.1	The reduced visibility warning system field devices shall be capable of being queried locally in the field, to understand their operational status.	Design – Confirm that the design includes assessment tools for understanding operational status of the field equipment. Field – Confirm that the assessment tools at the field devices are capable of querying the operational status of the field equipment.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	
5.2	When a communications connection to the ATMS is present and electrical current sensing devices are available, these devices shall be capable of being polled through the ATMS, to remotely query the operational status of field devices.	Design – Confirm that the design includes current sensing devices that the ATMS can poll to check the operational status of the field equipment. Field – Confirm that operators can use the ATMS user interface to check operational status of the field equipment using the current sensing devices.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
5.3	When a communications connection to the ATMS is present and electrical current sensing devices are available, the reduced visibility warning system shall provide automatic notifications to the ATMS, regarding operational issues with field devices.	Design – Confirm that the design includes current sensing devices that automatically notify the ATMS of operational issues with field equipment. Field – View the ATMS to confirm that automatic notifications are received by the ATMS (from the reduced visibility warning system) when operational issues with the field equipment occur.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	
5.4	If a communications connection to the ATMS is present, the ATMS may be capable of identifying faulty visibility sensors at the site of the reduced visibility warning system and generating a message in the ATMS that shows the location of the faulty sensor. (ATMS dependency)	Field – Conduct a test with an absent or faulty visibility sensor to ensure that the ATMS detects that the sensor is not functioning properly.	Field – Pass/Fail	ATMS dependency
6.1	When a communications connection to the ATMS is present, the ATMS shall allow users to add and delete reduced visibility warning systems in the ATMS once they are installed. (ATMS dependency)	Design – Confirm that the design allows the reduced visibility warning system to be added or deleted in the ATMS. Field – Confirm that operators can use the ATMS user interface to add or delete the reduced visibility warning system.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	ATMS dependency
6.2	When a communications connection to the ATMS is present, the ATMS shall allow users to establish the reduced visibility warning system location in the ATMS, in order to process reduced visibility alerts received and assign	Design – Confirm that the design allows the reduced visibility warning system location to be established in the ATMS. Field – Confirm that the ATMS has established the reduced visibility warning system location in the ATMS.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	ATMS dependency

System Requirement		Testing Instructions	Type of Result	Comments / Notes
	them properly to roads. (ATMS dependency)			
6.3	When a communications connection to the ATMS is present, the reduced visibility warning system shall support local on-site configuration of the field devices to the ATMS.	Design – Confirm that the design allows the reduced visibility warning system to be configured to the ATMS from on-site at the field devices. Field – Confirm that field staff can configure the reduced visibility warning system to the ATMS at the site of the field devices.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	
7.1	When a communications connection to the ATMS is present, the ATMS shall allow users to access speed data from traffic detection approaching reduced visibility warning signs (when traffic detection is present), with corresponding timestamps of system activations and de-activations. (ATMS dependency)	Design – Confirm that the design allows for speed data from traffic detection approaching the reduced visibility warning signs to be accessed along with corresponding system activation and de-activation timestamps. Field – Confirm that ATMS users can view and access speed data from traffic detection approaching the reduced visibility warning signs, with corresponding timestamps of system activations and de-activations.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	ATMS dependency
7.2	When a communications connection to the ATMS is present, the ATMS shall allow users to query and access reduced visibility warning system data and corresponding speed data (when traffic detection is present) and create customized reports suitable for data analysis. (ATMS dependency)	Design – Confirm that the design allows the ATMS to create customized reports showing reduced visibility warning system data (e.g. activations and de-activations) and speed data from traffic detection approaching the warning signs. Field – Confirm that ATMS users can create customized reports showing data from reduced visibility warning systems and data	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	ATMS dependency

System Requirement		Testing Instructions	Type of Result	Comments / Notes
		from traffic detection approaching the system's warning signs.		
8.1	When a communications connection to the ATMS is present, the ATMS may have a mechanism for users to view and create reports of past reduced visibility warning system activations and de-activations, including corresponding timestamps. (ATMS dependency)	Design – Confirm that the design allows the ATMS to view and create reports of reduced visibility warning system activations and de-activations with corresponding timestamps. Field – Confirm that ATMS users can view and create reports of reduced visibility warning system activations and de-activations with corresponding timestamps.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	ATMS dependency
8.2	When a communications connection to the ATMS is present, the ATMS may have a mechanism for users to view and create reports showing data from visibility sensors, with corresponding timestamps. (ATMS dependency)	Design – Confirm that the design allows the ATMS to view and create reports of data from visibility sensors. Field – Confirm that ATMS users can view and create reports of data from visibility sensors.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	ATMS dependency
9.1	Reduced visibility warning system field devices shall be designed and installed in accordance with requirements for roadway clearance and crashworthiness (e.g. breakaway structures or protection.)	Design – Confirm that the reduced visibility warning system design meets current requirements for roadway clearance and crashworthiness. FAT – Confirm that reduced visibility warning system equipment meets current requirements for crashworthiness. Field – Confirm that field equipment is installed per design in accordance roadway clearance and crashworthiness requirements per the approved design.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. FAT – Pass/Fail Field - Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
9.2	Reduced visibility warning system design shall include the approach to mounting the field devices.	Design – Confirm installation considerations are included in design.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	
9.3	Reduced visibility warning system design shall include power connections.	Design – Confirm presence of power connections for external sources or self-sustaining power units.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	
9.4	Reduced visibility warning system design shall include components to support local communications.	Design – Confirm presence of components for local communications.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	
9.5	When a communications connection to the ATMS is present, the reduced visibility warning system design shall include components to support remote, long-distance communications.	Design – Confirm presence of components for remote communications.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	
9.6	Reduced visibility warning system design shall include adequate visibility of warning signs.	Design – Confirm that the warning sign design allows for adequate visibility to drivers.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	
9.7	Reduced visibility warning system design shall include accessibility to field devices for maintenance and repairs.	Design – Confirm that the design locates field devices in an accessible location for field staff to perform maintenance. Field – Confirm that the field devices can be accessed by field staff for maintenance activities.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	
10.1	A professional engineer registered in the State of Minnesota shall review and approve all design details of the complete reduced visibility warning system field deployment. The detection mechanisms, communications, traveler displays, and CAV dissemination	Design – Confirm review by a Minnesota professional engineer.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
	components should all be considered in the design.			
10.2	Reduced visibility warning system field devices shall include components to support safe lifting, transport, and installation of the devices.	FAT – Confirm presence of components to support safe movement and installation.	FAT – Pass/Fail	
10.3	Reduced visibility warning system field devices shall meet current specifications as approved by MnDOT or the agency/owner that is deploying and operating the reduced visibility warning system.	Design – Confirm that specifications have been developed or acquired from the agency/owner and are approved for use in final acceptance. Design - Confirm that specifications of the deploying/operating agency/owner are met. FAT – Confirm that field devices meet the agency/owner specifications.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. FAT – Pass/Fail	
10.4	Reduced visibility warning system design shall include TTC plans for installing or performing field work on reduced visibility warning system field devices.	Design – Confirm that the design includes TTC plans.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	
11.1	Reduced visibility warning system field devices shall be compatible with existing equipment and systems such as communications (e.g. fiber, etc.) and related systems and devices (e.g. ATMS, RWIS stations, etc.)	Design – Confirm that the design is compatible with existing equipment and systems for communications and data management, per local design choice. Field – Confirm that the field devices can communicate and interface with communications and related systems.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	
11.2	Newly procured reduced visibility warning system field devices shall be consistent with similar in-place devices	Advisory requirement – no testing required.	N/A	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
	to the extent possible, as technicians and installers are well-trained to install and repair these devices and can interchange parts.			
11.3	Reduced visibility warning system field devices shall utilize MnDOT standardized components, as available.	Design – Confirm that the design contains MnDOT standardized components, as available.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	
11.4	Reduced visibility warning system field devices, equipment, and software shall be procured to ensure interoperability and consistency with the latest standards and technologies.	Design – Confirm that the design is compatible and interoperable with current standards. FAT – Confirm that equipment conforms with current standards.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. FAT - Pass/Fail	
11.5	Consistency and compatibility needs shall not prevent or inhibit testing or eventual production use of new products or services.	Advisory requirement – no testing required	N/A	
12.1	Visibility sensors installed as part of reduced visibility warning systems shall produce visibility data in a format that is consistent with data from RWIS stations.	Design – Confirm that the design includes visibility sensors that produce data in a format consistent with RWIS station data.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	
13.1	Agency or privately owned CAVs may receive and process BSMs from other vehicles and use this information to support such applications as spot weather information warning.	Advisory requirement – no testing required	N/A	
13.2	Agency or privately owned CAVs may receive and process BSM Part 2 messages (such as atmospheric visibility status outside of the vehicle)	Advisory requirement – no testing required	N/A	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
	from other vehicles and use this information to support such applications as spot weather information warning.			
14.1	DOTs may locate roadside units to receive and process BSM and BSM Part 2 messages at key locations, to gather information about vehicle performance such as atmospheric visibility status outside of the vehicle, to help identify reduced visibility conditions.	Design – Confirm BSM and BSM Part 2 receipt and processing capabilities. Field – Demonstration of roadside unit capability to receive BSM and BSM Part 2 messages, process data, and trigger reduced visibility warning systems.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	
14.2	As the number of CAVs increases, DOTs shall consider deploying CAV infrastructure systems that are capable of requesting and receiving EDCM as a means to receive visibility data from CAVs.	Advisory requirement – no testing required	N/A	
14.3	DOTs shall develop data retention policies for CAV related data and regularly review these as the CAV industry matures and the amount of data generated is better understood.	Advisory requirement – no testing required	N/A	
15.1	DOTs may locate roadside units to broadcast information such as reduced visibility conditions (detected by visibility sensors) that will be received by CAVs.	Design – Confirm roadside unit communications and processing capabilities. FAT – Demonstration of roadside unit ability to: • Generate a CAV message in a standard format that conveys the reduced visibility related message.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. FAT - Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
		• Broadcast the generated CAV messages over industry standard communications, with appropriate message certifications. Field – Confirm with one or more on-board devices that the roadside unit is able to: • Generate a CAV message in a standard format that conveys the reduced visibility related message. • Broadcast the generated CAV message to via one or more standard communications mechanisms.	Field – Pass/Fail	
15.2	Roadside units may receive reduced visibility warning alerts from the ATMS, local warning signs, or other data information systems, for use by CAVs.	Design – Confirm roadside unit communications and processing capabilities. FAT – Demonstration of roadside unit: • Receiving CAV messages in standard formats. • Processing CAV messages to generate roadside safety messages to broadcast to vehicles. • Broadcast of roadside safety message with reduced visibility warning data included. Field – Confirm with one or more on-board devices that the roadside unit is able to:	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. FAT - Pass/Fail Field – Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
		• Receive CAV messages in standard formats. • Process CAV messages to generate roadside safety messages to broadcast to vehicles. • Broadcast of roadside safety message with reduced visibility warning data included.		
15.3	When local RSUs are connected to reduced visibility warning systems, either the warning systems or the RSU shall generate standards compliant messages (e.g. Road Safety Message (RSM) or other message formats used by the agency) for broadcast by the RSU.	Design – Confirm standards compliant messages generated by roadside units or reduced visibility warning systems. FAT – Demonstration of roadside unit or reduced visibility warning system to generate standards compliant CAV messages. Field – Confirm with one or more on-board devices that the roadside unit or the reduced visibility warning system is able to generate standards compliant CAV messages.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. FAT - Pass/Fail Field – Pass/Fail	
15.4	When local RSUs are connected to reduced visibility warning systems, either the warning systems or the RSU shall assign security credentials to the messages according to the agency approach and requirements for secure connections.	Design – Confirm that the security credentialing approach for CAV messages meets the agency approach and requirements for secure connections. FAT – Demonstration of roadside unit or reduced visibility warning system to assign security credentials to CAV messages.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. FAT - Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
		Field – Confirm with one or more on-board devices that CAV messages received from the roadside unit or the reduced visibility warning system have been assigned appropriate security credentials.	Field – Pass/Fail	
15.5	When local RSUs are connected to reduced visibility warning systems, either the warning systems or the RSU shall attach either low-fidelity or high-fidelity location reference (MAP) messages to accompany the warnings that are broadcast.	Design – Confirm that the RSU or reduced visibility warning system design includes ability to attach low-fidelity or high-fidelity location reference (MAP) messages to the warning messages that are broadcast. FAT – Demonstration that the RSU or reduced visibility warning system provides CAV messages that contain appropriate MAP messages. Field – Confirm with one or more on-board devices that CAV messages received from the roadside unit or the reduced visibility warning system contain appropriate MAP messages.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. FAT - Pass/Fail Field – Pass/Fail	
15.6	DOTs may use network cellular communications to broadcast messages describing reduced visibility conditions including the geographic boundaries of the warnings.	Advisory requirement – no testing required	N/A	
15.7	CAVs may ingest the messages describing reduced visibility conditions from the roadside units or cellular communications, to support on-board applications or automated driving system features.	Advisory requirement – no testing required	N/A	