DEPARTMENT OF TRANSPORTATION

Model Systems Engineering Document

ITS Application: Slippery Pavement Warning

FINAL – May 2020

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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 slippery pavement 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 – Slippery Pavement Warning

Transportation agencies sometimes deploy slippery pavement warning systems at roadway sections that are prone to recurring slippery conditions and cause more than typical crashes to occur. These systems detect reduced friction on the pavement surface and activate advanced warning signs to alert drivers of the slippery pavement 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 slippery pavement warning systems and related road weather data. Functions of slippery pavement 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 Slippery Pavement Warning

The following criteria provide guidance to help agencies make an initial decision about whether to deploy slippery pavement warning systems. Locations that meet these criteria may be suitable for deployment of slippery pavement warning systems.

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 slippery pavement, such as lower or non-technology solutions have been tried at this location (e.g. geometric improvement, pavement improvement, increased maintenance activity, operational improvements, static warning signs, manually activated signs, signs with temperature dependent ice warning thermometers) and have not had a positive impact on reducing crashes.

And

3. The location is prone to slippery conditions (e.g. ice, leaves on the road, etc.) during times that are outside of widespread impacts to pavement surfaces. For example, during winter storms it is common that conditions on most/all roads are slippery until treated. These locations would also be prone to encountering slippery conditions during other times (e.g. due to snow melt or local environmental situations) when travelers are not expecting inclement driving conditions.

Slippery Pavement Warning Environment/Components

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

Table 1: Slippery Pavement Warning Environment/Components with Corresponding Function

Environment/Component	Function
Core Components of Slippery Pavement Warning System	
1. Friction Sensors	Sensing equipment located on or near the roadway to detect conditions when the road surface experiences a reduction in friction.
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 friction sensors, depending upon local design. For stand-alone slippery pavement warning systems, this is the connection between the friction sensors and the warning sign(s). In situations where there is connectivity to ATMS, this component processes data from the friction sensors (and atmospheric sensors, if deployed) and sends it to the ATMS. In situations where operators use the ATMS to enter information about slippery pavement 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 could also communicate data from friction sensors (and atmospheric sensors, if deployed) to the RWIS station.

Environment/Component	Function
3. Warning Signs	Visual indicators to travelers that slippery conditions are likely on the pavement surface ahead. 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 dynamic message signs. Warning signs will activate when reduced friction on the pavement is detected, as atmospheric conditions favorable for resulting in slippery pavements 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 Slippery Pavement Warning System	
4. Atmospheric Sensors	Sensors that detect atmospheric conditions, such as temperature and humidity. When deployed, data from atmospheric sensors could supplement data from friction sensors to help identify atmospheric conditions that are likely to result in slippery pavement conditions.
5. Video	Cameras placed to enable roadway maintenance staff or operators to view impacted pavement sections and/or operability of warning signs. Cameras may convey still images or live video. *(See MnDOT Model Systems Engineering Document, ITS Application: Video)*
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 slippery pavement areas 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 friction sensors or from optional atmospheric sensors, or in-place RWIS sensors could be used for slippery pavement warning system detection.
8. Communications to ATMS	The communications infrastructure to allow data communications between the local slippery pavement warning system and the ATMS. Note that communications to the ATMS is optional and that there are situations where slippery pavement warning systems exist as stand-alone systems.

Environment/Component	Function
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 slippery pavement warning system site, generate notifications to be sent when warning signs are activated or de-activated, or allow remote control of the slippery pavement warning systems.
10. Traveler Information Systems	Agency traveler information systems that may access information about slippery pavement 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.
11. Electrical Current Sensing Device	A device that detects the flow of electrical current to the slippery pavement system's field devices (e.g. friction 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 slippery pavement and/or may receive messages broadcast from vehicles (e.g. Basic Safety Message (BSM)) to receive data from vehicles that may describe slippery 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. Slippery pavement warning systems (or the ATMS) may communicate slippery pavement warning information to CAV Infrastructure Systems to pass on to CAVs. Similarly, CAVs may detect conditions such as reduced friction (or atmospheric conditions that can result in slippery pavement conditions) 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 slippery pavement warning notices and alert drivers. CAVs may also be a source of information for reduced friction on pavement conditions or atmospheric conditions that can result in slippery pavement conditions.

A slippery pavement 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 connection from a slippery pavement 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 slippery pavement 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 slippery pavement warning system. Figure 2 illustrates a slippery pavement warning system that is connected to the ATMS.

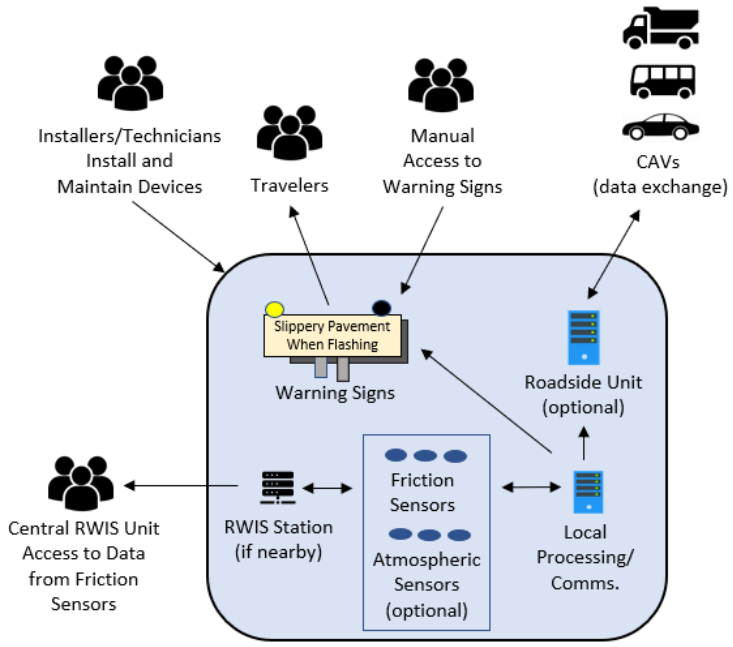


Figure 1: Illustration of Stand-Alone Slippery Pavement Warning System - Components and Related Systems/Users

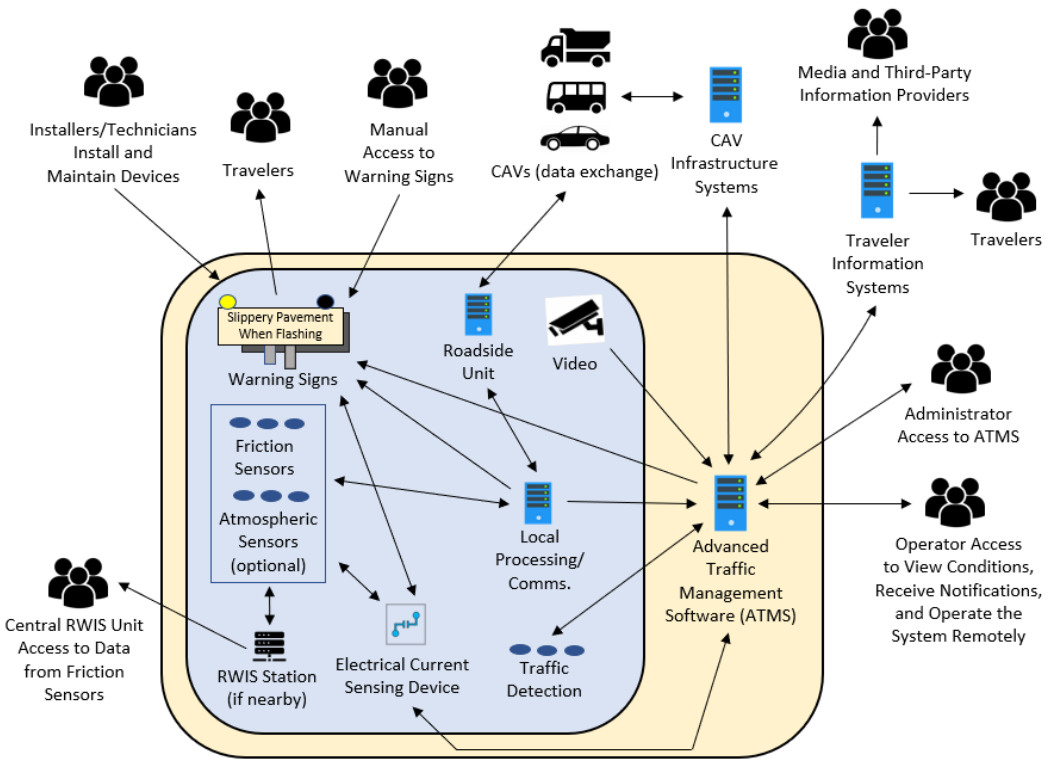


Figure 2: Illustration of Slippery Pavement Warning System Connected to ATMS - Components and Related Systems/Users

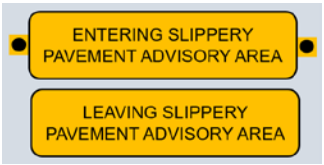
Examples of Warning Signs for Slippery Pavement Warning

As noted in Table 1, the number of signs, sign locations, and sign types could vary for each slippery pavement warning system deployment. The system could include one sign in each direction approaching the slippery pavement condition or multiple signs, each with their own messages, friction sensor placements, and activation thresholds. While local slippery pavement warning systems typically consist of static signs with flashing beacons located in advance of the recurring slippery pavement condition, some slippery pavement warning systems may include other types of warning signs.

Table 2 provides examples of warning signs that may be included in slippery pavement warning systems.

Table 2: Examples of Warning Signs for Slippery Pavement Warning

Warning Sign Type	*Description*	*Photos/Graphics*[1]
Static Signs with Flashing Beacons	Static signs with attached beacons that begin to flash when friction sensors (with supplemental data from atmospheric sensors, if deployed) indciate that the pavement surface friction has dropped below a pre-determined threshold. The beacons stop flashing when the pavement surface friction level returns to higher than the pre-determined threshold.	

Signs for Entering and Leaving an Advisory Area	Signs that advise drivers at the start and end of areas with recurring slippery pavement conditions. Static signs for advanced warning may include flashing beacons that activate when slippery pavement conditions are present. These signs may have messages such as "entering slippery pavement advisory area" or other site-specific messages.	
Dynamic Message Signs (DMS) with Automated Messages	DMS that display advisory messages based on current conditions. Pre-determined messages are posted to DMS located upstream of the slippery pavement area, based on pre-determined thresholds or vehicle speeds approaching the condition. Messages may or may not include advisory speeds. (See *MnDOT Model Systems Engineering Document, ITS Application: Dynamic Message Signs*.)	

[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 slippery pavement warning system.*

Role of Asset Management Systems

Components of slippery pavement 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 slippery pavement warning field devices (e.g. data from friction 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 slippery pavement warning system (e.g. via the ATMS or RWIS), and as such are secondary to local slippery pavement warning systems. Any specific functions of asset management systems related to slippery pavement warning will be addressed during final design of the slippery pavement warning systems, as applicable.

Examples of Communications Technologies Supporting Slippery Pavement Warning

The slippery pavement warning application relies upon a number of communications technologies (detailed in a separate document - *Model System Engineering Document, ITS Application: Communications*) to transfer the slippery pavement 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 Slippery Pavement Warning

Slippery Pavement Warning Application Communications	Communications Technologies Supporting Slippery Pavement Warning Applications
Friction sensors (and atmospheric sensors, if deployed) 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 friction sensors (and atmospheric sensors, if deployed) and warning signs.
Slippery pavement warning field systems to ATMS	• **Long-range communications** – Ethernet connections using fiber or copper mediums to communicate pavement friction information from slippery pavement 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 slippery pavement 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 pavement friction information from slippery pavement 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 pavement friction data from slippery pavement warning field systems to the ATMS in locations where agency owned communications are not practical.
ATMS to CAVs (slippery pavement warnings)	• **Public internet** – Use of the public internet allows information (e.g. slippery pavement 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 slippery pavement 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 slippery pavement warning system deployment and operations.

Table 4: Slippery Pavement 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 roadway maintenance staff who interact with the slippery pavement warning system and take subsequent action to treat slippery pavements. Where a communications connection is warranted and available, operators may enter slippery pavement conditions (not detected by field devices) or may view reduced friction 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 slippery pavement warning system field equipment or the ATMS capable of supporting slippery pavement warnings.
Technicians and Installers	Technical staff responsible for installing, maintaining, and troubleshooting field equipment that detects pavement friction conditions, processes and communicates the slippery pavement 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 pavement friction 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 slippery pavement notices and alert drivers. CAVs may also be a source of pavement friction 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 connection to the ATMS is present…”) depending on various situations, such as whether the local slippery pavement warning system has a connection to the ATMS or whether the slippery pavement 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 slippery section of pavement.	***Need 1: Real-time, En-route, Local Slippery Pavement Notification*** Travelers need to view information in advance of locations where a slippery condition is impacting the roadway surface, with enough time to adjust their speed accordingly prior to reaching the slippery area.
- Without advanced notice, travelers may not be prepared to encounter slippery pavement conditions along their planned route.	***Need 2: Advanced Slippery Pavement Information*** Travelers need a mechanism for viewing locations where slippery pavement conditions are occurring, in advance of their trip.
Operators Needs	
- Reduced friction on the pavement can occur at unexpected times, even without current precipitation being observed, such as snow blowing across the road and creating a slippery condition.	***Need 3: Automated Activation of Local Slippery Pavement Warning Displays*** In locations prone to recurring slippery pavement conditions, operators need the presence of reduced pavement friction 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 friction on the pavement, and operators can benefit from understanding when reduced friction conditions are occurring on the pavement so they can take subsequent actions.	***Need 4: Operator Interaction with Slippery Pavement Warning Systems*** When local conditions warrant operator influence, operators need a mechanism to interact with slippery pavement warning systems to view conditions and warning displays from a remote location, activate or de-activate the warning 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 slippery pavement warning system operations.	***Need 5: Slippery Pavement Warning System Assessment*** Administrators need the ability to query and understand the operational status of slippery pavement warning system field devices. Depending on whether or not the slippery pavement warning system field equipment has a connection to the ATMS, this assessment may occur in the field or remotely.
- The locations of recurring reduced friction pavement conditions and slippery pavement warning field equipment are important for maintaining an overall understanding of conditions and assets in the field.	***Need 6: Local Slippery Pavement Warning System Configuration*** When a connection to the ATMS is present, administrators need to be able to configure the local slippery pavement warning systems by establishing the locations of the impacted road sections and the slippery pavement 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 slippery pavement warning displays, in order to understand effectiveness of slippery pavement warning systems.	***Need 7: Traffic Data to Assess Driver Response to Slippery Pavement Warning Displays*** When a connection to the ATMS is present, administrators need speed data from traffic detection, to assess vehicle speeds approaching activated slippery pavement 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 friction on the pavement and overall system operations.	***Need 8: Access to Historical Data from Slippery Pavement Warning Systems*** When a connection to the ATMS is present, operators need a mechanism to access historical data from slippery pavement warning systems, such as reports of system activations and data from friction sensors (and atmospheric sensors, if deployed), to help them understand the frequency of activations and impacts to the road segment when recurring instances of reduced friction on the pavement occur.
Technicians and Installers Needs	
- Proper use of field equipment to detect and disseminate slippery pavement 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 slippery pavement 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 slippery pavement 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 Slippery Pavement Warning Systems*** When a slippery pavement warning system is connected to an RWIS station, the Central RWIS Unit needs data from the friction sensors (and atmospheric sensors, if deployed), 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 friction on the pavement is detected.
- Vehicle data (e.g. friction sensors, wheel slippage) can offer insight into reduced pavement friction 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 friction on the pavement whenever possible.
- CAVs will benefit from slippery pavement 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 Slippery Pavement Warnings*** CAVs need to receive infrastructure-generated slippery pavement warnings as they approach these conditions.

Operational Concepts

The operational concepts below are presented for slippery pavement 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 slippery pavement 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 slippery pavement warning operational concepts from the travelers' perspective, and relates each concept to a need, as defined in the previous section.

Table 6: Slippery Pavement Warning Operational Concepts – Travelers' Perspective

Need (Travelers' Perspective)	Operational Concept
Travelers' Perspective related to ***Need 1: Real-Time, En-route, Local Slippery Pavement Notification***	1.1 Travelers driving on selected routes that are prone to recurring slippery pavement conditions may observe static signs or a DMS with a message such as "Slippery Pavement When Flashing" and/or a graphic showing a vehicle slipping. 1.2 Travelers will view warning signs in advance of the slippery pavement condition, with enough time to reduce their speed prior to reaching the slippery pavement. 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 pavement friction is detected, the flashing beacons will be activated or the DMS message will be displayed, and travelers will be alerted to the slippery pavement 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 slippery pavement.
Travelers' Perspective related to ***Need 2: Advanced Slippery Pavement 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 slippery pavement conditions, travelers may see locations where these conditions are occurring. 2.2 Travelers accessing local news media broadcasts may view or hear notices of slippery pavement conditions. 2.3 Travelers will likely receive more consistent and current notices of slippery pavement impacts if the slippery

Need (Travelers' Perspective)	Operational Concept
	pavement warning system has a connection to the ATMS to automate reporting based on real-time conditions.

Operators' Perspective

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

Table 7: Slippery Pavement Warning Operational Concepts – Operators' Perspective

Need (Operators' Perspective)	Operational Concept
Operators' perspectives related to: ***Need 3: Automated Activation of Local Slippery Pavement Warning Displays***	3.1 In locations prone to slippery roadway sections, there may be local slippery pavement warning systems installed to automatically detect reduced pavement friction conditions. 3.2 The detection of reduced pavement friction 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 pavement friction conditions return to a normal level, the activation displays will turn off automatically, without operator input. 3.5 Friction sensors (and atmospheric sensors, if deployed) may include in-place pavement surface detection devices deployed as part of an existing nearby RWIS station.
Operators' perspectives related to ***Need 4: Operator Interaction with Slippery Pavement Warning Systems***	4.1 When a communications connection to the ATMS is present, notices of local slippery pavement 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, i.e. roadway maintenance staff, may receive automated notifications from the ATMS (via email, text message, or other mechanisms) when the slippery pavement 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 slippery pavement warning systems configured in the system to view if reduced pavement friction conditions have been detected, when a

Need (Operators' Perspective)	Operational Concept
	communications connection to the slippery pavement warning system is present. 4.4 When a communications connection to the ATMS is present, operators may use video, when available, to verify and monitor slippery pavement conditions or the current status of the local warning signs using cameras deployed in the field, as available. 4.5 When a communications connection from the slippery pavement warning system to the ATMS is present, operators will use the ATMS to manually activate the slippery pavement warning system remotely, in the event that slippery pavement conditions are identified that local friction 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 friction on the pavement. This could include local sites where operational activities (e.g. snowmaking at ski hills) can contribute to slippery pavement conditions. In circumstances like this, agreements may exist for local venues to call operators to alert them to activities conducive to slippery pavement and request operators to activate warning systems. 4.6 When a communications connection to the ATMS is present, the slippery pavement 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 slippery pavement warning systems will not rely on automated timeout of messages. 4.7 Operators, i.e. roadway maintenance staff, will sometimes manually activate the slippery pavement warning sign locally in the field in the event slippery pavement conditions are identified that local friction sensors do not detect. The supporting systems will cause the local warning signs to activate as they would if the friction sensors had detected the slippery pavement condition. In these situations, the warning signs would need to be manually de-activated.

Administrators' Perspective

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

Table 8: Slippery Pavement Warning Operational Concepts - Administrators' Perspective

Need (Administrators' Perspective)	Operational Concept
Administrators' perspective related to ***Need 5: Slippery Pavement Warning System Assessment***	5.1 Administrators will query and understand the operational status of slippery pavement 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 slippery pavement warning system field devices. 5.3 If a communications connection to the ATMS is present, the ATMS may include functionality to identify faulty friction sensors at the site of the slippery pavement 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 Slippery Pavement Warning System Configuration***	6.1 Administrators will configure the local slippery pavement warning systems once they are installed, if a communications connection to the ATMS is present. Configuration will link the local slippery pavement 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 slippery pavement 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 slippery pavement warning system configuration in the field or remotely when a communications connection to the ATMS is present. 6.4 Administrators may connect the local slippery pavement 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 Slippery Pavement 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 slippery pavement 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 slippery pavement warning system.
Operators' perspectives related to ***Need 8: Access to Historical Data from Slippery Pavement Warning Systems***	8.1 Administrators will view historical data from friction sensors (and atmospheric sensors, if deployed) and past instances of slippery pavement warning system activations and de-activations, to help debrief from incidents or to understand the frequency and timing of reduced friction conditions.

Technicians/Installers' Perspective

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

Table 9: Slippery Pavement 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 Slippery pavement 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 Slippery pavement 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 Slippery pavement warning system field devices will be deployed such that technicians and installers can access the devices to perform maintenance. 9.4 Slippery pavement warning system field devices will be mounted on appropriate support structures, as needed. 9.5 Friction sensors (and any optional atmospheric sensors, if deployed) will be calibrated to activate slippery pavement warning systems when pavement friction conditions are reduced to a level that poses a potential risk to the roadway.
Technicians and Installers' Perspectives related to ***Need 10: Safety Standards***	10.1 Technicians and installers need the slippery pavement 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 slippery pavement warning systems.
Technicians and Installers' Perspectives related to ***Need 11: Equipment Consistency***	11.1 Legacy field devices for slippery pavement warning systems will continue to be used. 11.2 Procurement of new field devices for slippery pavement 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 slippery pavement 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 slippery pavement 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: Slippery Pavement 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 Condition Data from Slippery Pavement Warning Systems***	12.1 When an RWIS station is nearby the slippery pavement warning system site, the friction sensors will communicate pavement surface condition data to the RWIS station in in real-time. 12.2 When optional atmospheric sensors are deployed and an RWIS station is nearby the slippery pavement warning system site, the atmospheric sensors will communicate pavement surface condition data to the RWIS station in in real-time. 12.3 The Central RWIS Unit will access the slippery pavement warning system's friction sensor data (and atmospheric sensor

	data, if deployed) from the RWIS station, to supplement their overall road weather condition datasets. 12.4 In situations where a nearby RWIS station is not present, the Central RWIS Unit may access slippery pavement warning system data through the ATMS, if a 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 slippery pavement 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: Slippery Pavement 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 traction control status and antilock brake system status. 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 friction 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 pavement friction conditions, such as traction control status and antilock brake system status. 14.3 MnDOT may generate Road Safety Messages (RSMs) and broadcast them to CAVs, reporting reduced pavement friction 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 Slippery Pavement Warnings***	15.1 MnDOT may connect roadside units (RSUs) to the Slippery Pavement Warning System's field devices to broadcast messages describing detections of reduced pavement friction 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 slippery pavement 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 slippery condition messages appropriately. 15.4 CAV infrastructure systems operated by MnDOT may receive slippery pavement condition reports from the ATMS (that originally were detected by slippery pavement 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 slippery pavement warning systems, it is important for deploying agencies to determine agency-level roles for ownership, operation, and maintenance of slippery pavement warning systems, 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 slippery pavement 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 slippery pavement warning.

Table 12: Operation and Maintenance Roles and Responsibilities

User Group	Role/Responsibility
Travelers	• View messages on slippery pavement warning signs to make decisions about reducing vehicle speeds in anticipation of potentially slippery pavement conditions.
Operators	• Monitor the status of slippery pavement 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 nearby cameras to assess pavement surface conditions or warning sign display statuses. • Add or edit slippery pavement events in CARS (when they are informed of these conditions). • Activate and de-activate slippery pavement 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 slippery pavement warning systems to the ATMS (if connected to the ATMS). • Connect new slippery pavement warning system's friction sensors (and atmospheric sensors, as deployed) to nearby RWIS stations, as needed. • Query the operational status of slippery pavement warning system equipment using the ATMS, to identify operational issues.

User Group	Role/Responsibility
	• Receive automatic notifications about operational issues (if connected to the ATMS). • Notify technicians and installers of operational issues, to initiate repairs as needed. • Access vehicle speed data and slippery pavement warning system activation history (if connected to the ATMS) to evaluate the effectiveness of slippery pavement warning systems.
Technicians/Installers	• Prepare needed designs for slippery pavement warning system supporting infrastructure and support structures. • Install slippery pavement warning systems (including needed traffic control). • Troubleshoot technical issues with the slippery pavement 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 slippery pavement warning systems with the ATMS (if connected to ATMS). • Participate in connecting friction (and atmospheric sensors, as deployed) sensors to nearby RWIS, as needed.
Central RWIS Unit	• Define formats needed for data to be collected by friction sensors (and atmospheric sensors, as deployed), if these devices will communicate pavement condition data to a nearby RWIS station. • Access pavement condition data (e.g. reduced friction detections) generated by local slippery pavement warning systems and communicated to nearby RWIS stations (if RWIS stations are nearby the slippery pavement warning system site.)

Operational Scenarios

Scenarios are intended to describe examples of how users would interact with the slippery pavement 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 Slippery Pavement Warning System
- Scenario B: Automated Activation of a Slippery Pavement Warning System
- Scenario C: Slippery Pavement Warning System Monitoring and Control with ATMS
- Scenario D: Manual Activation of a Slippery Pavement Warning Sign at the Site
- Scenario E: Maintenance and Repair of Slippery Pavement Warning Systems
- Scenario F: Slippery Pavement Warning System Friction Sensors Connected to RWIS Station
- Scenario G: CAV Use of Messages from RSUs at Slippery Pavement Warning Systems
- Scenario H: CAV Use of Messages from Wide Area Communications Reporting Slippery Pavement Warning Systems

Scenario A: Deploying a Slippery Pavement Warning System

MnDOT District 4 staff identify a section of pavement that is prone to becoming slippery when snow blows across the road and sticks to the pavement. The pavement approaching this slippery section tends to remain dry, therefore drivers often don't expect to experience the problematic slippery pavement section. The pavement section is located 30 miles from the closest district maintenance shop, making it difficult to treat the slippery pavement section in a timely manner. District 4 staff determine that this pavement section would benefit from a slippery pavement 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 section of pavement is not currently instrumented with friction sensors. During deployment, installers work with administrators and operators to configure the slippery pavement 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 friction sensors can communicate data to RWIS. The slippery pavement 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 Slippery Pavement Warning System

MnDOT identifies a section of pavement that is prone to recurring slippery conditions and has decided to install a slippery pavement warning system. The recurring slippery pavement site is in a rural area, located several miles from a maintenance shop and does not have long-distance communications infrastructure nearby. During the planning phase, MnDOT determines that it would be cost prohibitive to install long-distance communications infrastructure to the site, and therefore the slippery pavement warning system will not communicate with the ATMS. The slippery pavement warning system is installed and operates only with local processing and communications at the site. As ice buildup forms on the pavement, the friction sensors detect the slippery pavement condition when the pavement friction reaches a pre-determined threshold. The friction sensors activate flashing beacons on static warning signs that indicate "Ice on Road When Flashing," located upstream of the slippery pavement section in both directions. An approaching motorist sees a warning sign and reduces the vehicle's speed prior to reaching the slippery pavement section. A few hours later the slippery pavement condition is treated during routine maintenance activities. The sign's flashing beacons continue to flash until the friction sensors detect that the pavement friction has returned to a pre-determined normal level, at which time the beacons stop flashing.

Scenario C: Slippery Pavement Warning System Monitoring and Control with ATMS

A slippery pavement warning system deployed in central Minnesota is connected to the ATMS. As friction levels on the pavement at the slippery pavement warning system site drop below a pre-determined level, the friction sensors detect the condition and trigger activation of the warning signs. Because the slippery pavement 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 slippery pavement warning system has been activated or de-activated is enabled. This notification feature is configured in the ATMS to send text messages to the district maintenance supervisor and selected operators, for all activations and de-activations. Therefore, at the time of activation, the ATMS sends an automated text message to the pre-identified maintenance supervisor and operators, alerting them that the slippery pavement warning system has been activated. Upon receiving the text message notification, the maintenance supervisor sends a truck to treat the slippery pavement section. Operators view nearby cameras to assess the pavement condition and view the operational status of the warning sign. After the

road treatment takes effect and the pavement friction has returned to a pre-determined normal level, the maintenance supervisor and operators receive a notification that the slippery pavement warning system has been de-activated. Operators view nearby cameras and see that the beacons on the warning sign are still flashing, though it appears the pavement section is dry. Maintenance staff in the field confirm that the icy pavement section is dry, then operators use the ATMS to de-activate the warning sign remotely.

Scenario D: Manual Activation of a Slippery Pavement Warning Sign at the Site

During a cold winter day, a member of MnDOT's roadway maintenance staff drives by a slippery pavement warning system on a rural highway and sees that the sign is not activated (beacons on the sign are not flashing) even though ice is beginning to form on the pavement downstream of the sign. The slippery pavement warning system is not connected to the ATMS. This maintenance staff manually activates the beacons on the sign and calls a nearby maintenance vehicle to treat the icy pavement. The pavement is treated with de-icing material. After a few hours, the maintenance staff returns to the site, observes that the slippery conditions have melted and returned to normal, and de-activates the sign. A few days later, the same roadway maintenance staff drives by the warning sign and sees that the slippery pavement warning system appears to be functioning properly, as it has activated automatically with ice formation on the pavement.

Scenario E: Maintenance and Repair of Slippery Pavement Warning Systems

Over the course of a few weeks during the winter months, MnDOT district field staff periodically drive by a slippery pavement warning system and notice that it is consistently not activating when the pavement downstream of the sign is slippery. The district field staff contact administrators and technicians to inform them that the slippery pavement 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 friction sensors are not working properly and replaces the faulty devices. Several miles away in the same district, a slippery pavement warning system is connected to the ATMS. At this site, one of the friction sensors is not operating properly. The ATMS includes functionality (i.e. algorithms) to assess the operability of the friction sensors on a regular basis to identify faulty sensors. When this friction 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 slippery pavement warning system and operations are not impacted.

Scenario F: Slippery Pavement Warning System Friction Sensors Connected to RWIS Station

A new slippery pavement warning system is being deployed at a rural section of roadway just west of the Minneapolis metro area. There is an RWIS station nearby, but the impacted pavement section does not yet have friction sensors in place. During installation of the slippery pavement warning system, installers work with administrators to connect the new friction sensors to the nearby RWIS station, and the pavement surface condition data from the newly installed friction 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 pavement surface condition data from the RWIS station, and uses the data to inform maintenance operations on an ongoing basis.

Scenario G: CAV Use of Messages from RSUs at Slippery Pavement Warning Systems

MnDOT is operating a slippery pavement warning system with a roadside unit (RSU) that broadcasts messages describing reduced pavement friction detections at the site of the warning system. As friction

sensors detect pavement friction levels that drop below a pre-determined threshold, the RSU sends periodic messages indicating the slippery pavement detection. A nearby vehicle equipped with CAV technology is approaching the slippery pavement area. The CAV receives and processes the reduced pavement friction 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 slippery pavement area.

Scenario H: CAV Use of Messages from Wide Area Communications Reporting Slippery Pavement Warning Systems

MnDOT is operating multiple slippery pavement 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 friction sensors have determined conditions may be slippery. 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 slippery pavement 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 slippery pavement 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 slippery pavement 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 slippery pavement warning system) in order to perform the functions as described. In particular, deployments where the slippery pavement 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 slippery pavement warning system and perform the functions described.

Table 13: Slippery Pavement Warning System Requirements by Need

Need	System Requirement
Travelers	
1. Travelers need to view information in advance of locations where a slippery condition is impacting the roadway surface, with enough time to adjust their speed accordingly prior to reaching the slippery area.	1.1. In locations that experience recurring icy pavement conditions, slippery pavement warning system deployments shall be considered, to advise travelers of locations where slippery pavement conditions may impact the roadway surface. 1.2. Slippery pavement warning systems shall activate visual alerts to drivers when slippery pavement conditions are detected downstream. 1.3. Warning signs for slippery pavement warning systems shall be located such that the sign displays are visible to approaching drivers. 1.4. Warning signs (types, placements, etc.) shall be designed in accordance with the Minnesota MUTCD. 1.5. Warning signs shall be placed in advance of the slippery pavement 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 slippery pavement conditions are occurring, in advance of their trip.	2.1. When a communications connection to the ATMS is present, the slippery pavement 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 slippery pavement conditions, operators need the presence of reduced pavement friction 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 reduced friction on the pavement by friction sensors (with supplemental data from atmospheric sensors, if deployed) shall automatically activate the warning sign displays to alert travelers of slippery pavement conditions ahead. 3.2. The slippery pavement warning activations shall turn off automatically as friction sensors (with supplemental data from atmospheric sensors, if deployed) detect that the reduced friction condition has diminished. 3.3. If in-place friction sensors (and atmospheric sensors, if deployed) that are part of a nearby RWIS station are used for a slippery pavement warning system, these sensors shall be capable of detecting reduced friction pavement conditions such that the slippery pavement warning system can utilize the sensor data to activate and de-activate the warning signs. 3.4. To the extent practical, slippery pavement warning system components (i.e. field devices) shall be compliant with NTCIP standards.
4. When local conditions warrant operator influence, operators need a mechanism to interact with slippery pavement warning systems to view conditions and warning displays from a remote location, activate or de-activate the warning 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 slippery pavement warning system shall communicate reduced friction 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 slippery pavement warning systems configured in the ATMS, to view the activation statuses of the slippery pavement warning systems. (ATMS dependency) 4.4. When a communications connection from the slippery pavement warning system to the ATMS is present, the ATMS shall have a mechanism to manually activate and de-activate

Need	System Requirement
	the slippery pavement warning system remotely. (ATMS dependency) 4.5. Slippery pavement 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 slippery pavement warning system site, video field devices shall be positioned such that users can view the status of the warning signs and the impacted pavement sections via the ATMS. 4.7. 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. 4.8. 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 slippery pavement warning system field devices. Depending on whether or not the slippery pavement warning system field equipment has a connection to the ATMS, this assessment may occur in the field or remotely.	5.1. The slippery pavement 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 slippery pavement 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 friction sensors at the site of the slippery pavement warning system and generating a message in the ATMS that shows the location of the faulty sensor. (ATMS dependency)
6. When a connection to the ATMS is present, administrators need to be able to configure the	6.1. When a communications connection to the ATMS is present, the ATMS shall allow users to add and delete slippery pavement warning systems in the ATMS once they are installed. (ATMS dependency)

Need	System Requirement
slippery pavement warning systems by establishing the locations of the impacted road sections and the slippery pavement warning system devices (e.g. detection, signage) in the ATMS.	6.2. When a communications connection to the ATMS is present, the ATMS shall allow users to establish the slippery pavement warning system location in the ATMS, in order to process reduced friction on pavement alerts received and assign them properly to roads. (ATMS dependency) 6.3. When a communications connection to the ATMS is present, the slippery pavement warning system shall support local on-site configuration of the field devices to the ATMS.
7. When a connection to the ATMS is present, administrators need speed data from traffic detection, to assess vehicle speeds approaching activated slippery pavement 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 connection to the ATMS is present, the ATMS shall allow users to access speed data from traffic detection approaching slippery pavement warning signs (when traffic detection is present), with corresponding timestamps of system activations and de-activations. (ATMS dependency) 7.2. When a connection to the ATMS is present, the ATMS shall allow users to query and access slippery pavement 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 connection to the ATMS is present, administrators need a mechanism to access historical data from slippery pavement warning systems, such as reports of system activations and data from friction sensors, to help them understand the frequency of activations and impacts to the road segment when recurring instances of reduced friction on the pavement occur.	8.1. When a connection to the ATMS is present, the ATMS may have a mechanism for users to view and create reports of past slippery pavement warning system activations and de-activations, including corresponding timestamps. (ATMS dependency) 8.2. When a connection to the ATMS is present, the ATMS may have a mechanism for users to view and create reports showing data from friction sensors (and atmospheric sensors, if deployed), such as pavement friction or atmospheric condition information with corresponding timestamps. (ATMS dependency)
Technicians and Installers	
9. Technicians and installers need power, communications, and support structures to be	9.1. Slippery pavement warning system field devices shall be designed and installed in accordance with requirements for roadway clearance and crashworthiness (e.g. breakaway structures or protection.)

Need	System Requirement
available at locations where field equipment for slippery pavement 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.	9.2. Slippery pavement warning system design shall include the approach to mounting the field devices. 9.3. Slippery pavement warning system design shall include power connections. 9.4. Slippery pavement warning system design shall include components to support local communications. 9.5. When a communications connection to the ATMS is present, the slippery pavement warning system design shall include components to support remote, long-distance communications. 9.6. Slippery pavement warning system design shall include adequate visibility of warning signs. 9.7. Slippery pavement 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 slippery pavement warning system field deployment. The detection mechanisms, communications, traveler displays, and CAV dissemination components should all be considered in the design. 10.2. Slippery pavement warning system field devices shall include components to support safe lifting, transport, and installation of the devices. 10.3. Slippery pavement warning system field devices shall meet current specifications as approved by MnDOT or the agency/owner that is deploying and operating the slippery pavement warning system. 10.4. Slippery pavement warning system design shall include TTC plans for installing or performing field work on slippery pavement warning system field devices.

Need	System Requirement
11. Technicians and installers need consistency and compatibility in the slippery pavement warning equipment to achieve efficiencies in procurement, maintenance, and training.	11.1. Slippery pavement 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 slippery pavement 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. Slippery pavement warning system field devices shall utilize MnDOT standardized components, as available. 11.4. Slippery pavement 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 local slippery pavement warning system is connected to an RWIS station, the Central RWIS Unit needs data from the friction sensors (and atmospheric sensors, if deployed), to increase their understanding of road weather conditions.	12.1. Friction sensors installed as part of slippery pavement warning systems shall produce road surface condition data in a format that is consistent with data from RWIS stations. 12.2. If optional atmospheric sensors are deployed as part of slippery pavement warning system, these sensors shall produce atmospheric condition 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 friction on the pavement 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 traction control status and antilock brake system status) 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 friction on the	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 traction control status and antilock brake system status, to help identify reduced friction on pavement conditions.

Need	System Requirement
pavement whenever possible.	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 pavement friction 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 slippery pavement warnings as they approach these conditions.	15.1. DOTs may locate roadside units to broadcast information such as slippery pavement conditions (detected by friction sensors and atmospheric sensors, if deployed) that will be received by CAVs. 15.2. Roadside units may receive slippery pavement 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 slippery pavement 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 slippery pavement 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 slippery pavement 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 slippery pavement conditions, including the geographic boundaries of the warnings. 15.7. CAVs may ingest the messages describing slippery pavement 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 slippery pavement warning;
- Concepts for the use of slippery pavement 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 slippery pavement 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 slippery pavement 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 Slippery Pavement Warning Needs

MN Statewide Regional ITS Architecture: Need/Potential Solutions	ARC-IT: Service Packages	ARC-IT: Processes	Slippery Pavement 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 Slippery Pavement Notification • Need 2: Advanced Slippery Pavement Information • Need 3: Automated Activation of Local Slippery Pavement Warning Displays • Need 15: Vehicle Use of Infrastructure-generated Slippery Pavement Warnings
• ATIS04 Provide current and forecast road and weather condition information	• TM12 Dynamic Roadway Warning	• Manage Roadway Warning System	• Need 4: Operator Interaction with Slippery Pavement Warning Systems • Need 5: Slippery Pavement Warning System Assessment • Need 6: Local Slippery Pavement 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 Slippery Pavement Warning Systems • Need 8: Access to Historical Data from Slippery Pavement Warning Systems
• ATIS04 Provide current and forecast road and weather condition information	• TM12 Dynamic Roadway Warning	• Monitor Roadside Equipment Operation	• Need 5: Slippery Pavement 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 Slippery Pavement Warning Systems

MN Statewide Regional ITS Architecture: Need/Potential Solutions	ARC-IT: Service Packages	ARC-IT: Processes	Slippery Pavement 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: Slippery Pavement 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 Slippery Pavement Warning Displays
• ATIS04 Provide current and forecast road and weather condition information	• MC09 Infrastructure Monitoring	• Collect Infrastructure Sensor Data	• Need 5: Slippery Pavement 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 Slippery Pavement 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 Slippery Pavement 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	Slippery Pavement 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 Slippery Pavement Notification
• WTR01 Provide automated monitoring of road weather conditions	• WX02 Weather Information Processing and Distribution	• Collect Environmental Data	• Need 12: Road Condition Data from Slippery Pavement 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 Slippery Pavement 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 Slippery Pavement 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 Slippery Pavement 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 Slippery Pavement 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 slippery pavement warning to confirm that the system is developed, installed, and operating as specified by the system requirements.

Each slippery pavement 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 slippery pavement 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 slippery pavement 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 slippery pavement 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 slippery pavement warning to verify the quality assurance/quality control and slippery pavement 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 slippery pavement warning.

Table 15: Model Test Plan for Slippery Pavement Warning

System Requirement		Testing Instructions	Type of Result	Comments / Notes
1.1	In locations that experience recurring icy pavement conditions, slippery pavement warning system deployments shall be considered, to advise travelers of locations where slippery pavement conditions may impact the roadway surface.	Advisory requirement – no testing required	N/A	
1.2	Slippery pavement warning systems shall activate visual alerts to drivers when slippery pavement conditions are detected downstream.	Field – Conduct test to confirm all supporting infrastructure is installed and operational (e.g. detection, power, communications) so the slippery pavement warning system activates the visual alerts when reduced friction on the pavement is detected.	Pass/Fail	
1.3	Warning signs for slippery pavement 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 be designed in accordance with the Minnesota MUTCD.	Design – Confirm that the warning signs were designed in accordance with the Minnesota MUTCD. 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 slippery pavement condition, at a distance such that the signs provide adequate perception-response time for the driver. (See	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
	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 slippery pavement 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 slippery pavement warning system is designed to send alerts to the ATMS for system activations and de-activations. Field - Conduct test to confirm that the slippery pavement 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 friction on the pavement by friction sensors (with supplemental data from atmospheric sensors, if deployed) shall automatically activate the warning sign displays to alert travelers of slippery pavement conditions ahead.	Design – Confirm that the slippery pavement warning system display is designed to automatically activate when reduced friction on the pavement is detected. Field – Conduct test to confirm that the slippery pavement warning system will activate when reduced friction on the pavement is detected.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field – Pass/Fail	
3.2	The slippery pavement warning activations shall turn off automatically as friction sensors (with supplemental data from atmospheric sensors, if	Design – Confirm that the slippery pavement warning system display is designed to automatically de-activate	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	

	System Requirement	Testing Instructions	Type of Result	Comments / Notes
	deployed) detect that the reduced friction condition has diminished.	when the reduced friction condition on the pavement has diminished. Field – Conduct test to confirm that the slippery pavement warning system will de-activate when the reduced friction condition on the pavement has diminished.	 Field – Pass/Fail	
3.3	If in-place friction sensors (and atmospheric sensors, if deployed) that are part of a nearby RWIS station are used for a slippery pavement warning system, these sensors shall be capable of detecting reduced friction pavement conditions such that the slippery pavement warning system can utilize the sensor data to activate and de-activate the warning signs.	Design – Confirm that the in-place friction sensors (and any atmospheric sensors, if deployed) are capable of detecting pavement friction levels in accordance with the slippery pavement system design, to activate and de-activate warning signs. Field – After the in-place friction sensors (and any atmospheric sensors, if deployed) have been connected to communicate with the slippery pavement warning system, conduct a test to confirm that the signs activate with reduced friction levels on the pavement and de-activate when reduced friction 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, slippery pavement warning system components (i.e. field devices) shall be compliant with National Transportation Communications for ITS Protocol (NTCIP) standards.	Design – Confirm NTCIP compliance for slippery pavement warning field devices, to the extent practical.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
4.1	When a communications connection to the ATMS is present, the slippery pavement warning system shall communicate reduced friction 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.)	Design – Confirm that the design allows field devices to communicate reduced friction on pavement detections to the ATMS. Field – Confirm that the ATMS receive notices of reduced friction on pavement detections.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	
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 pavement warning 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 slippery pavement warning systems configured in the ATMS, to view the activation statuses of the slippery pavement warning systems. (ATMS dependency)	Field – Confirm that the ATMS displays the slippery pavement warning systems configured in the ATMS. Field – Confirm that the ATMS is configured to display instances when reduced friction on pavement conditions have been detected by the slippery pavement warning system. Field – Confirm that the ATMS is configured to display instances when reduced friction on pavement conditions have diminished, as detected by the slippery pavement warning system.	Field - Pass/Fail	ATMS dependency

System Requirement		Testing Instructions	Type of Result	Comments / Notes
		Field – Confirm that the ATMS is receiving data communications from the slippery pavement warning system describing the system activations. Field – Confirm that the ATMS is receiving data communications from the slippery pavement warning system describing the system de-activations.		
4.4	When a communications connection from the slippery pavement warning system to the ATMS is present, the ATMS shall have a mechanism to manually activate and de-activate the slippery pavement warning system remotely. (ATMS dependency)	Design – Confirm that the design allows the slippery pavement warning system displays to be manually activated remotely using the ATMS, per local design choice. Field – Confirm that the slippery pavement warning system display can be manually activated remotely using the ATMS. Field – Confirm that the slippery pavement 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 Field - Pass/Fail	ATMS dependency
4.5	Slippery pavement 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 slippery pavement warning system display to be manually activated and de-activated locally at the device. Field – Confirm that the slippery pavement 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	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
4.6	When a communications connection to the ATMS is present and video is deployed at the slippery pavement warning system site, video field devices shall be positioned such that users can view the status of the warning signs and the impacted pavement sections via the ATMS.	Design – Confirm that the design shows video field devices positioned to enable adequate viewing of impacted pavement sections and warning signs via the ATMS, with field device features such as pan-tilt-zoom as needed. Field – Confirm adequate viewing of impacted pavement sections and warning signs by using the ATMS to access video field devices and view the site.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	
4.7	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 (option is either display of one message or no message) the communications would be to activate or de-activate.	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	
4.8	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	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
5.1	The slippery pavement 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 their operational status.	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	
5.3	When a communications connection to the ATMS is present and electrical current sensing devices are available, the slippery pavement 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 slippery pavement 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 friction sensors at the site of the slippery pavement warning system and	Field – Conduct a test with an absent or faulty friction sensor to ensure that the ATMS detects that the sensor is not functioning properly.	Field – Pass/Fail	ATMS dependency

System Requirement		Testing Instructions	Type of Result	Comments / Notes
	generating a message in the ATMS that shows the location of the faulty sensor. (ATMS dependency)			
6.1	When a communications connection to the ATMS is present, the ATMS shall allow users to add and delete slippery pavement warning systems in the ATMS once they are installed. (ATMS dependency)	Design – Confirm that the design allows the slippery pavement 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 slippery pavement 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 slippery pavement warning system location in the ATMS, in order to process reduced friction pavement alerts received and assign them properly to roads. (ATMS dependency)	Design – Confirm that the design allows the slippery pavement warning system location to be established in the ATMS. Field – Confirm that the ATMS has established the slippery pavement warning system location in the ATMS.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	ATMS dependency
6.3	When a communications connection to the ATMS is present, the slippery pavement warning system shall support local on-site configuration of the field devices to the ATMS.	Design – Confirm that the design allows the slippery pavement warning system to be configured to the ATMS from on-site at the field devices. Field – Confirm that field staff can configure the slippery pavement 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 connection to the ATMS is present, the ATMS shall allow users to access speed data from traffic detection approaching slippery pavement warning signs (when traffic	Design – Confirm that the design allows for speed data from traffic detection approaching the slippery pavement warning signs to be accessed along with	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	ATMS dependency

	System Requirement	Testing Instructions	Type of Result	Comments / Notes
	detection is present), with corresponding timestamps of system activations and de-activations. (ATMS dependency)	corresponding system activation and de-activation timestamps. Field – Confirm that ATMS users can view and access speed data from traffic detection approaching the slippery pavement warning signs, with corresponding timestamps of system activations and de-activations.	Field - Pass/Fail	
7.2	When a connection to the ATMS is present, the ATMS shall allow users to query and access slippery pavement 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 slippery pavement 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 slippery pavement warning systems and data from traffic detection approaching the system's warning signs.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	ATMS dependency
8.1	When a connection to the ATMS is present, the ATMS may have a mechanism for users to view and create reports of past slippery pavement 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 slippery pavement warning system activations and de-activations with corresponding timestamps. Field – Confirm that ATMS users can view and create reports of slippery pavement 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

System Requirement		Testing Instructions	Type of Result	Comments / Notes
8.2	When a connection to the ATMS is present, the ATMS may have a mechanism for users to view and create reports showing data from friction sensors (and atmospheric sensors, if deployed),, such as pavement friction or atmospheric condition information with corresponding timestamps. (ATMS dependency)	Design – Confirm that the design allows the ATMS to view and create reports of data from friction sensors and atmospheric sensors, if deployed. Field – Confirm that ATMS users can view and create reports of data from friction sensors and atmospheric sensors, if deployed.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. Field - Pass/Fail	ATMS dependency
9.1	Slippery pavement 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 slippery pavement system design meets current requirements for roadway clearance and crashworthiness. FAT – Confirm that slippery pavement 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	
9.2	Slippery pavement 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	Slippery pavement 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	Slippery pavement 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.	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
9.5	When a communications connection to the ATMS is present, the slippery pavement 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	Slippery pavement warning system design shall include adequate visibility of warning signs.	Design – Confirm that warning sign design allows for adequate visibility to drivers.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	
9.7	Slippery pavement 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 slippery pavement warning system field deployment. The detection mechanisms, communications, traveler displays, and CAV dissemination components should all be considered in the design.	Design – Confirm review by a Minnesota professional engineer.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	
10.2	Slippery pavement 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	Slippery pavement warning system field devices shall meet current specifications as approved by MnDOT or the agency/owner that is deploying	Design – Confirm that specifications have been developed or acquired from the agency/owner and are approved for use in final acceptance.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	

	System Requirement	Testing Instructions	Type of Result	Comments / Notes
	and operating the slippery pavement warning system.	Design - Confirm that specifications of the deploying/operating agency/owner are met. FAT – Confirm that field devices meet the agency/owner specifications.	FAT – Pass/Fail	
10.4	Slippery pavement warning system design shall include TTC plans for installing or performing field work on slippery pavement 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	Slippery pavement 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 slippery pavement 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.	Advisory requirement – no testing required.	N/A	
11.3	Slippery pavement 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.	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
11.4	Slippery pavement 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	Friction sensors installed as part of slippery pavement warning systems shall produce road surface condition data in a format that is consistent with data from RWIS stations.	Design – Confirm that the design includes friction sensors that produce data in a format consistent with RWIS station data.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required.	
12.2	If optional atmospheric sensors are deployed as part of slippery pavement warning system, these sensors shall produce atmospheric condition data in a format that is consistent with data from RWIS stations.	Design – If atmospheric sensors are part of the approved design, confirm that the design includes atmospheric 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 traction control status and antilock brake system status) from other vehicles and use this information to support such	Advisory requirement – no testing required	N/A	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
	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 traction control status and antilock brake system status, to help identify reduced friction on pavement 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 slippery pavement 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 pavement friction 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 slippery pavement conditions (detected by friction sensors and atmospheric sensors, if deployed)) 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 slippery pavement 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 slippery pavement related message. • Broadcast the generated CAV message to via one or more standard communications mechanisms.	Field – Pass/Fail	
15.2	Roadside units may receive slippery pavement 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 slippery pavement warning data included.	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
		Field – Confirm with one or more on-board devices that the roadside unit is able to: • Receive CAV messages in standard formats. • Process CAV messages to generate roadside safety messages to broadcast to vehicles. • Broadcast of roadside safety message with slippery pavement warning data included.		
15.3	When local RSUs are connected to slippery pavement 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 slippery pavement warning systems. FAT – Demonstration of roadside unit or slippery pavement warning system to generate standards compliant CAV messages. Field – Confirm with one or more on-board devices that the roadside unit or the slippery pavement 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 slippery pavement warning systems, either the warning systems or the RSU shall assign security credentials to the messages according to the agency	Design – Confirm that the security credentialing approach for CAV messages meets the agency approach and requirements for secure connections.	Design – Pass/Fail per Content Review. If "Fail," indicate changes required. FAT - Pass/Fail	

	System Requirement	Testing Instructions	Type of Result	Comments / Notes
	approach and requirements for secure connections.	FAT – Demonstration of roadside unit or slippery pavement warning system to assign security credentials to CAV messages. Field – Confirm with one or more on-board devices that CAV messages received from the roadside unit or the slippery pavement warning system have been assigned appropriate security credentials.	Field – Pass/Fail	
15.5	When local RSUs are connected to slippery pavement 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 slippery pavement 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 slippery pavement 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 slippery pavement 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 slippery pavement conditions, including the geographic boundaries of the warnings.	Advisory requirement – no testing required	N/A	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
15.7	CAVs may ingest the messages describing slippery pavement 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	