DEPARTMENT OF TRANSPORTATION

Model Systems Engineering Document

ITS Application: Dynamic Message Signs

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Contents

Acronyms

ARC-IT	• National Architecture Reference for Cooperative and Intelligent Transportation
ATMS	• Advanced Traffic Management Software
CAV	• Connected and Automated Vehicle
CCTV	• Closed Circuit Television
DMS	• Dynamic Message Signs
HOT	• High Occupancy Toll
HOV	• High Occupancy Vehicle
ICM	• Integrated Corridor Management
ILCS	• Individual Lane Control Signs
IRIS	• Intelligent Roadway Information System
ITS	• Intelligent Transportation System
LAN	• Local Area Network
MCM	• Maintenance and Construction Management
MnDOT	• Minnesota Department of Transportation
MUTCD	• Manual on Uniform Traffic Control Devices
NRTL	• Nationally Recognized Testing Laboratory
NTCIP	• National Transportation Communications for ITS Protocol
OBE	• On-Board Equipment
OSHA	• Occupational Safety and Health Administration
RSM	• Roadside Safety Message
RSU	• Roadside Units
RTMC	• Regional Transportation Management Center
SEA	• Systems Engineering Analysis
TTC	• Temporary Traffic Control
VPN	• Virtual Private Network
WAN	• Wide Area Network

Purpose and Description of ITS Application: DMS

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 Dynamic Message Signs (DMS). The content of this document will be a systems engineering analysis resource to support project compliance as set forth in 23 CFR Section 940 (Rule 940). This document can be used in conjunction with the Minnesota Statewide Regional Intelligent Transportation System (ITS) Architecture and related systems engineering 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 DMS

Transportation agencies commonly use DMS applications to safely and effectively display messages to travelers to view while they are en-route to their destination. DMS messages can be read by all travelers observing the signs. As operations of Connected and Automated Vehicles (CAVs) expand, several data exchanges between DMS and CAVs are anticipated, and these are presented in this document. DMS messages are either posted manually by operators or automatically through related systems. In addition to the physical signs deployed in the field, there are additional components that collectively comprise DMS Applications.

Table 1 describes the environment/components that are critical to the operations of DMS or interface with, either directly or indirectly, DMS applications.

Table 1: DMS Environment/Components

Environment/Component	Function
1. Permanent DMS	The physical signs installed in the field and connected to permanent communications.
2. Portable DMS	The physical signs that are portable and moved to temporary locations with communication capabilities for remote control (portable signs limited to on-site message posting are not included in this document).
3. DMS Control Software	The software system or systems used to remotely monitor, control, and configure DMS through existing communications infrastructures.
4. Supporting Communications	The communications infrastructure to allow data communications to the DMS from remote locations. (See details in the *Model System Engineering Document, ITS Application: Communications* document.)

Environment/Component	Function
5. Advanced Traffic Management Software (ATMS)	The software that is used by traffic operations personnel to monitor traffic and control infrastructure systems. Examples of relations to DMS are that the ATMS systems may calculate and determine DMS messages automatically, such as travel time calculations or dynamic road pricing. MnDOT's ATMS, known as IRIS, also acts as the DMS Control Software.
6. CAV Infrastructure Systems	The systems deployed by the DOTs to communicate with on-board units within CAVs. DMS or DMS Control Software may communicate data with CAV Infrastructure Systems.
7. 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 DMS communicate directly with the CAVs.

The primary DMS components and related systems are illustrated in Figure 1 below.

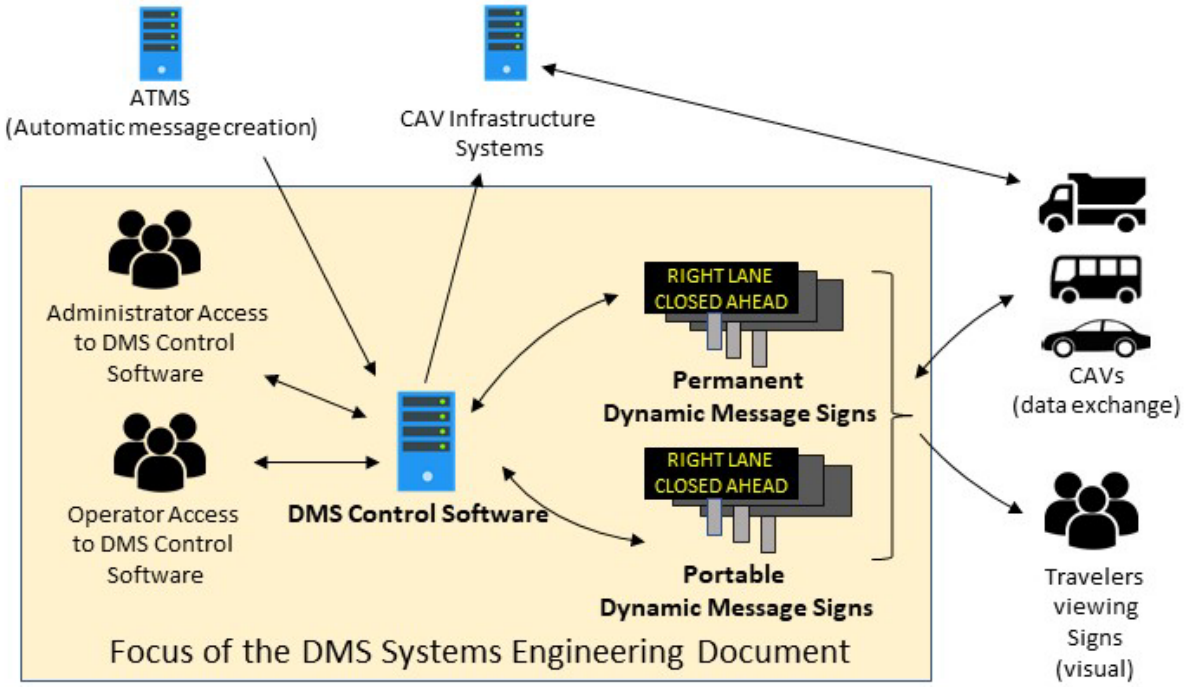

Figure 1: Illustration of Primary DMS Application Components and Related Systems/Users

Examples of Permanent and Portable DMS

As noted above, the primary field devices described in this document are permanent DMS including a variety of sizes and functions ranging from color full matrix to Individual Lane Control Signs (ILCS) to travel time combination static/dynamic signs. Portable DMS are also covered in this document, although the operational concepts are limited to the most typical uses by MnDOT.

Table 2 provides an overview of the DMS field equipment included in this document.

Table 2: Overview of DMS

DMS Type	Description	Picture
Full Matrix	Typically used to convey messages to drivers with a combination of text and graphics. Example uses include travel time messages, incident or other alert messages, emulating static signs or ILCS, and High Occupancy Toll (HOT) lane status. May be mounted overhead above lanes of travel, or off to the side of the road. Access to the sign is either front access, rear access, or walk-in.	
ILCS	Small signs typically mounted over each lane to display status of the lane. Status may include images such as 'X' to indicate closure or arrows to recommend merging. Lane control signs may also be used to indicate the status of High Occupancy Vehicle (HOV)/HOT lanes (e.g. open to all traffic).	
Dynamic Inserts	Signs dedicated to the regular display of real-time status, described by a static portion of the sign. Uses may include travel time displays where destinations are on static signs, parking lot status (number of vacant spots is dynamic), transit (arrival/departure time is dynamic), pricing (real-time price is dynamic).	
Portable DMS	Signs that are typically on trailers or MnDOT vehicles and deployed to locations when dissemination is needed for a temporary period, including work zones, special events, and some incidents.	
Character or Line Matrix	Less flexibility in display from the full matrix as the sign is divided into characters or lines with a matrix assigned to each. Example use cases are similar to full matrix signs. Less preferred than full matrix signs.	

Examples of Communications Technologies Supporting DMS

The DMS application relies upon a number of communications technologies (detailed in a separate document - *Model System Engineering Document, ITS Application: Communications*) to display messages on field devices for eventual end users. The following table summarizes examples of communications technologies used today.

Table 3: Examples of Current Communications Supporting DMS Applications

DMS Application Communications	Communications Technologies Supporting DMS Applications
DMS Control Software to DMS	• **Long range communications** – Ethernet connections using fiber or copper mediums to communicate between the ATMS and cabinets or switches that connect locally to permanent DMS. • **Short-range wireline or wireless communications** – Ethernet or serial connections using fiber or copper mediums or wireless connections using WiFi, microwave, or FM radio, depending on local conditions, to support two-way communications over the short distances from the cabinets or switched to permanent DMS. • **DOT operated Local Area Network (LAN) or Wide Area Network (WAN)** – Private communications network that allows connections to permanent DMS with standard security concerns. • **Virtual Private Network (VPN) over public internet** – Secure and encrypted communications over less secure networks and the public internet allow communications from the ATMS to permanent DMS in locations where agency owned communications are not practical. • **Public internet** – Use of the public internet allows information to be shared from the ATMS to Portable DMS, typically in cooperation with commercial cellular phone connectivity to the Portable DMS. • **Commercial wireless communications** – Services provided by third party providers over commercial networks, such as cellular, allow wireless communications between the ATMS to Portable DMS, including DMS message content and operational status.
DMS to CAVs	• **Short-range, wireless, low latency Communications** – Extremely low latency communications from DMS to CAVs that are able to support credentials-based security protocols within a line of sight range of generally 300 meters or less. • **Commercial wireless communications** – Services provided by third party providers over commercial networks such as cellular allow wireless communications of DMS message content to CAVs directly from the DMS.

DMS Application Communications	Communications Technologies Supporting DMS Applications
DMS Control Software to CAVs (DMS message content)	• **Public internet** – Use of the public internet allows DMS message may enable content to be shared from the DMS Control Software to CAVs. • **Commercial wireless communications** – Services provided by third party providers over commercial networks, such as cellular, may allow wireless communications of DMS message content to CAVs directly from the DMS Control Software.

Stakeholders and Typical Conditions

Stakeholders

Table 4 identifies the stakeholder groups that interface with one or more aspects of DMS deployment and operations.

Table 3: Stakeholder Groups Interfacing with DMS Deployment and Operations

Stakeholder	Description
Travelers	Vehicle drivers and passengers operating traditional vehicles and CAVs. Special cases might be pedestrians/bus riders viewing specialty DMS
Operators	Regional Transportation Management Center (RTMC) operators or other agency operators responsible for creating and removing messages on DMS and monitoring the status of DMS. In regard to Portable DMS, the operator may be in the RTMC, in the field (e.g. a supervisor in the work zone), or remote but not in the RTMC (e.g. work zone project manager).
Administrators	A combination of operators and technical staff responsible for configuring, updating, verifying the status of DMS.
Technicians and Installers	Technical staff responsible for installing, maintaining, and troubleshooting the DMS in the field and the software system(s) that control the DMS (i.e. the ATMS). May include DOT staff, contractors, and consultants, performing actions both in the field and remotely.
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.

Typical and Local Conditions

DMS are commonly installed on the side of the road or over the road and positioned to be viewed by all lanes of travel. Site selection is typically a combination of two key factors:

1. Identifying locations upstream of key decision points in order to maximize travelers' options to respond to the messages they read; and
2. Identifying locations that are conducive to DMS deployment, such as those with existing power and communications supplies, those with existing support structures (e.g. bridges or existing infrastructure), and those with right-of-way space and terrain that is suitable for adding DMS infrastructure.

Stakeholder Needs

Table 5 identifies a series of challenges and the related needs for each stakeholder group identified above.

Table 4: Stakeholder Needs

Problem / Challenge	Needs (As a Result of the Problem / Challenge)
Travelers Needs	
- Travelers who are unaware of congestion or delays will miss opportunities to divert to alternate routes.	***Need 1: Real-time travel time/congestion notification*** Travelers need to view information on DMS upstream of key decision points in order to consider route diversions to avoid delays related to weather, incidents, or other causes of congestion.
- Without upstream warnings about incidents, isolated inclement weather conditions, or other hazards, travelers are unaware of the conditions they are advancing towards.	***Need 2: Real-time non-recurring event notification*** Travelers need to view information on DMS describing unplanned events at strategic locations (e.g. crashes, unusual driving conditions, special events, weather condition alerts, queue warning, etc.).
- DMS displays that are not visible to all drivers, difficult to read, or confusing to drivers may cause distractions and safety issues.	***Need 3: DMS Display Readability*** Travelers need DMS displays to be visible and legible at posted speeds from all lanes of travel.
- If DMS are only operational in some conditions, travelers will not be able to rely on their operation.	***Need 4: Consistent Up-time*** Travelers need DMS to function in all Minnesota weather conditions.
Operators Needs	
- Traffic management devices in the field must be controlled by operators without requiring operators to be local to the device.	***Need 5: Remote DMS Control*** Operators need to be able to control the messages displayed on DMS (post and remove messages) from National Transportation Communications for ITS Protocol (NTCIP) compliant DMS control software from locations remote to the DMS.
- Without reliable verification, the operators cannot be certain if messages are posted to the DMS or if the DMS is functioning properly.	***Need 6: DMS Monitoring*** Operators need to be able to monitor the operational status of each DMS (what is displayed and whether the device is connected/operational) from NTCIP compliant DMS control software from locations remote to the DMS.
- Without a user interface, operators would have no mechanism to control the DMS.	***Need 7: DMS Control Software*** Operators need an interface to the DMS that enables them to select pre-defined messages, create free-text messages, post graphics to the sign, monitor the sign status, and remove messages posted.

Problem / Challenge	Needs (As a Result of the Problem / Challenge)
- Manual determination of all DMS messages by operators can cause delay and inconsistencies in providing real-time traveler information.	***Need 8: Automated Message Creation*** Operators need a mechanism to automatically create some DMS messages (e.g. travel times, and other pre-defined response plans).
- Manual creation of all DMS messages by operators can provide inconsistencies in providing information.	***Need 9: DMS Message Library*** Operators need a library of standard messages that can be customized for a given situations to improve consistency in posted messages.
Administrators Needs	
- DMS operation requires configuration of signs and periodic updates to the device.	***Need 10: DMS Configuration*** Administrators need to be able to configure signs, either remotely or at the sign.
Technicians and Installers Needs	
- Proper use of DMS require communications, power, and installation on a structure at the deployment site.	***Need 11: DMS Supporting Infrastructure*** Technicians and installers need power, communications, and a support structure to be available at the site the DMS is deployed.
- DMS deployed in the field must not harm technicians, installers, or anyone in vicinity of the DMS.	***Need 12: Safety Standards*** Technicians and installers need the DMS to adhere to appropriate safety standards, specifications, and protocols.
- In situations where Portable DMS are used, their deployment will need to be quick and efficient.	***Need 13: Portable DMS Functionality*** Technicians and installers responsible for Portable DMS deployments need complete equipment solutions suitable for roadside deployment.
CAV Infrastructure Systems and CAVs Needs	
- MnDOT may deploy CAV Infrastructure Systems that communicate DMS messages to and from CAVs, either through roadside units (RSUs) or cloud-based communications.	***Need 14: CAV Message Receipt*** CAV Infrastructure Systems need a mechanism to receive static and dynamic information to be relayed to the travelers.
- In some situations, CAVs may benefit from direct data exchanges with DMS.	***Need 15: CAV Local Connection*** CAVs may need a mechanism to communicate directly with DMS.

Operational Concepts

The previous section defined a series of stakeholders that are expected to interact with DMSs and their needs likely to be addressed by DMS. This categorization will be further used in this section to describe the operational concept for DMS from each user's perspective. The operational concept is intended to help each user see how their needs have been interpreted and how the DMS are expected to address their needs. It is presented in a sequential manner from each user's perspective, with the needs included in the tables for reference.

Travelers' Perspective

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

Table 5: DMS Operational Concepts – Travelers' Perspective

Need (Travelers' Perspective)	Operational Concept
Travelers' Perspective linked to ***Need 1: Real-time travel time/congestion notification***	1.1 Travelers in areas that experience recurring unreliable travel times may view permanent DMS messages describing travel times (or other indicators of congestion) to help them understand their trip and consider alternate routes that may include high occupancy toll options. 1.2 In locations without recurring travel time challenges, as travelers' approach long-term work zones (e.g. lasting the majority of the work zone season) or other long-term events where there are no upstream permanent DMS, travelers may view Portable DMS temporarily displaying travel times through the activity. 1.3 Travel time displays on DMS will report time to recognizable downstream landmarks from the location of the DMS. 1.4 Travelers will have access to DMS displays of travel times during regular periods each day (or each commute day), allowing commuters or regular travelers to rely on consistent access to the information, at key locations during commute hours. 1.5 When incidents or high priority activities occur (e.g. AMBER Alerts), travelers may view other descriptions in place of travel times. In key locations, specific DMS solely for travel times might enable uninterrupted travel time viewing.
Travelers' perspectives linked to ***Need 2: Real-time non-recurring event notification***	2.1 In situations where non-recurring events (e.g. incidents, roadwork, queues forming from congestion, and other non-recurring events) occur downstream of permanent DMS, travelers throughout Minnesota will view messages on permanent DMS that describe those events impacting travel downstream of the road they are traveling or on

Need (Travelers' Perspective)	Operational Concept
	contiguous routes. Travelers may respond to this information through any number of actions, including: diverting to alternate routes, preparing to slow or stop as they approach the event, or simply understanding the conditions to be expected. 2.2 In situations where non-recurring events occur in locations without upstream permanent DMS, travelers may benefit from Portable DMS deployed temporarily. These are most likely to occur in situations of long-term work zones or situations when DMS mounted on vehicles can be deployed. 2.3 Travelers that are approaching adverse driving conditions that differ from the conditions they are already observing (e.g. reduced visibility, hazardous road conditions) may see advisory messages on DMS in advance of encountering the condition. Advisory messages will depend upon the conditions being either measured or manually recorded and the proximity to permanent DMS. 2.4 In situations where lane or road closures are planned in advance, travelers may view descriptions of the upcoming activities likely to impact travel allowing travelers to plan alternate options in advance. These situations may involve the use of temporary DMS, placed for the purpose of temporarily advising travelers and to be removed, either when the work zone activities begin or end. 2.5 In situations where lane closures occur, travelers may view graphics on ILCSs alerting them to the need to change lanes. *CAVs may support this concept for travelers in with in-vehicle applications.* 2.6 In situations where congestion, weather, or other conditions exist, travelers may view alerts on ILCS or full DMS advising of recommended travel speeds to increase safety or mobility. *CAVs may support this concept for travelers in with in-vehicle applications*.
Travelers' perspectives linked to ***Need 3: DMS Display Readability***	3.1 Travelers will generally be able to view the DMS regardless of the lane of travel they are in. In some locations, DMS may be located on the side of the road, and vehicles passing other large vehicles may have the DMS obscured. However, in areas with higher volumes of traffic, DMS will be located for visibility from all lanes, preferably as close to centered between all lanes as possible. 3.2 Travelers following posted speed limits will have time to read the full message displayed on the DMS, including

Need (Travelers' Perspective)	Operational Concept
	situations when multi-phased displays of messages are used. 3.3 Travelers will find that the size, brightness, and fonts of characters on the DMS allow them to read the words and numbers displayed on the DMS. 3.4 In situations where travelers observe graphics or images on the DMS, they will be commonly understood and not confusing or distracting. DMS displays will follow the Manual on Uniform Traffic Control Devices (MUTCD) to the extent possible.
Travelers' perspectives related to ***Need 4: Consistent Up-time***	4.1 Travelers will come to understand that blank DMS generally represent situations where no events or adverse conditions impacting traffic immediately downstream are known by MnDOT. 4.2 There will not be situations where the heat, cold, wind, or precipitation cause DMS to not function.

Operators' Perspective

Table 7 describes the DMS operational concepts from the operators' perspective, and relates each concept to a need, as defined in the previous section.

Table 6: DMS Operational Concepts - Operators' Perspective

Need (Operators' Perspective)	Operational Concept
Operators' perspectives related to: ***Need 5: Remote DMS Control***	5.1 Operators responsible for performing freeway and arterial traffic management and operations will monitor cameras, incident reports, and other data sources to determine when messages are appropriate for display on DMS. 5.2 Operators will use an NTCIP compatible DMS Control Software to communicate the current message to be displayed to the DMS. 5.3 Operators will use an NTCIP compatible DMS Control Software to communicate to remove messages from DMS when they are no longer appropriate, either by replacing them with a different message or displaying no messages. 5.4 Operators responsible for Portable DMS control may control the DMS locally at the sign or require another remote access mechanism to post messages. 5.5 Operators will rely on aspects of the DMS Control Software, the DMS field device, and the communications to prevent cybersecurity to the extent possible.
Operators' perspectives related to: ***Need 6: DMS Monitoring***	6.1 Operators will use an NTCIP compatible DMS Control Software to view current messages displayed on DMS.

Need (Operators' Perspective)	Operational Concept
	(These reports will be information communicated by the DMS to the DMS Control Software describing the current message displayed on the DMS). 6.2 Operators may use cameras to verify that DMS messages sent to the sign are displayed and removed appropriately. 6.3 Operators will use an NTCIP compatible DMS Control Software to view the operational status of the DMS, including if communications to the DMS are functioning, and the self-diagnostics performed by the DMS. 6.4 Based on the communications and reporting from each DMS, operators will use the DMS control software to view the overall status of DMS, including which have messages displayed, which are operational but have not messages displayed, and which are not currently operational. 6.5 Operators may rely on field staff to perform on-site verification of messages displayed and overall status of the sign.
Operators' perspectives related to: ***Need 7: DMS Control Software***	7.1 Operators will consider information from multiple sources (e.g. cameras, traffic data, and event reports) and determine messages to be posted to DMS. This may include a message to be displayed on a single DMS or one message to be displayed on multiple DMS. 7.2 Operators will use a DMS control software as the interface to communicate the desired message to the appropriate DMS(s). 7.3 Depending upon privileges, some operators will only be able to select from pre-defined messages, when determining messages for DMS display. 7.4 Some operators will have the option to either select from pre-defined messages or type free text messages. 7.5 Operators will have the option to view what the message display will look like on the DMS before finally sending the message. 7.6 Operators may not understand the priority of current messages displayed and therefore will rely upon the DMS control software to consider priorities of different messages when handling simultaneous requests for messages to be posted. 7.7 Operators will use the DMS control software for viewing the status and current messages displayed on each DMS.

Need (Operators' Perspective)	Operational Concept
	7.8 Operators will rely on the DMS control software to understand the capabilities of each DMS they are creating messages for (e.g. only be able to select color if it is a color sign, restricted to size and capabilities).
Operators' perspectives related to: ***Need 8: Automated Message Creation***	8.1 In situations where DMS are used to display messages triggered automatically by algorithms (e.g. travel times, ice detection, etc.) operators are not expected to manually monitor the changing conditions and post updated messages but may perform some actions such as verifying the messages. For these, the DMS control software would automatically create messages as the thresholds are met (i.e. "algorithm based automated messaging"). 8.2 In situations where operators wish to pre-select which messages appear on which signs based on time-of day, operators will use the DMS control software to pre-define the time periods when automated message creation occurs (i.e. "time of day automated messaging"). 8.3 Operators will use the DMS control software and related software systems to configure what automated message creation occurs (e.g. calculations of travel times, determining alert messages based on sensor inputs and defined triggers, etc.). 8.4 Operators will have the ability to manually post messages to DMS that would override the automated messages being created and sent to the DMS. 8.5 External systems may perform the analysis to determine pre-defined messages. In these situations, the DMS control software would accept and act upon these commands from external systems.
Operators' perspectives related to: ***Need 9: DMS Message Library***	9.1 Operators will use pre-defined DMS messages (containing either all text or a combination of text and graphics) when controlling the DMS. 9.2 Operators with access rights will have the ability to enter new messages into the pre-defined library of messages. 9.3 Pre-defined messages may include priorities assigned to the message to support the DMS control software in prioritizing simultaneous messages.

Administrators' Perspective

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

Table 7: DMS Operational Concepts - Administrators' Perspective

Need (Administrators' Perspective)	Operational Concept
Administrators perspective related to ***Need 10: DMS Configuration***	10.1 Administrators will configure the signs once they are installed. Configuration will link the DMS to the DMS control software. 10.2 In situations where the software within the sign is upgraded or the DMS control software is upgraded, configuration may be required to maintain compatibility. 10.3 Administrators may perform portions of the configuration at the sign (in the field) or may configure the sign remotely. 10.4 In situations where remote control of the DMS by operators is not possible, Administrators at the site of the DMS will be able to connect a laptop to the DMS and control the message display by using the DMS manufacturer software for sign control.

Technicians/Installers' Perspective

Table 9 describes the DMS operational concepts from the perspective of the technicians and installers of DMS, and relates each concept to a need, as defined in the previous section.

Table 8: DMS Operational Concepts - Technicians/Installers' Perspective

Need (Technicians/Installers' Perspective)	Operational Concept
Technicians and Installers Perspectives related to ***Need 11: DMS Supporting Infrastructure***	11.1 Site selection and preparation for DMS will result in analysis and selection of an existing structure (e.g. a bridge or existing pole) to support the DMS. If an existing structure is not available, installers will design and deploy a DMS structure. 11.2 Installation of the DMS will include the necessary design and installation of supporting infrastructure, including power, communications, sign visibility, sign accessibility, etc.
Technicians and Installers Perspectives related to ***Need 12: Safety Standards***	12.1 Installers will only install DMS that are tested, certified, and labeled by a Nationally Recognized Testing Laboratory (NRTL) as acceptable under Occupational Safety and Health Administration (OSHA) regulations. 12.2 Technicians and installers will rely upon installation instructions and guidelines from the DMS vendor. 12.3 Technicians and installers will be responsible for performing appropriate temporary traffic control (TTC) in compliance with the MUTCD when installing or performing field work on permanent or Portable DMS.

Need (Technicians/Installers' Perspective)	Operational Concept
Technicians and Installers Perspectives related to ***Need 13: Portable DMS Functionality***	13.1 In situations where Portable DMS are used, it is likely the installers/technicians will be a different group from those responsible for permanent DMS. This may include work zone contractors, MnDOT maintenance personnel, or others. 13.2 In some situations, Portable DMS will be planned for deployments. In these situations, messages to be displayed will be coordinated in advance, configured in the sign, and the sign moved to the designated location when convenient and least disruptive. 13.3 In some situations, Portable DMS will be moved to the site of an unplanned event, configured with a message for immediate display. 13.4 Technicians and installers will be responsible for configuring the Portable DMS when it arrives at the site and getting the Portable DMS recognized by the DMS control software, if necessary.

CAV Infrastructure Systems and CAVs' Perspective

Table 10 describes the DMS 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 9: DMS Operational Concepts - CAV Infrastructure and Vehicle Perspective

Need (CAV Infrastructure Systems and CAVs' Perspective)	Operational Concept
CAV Infrastructure Systems Perspectives on ***Need 14: CAV Message Receipt***	14.1 CAV infrastructure systems responsible for creating Roadside Safety Messages (RSM) will benefit from information about the current messages displayed on the DMS. 14.2 CAV Infrastructure systems such as roadside units may benefit from sharing utilities (e.g. power, communications), and structures with DMS.
CAVs Perspectives on ***Need 15: CAV Local Connection***	15.1 CAV equipped maintenance vehicles (e.g. snow plows, pavement stripers, etc.) may communicate directly with DMS to initiate displays of messages describing field activities (e.g. DMS may display "snow plow ahead"). 15.2 CAVs may receive messages from DMS (either through vehicle to roadside communications, cloud based communications, or machine vision interface on-board cameras) and provide in-vehicle display of either the message or an alert to the driver based on the message displayed to all drivers. 15.3 If MnDOT were to implement 'virtual DMS' by communicating messages to CAVs for possible display to drivers, an increased

Need (CAV Infrastructure Systems and CAVs' Perspective)	Operational Concept
	number of drivers may benefit from the manual or automatically created messages, where there are no physical DMS. 15.4 CAVs may read machine readable static signs that allow the download of dynamic information, effectively increasing the number of DMS for CAVs.

Operational Scenarios/Roles and Responsibilities

Roles and Responsibilities

The Operational Concept section defined interactions of the primary stakeholders with the DMS and supporting software. The table below provides a high-level summary of the roles and responsibilities of the stakeholder groups.

Table 10: Operation and Maintenance Roles and Responsibilities

User Group	Role / Responsibility
Operators	• Determine appropriate messages to be posted and removed from DMS based on their knowledge and confirmations of current conditions and events • Post and remove messages from selected DMS using the DMS control software • Configure algorithms that determine automated DMS message displays (e.g. Travel Time Displays) • Monitor status of DMS functionality and alert technicians to any issues • Participate in configuring new DMS and Portable DMS into the DMS control software
Administrators	• Configure new permanent DMS and Portable DMS and assign them to the DMS Control software • Upgrade DMS as appropriate and maintain consistency between DMS control software and DMS • Monitor the status of the DMS control software to determine when upgrades are needed
Technicians/Installers	• Prepare needed designs for DMS supporting infrastructure and support structures • Install DMS (including needed traffic control) • Troubleshoot technical issues with the DMS and or DMS control software • Perform routine maintenance in accordance with the DMS maintenance manual • Participate in configuring DMS with the DMS central control software • Setup Portable DMS, including message selection when appropriate
Travelers	• View DMS and use the information displayed to make decisions regarding route selection and or to adjust speed in anticipation of upcoming conditions.

Operational Scenarios

Scenarios are intended to describe how users will interact with the DMS (field equipment or DMS control software) and specifically to provide a temporal description of the sequence of events. The following scenarios briefly describe how users will be impacted and how they are expected to respond.

- Scenario A: Travel Time Displays
- Scenario B: Incident Message Display

- Scenario C: DMS Sign Malfunction
- Scenario D: Portable DMS Deployment
- Scenario E: Portable DMS With CAV Connections

Scenario A: Travel Time Displays

On a typical weekday morning peak period, automated algorithms have been computing travel times and communicating them to the ATMS that has been posting them on local DMS Travelers from the south suburbs commuting northbound on Highway 77 view travel times to I-494. Immediately downstream from this DMS is the intersection that travelers can merge onto I-35E northbound as an alternate to reaching I-494. This morning, travel times to I-494 on Hwy 77 are typical and most travelers are continuing along Hwy 77. About an hour into the commute period, the travel time posted for Hwy 77 to I-494 continues to rise, causing some travelers to divert onto I-35E.

Nearly two hours into the commute period, a large object is reported in a travel lane on Hwy 77. The operator of the RTMC is alerted to the object and uses a nearby camera to verify that the left lane is closed. The RTMC operator decides to post a message to this DMS alerting travelers to the lane closure. The RTMC operator uses the ATMS to select pre-defined phrases to craft the message and posts the message to the DMS. The ATMS determines that the priority of the message overrides the travel time displays and sends a message to the DMS to remove the travel time display and display the lane closure message. The RTMC operator uses the camera to verify when the object has been cleared and uses the ATMS to remove the message from display. This causes the travel time display to return to the DMS.

Scenario B: Incident Message Display

The operator of the RTMC is alerted to the crash through State Patrol dispatch and uses a nearby camera to verify the crash. The RTMC operator uses the ATMS to view the status of nearby DMS and selects the nearest upstream DMS to post a message to. This operator is able to select a combination of pre-defined messages in the ATMS describing the incident and lane closure details to create the message. Within seconds, the selected message is sent to the most upstream DMS. The operator views a confirmation in the ATMS that the DMS is now displaying the selected message. In addition, the operator is able to select a Closed Circuit Television (CCTV) in viewing range of the DMS and is able to confirm that the message was posted successfully. As the incident clears, the RTMC operator uses the ATMS to monitor nearby cameras and therefore the impacts of the incident. When appropriate, the operator uses the ATMS to remove the message on the DMS.

Scenario C: DMS Sign Malfunction

On a typical day, as RTMC operators prepare for the upcoming peak period, they notice an alert in IRIS. The operator is able to use the ATMS to select the DMS and view the condition of the sign. The operator views the fact that portions of the pixels on the DMS are not functioning properly. This is the result of the ATMS communicating to the DMS and the DMS conducting a self-assessment on the status of the sign. The RTMC operator logs the outage. Later that day, a technician is dispatched to troubleshoot the DMS.

Scenario D: Portable DMS Deployment

A work zone is planned on a MnDOT-operated arterial in the Twin Cities. While no long-term lane closures are planned, it is anticipated that there will be times when delays occur, possibly causing local congestion. As there are no permanent DMS upstream of the closure, a Portable DMS is moved to a position upstream of the planned activities. The work zone contractor is responsible for supplying the Portable DMS, locating

it at the site. This particular Portable DMS is equipped with wireless communications and remote connections. After locating the sign, the installer works with the MnDOT RTMC operators to configure the sign into the ATMS such that it can be recognized and controlled by RTMC operators.

Once the Portable DMS is operational, traffic detection devices located in advance of the work zone detect stopped traffic during a high-volume morning peak period. When the stopped traffic is detected, a message is automatically posted to the Portable DMS, warning drivers of stopped traffic ahead. This particular sign is not near a local power connection, so it is powered using a combination of battery and solar power.

Scenario E: Portable DMS with Connection to CAVs

MnDOT is operating a DMS with the capability to receive and act upon messages from DOT-operated CAVs. During a snow event, a CAV equipped MnDOT snow plow passes the DMS, it communicates a message that it is plowing and administering roadway treatment. At this time, the DMS receives the messages from the vehicle, interprets the message and automatically creates and displays a message that reads “snow plow ahead, use caution”. After a pre-determined time, with no additional vehicles passing the DMS and sending a similar status message, the DMS reverts back to not displaying any message.

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 DMS (the signs and supporting 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 *Operations Concepts*, 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.

Table 11: DMS Requirements by Need

Need	System Requirement
Travelers	
1. Travelers need to view information on DMS upstream of key decision points in order to consider route diversions to avoid delays related to weather, incidents, or other causes of congestion.	1.1. In locations that experience recurring unreliable travel times, permanent DMS shall be considered to advise travelers of travel times or delays. 1.2. In situations where long-term temporary events, such as work zones lasting approximately the entire construction season, are expected to create delays, Portable DMS shall be considered to advise travelers of travel times, delays or alternate routes. 1.3. DMS shall be located strategically to support travelers' decisions about alternate route selection to reach key downstream destinations. 1.4. When displaying travel times or delay information, DMS messages shall identify recognizable landmarks such as major roads or cities. 1.5. Travel time displays on DMS shall be operated on regular schedules that match periods of unreliable travel times, unless replaced by higher priority messages.

Need	System Requirement
2. Travelers need to view information on DMS describing unplanned events at strategic locations (e.g. crashes, unusual driving conditions, special events, weather condition alerts, queue warning, etc.).	2.1. Agencies shall consider DMS deployments in locations upstream of areas where unplanned events impact or impede traffic at least two times per month and where alternate routes are available if drivers were aware of these events. 2.2. Agencies shall consider DMS upstream of horizontal or vertical curves that prevent drivers from viewing stopped traffic in advance. 2.3. In rural areas, permanent DMS deployments shall be considered such that they minimize the distance between signs to the extent possible. 2.4. Portable DMS shall be considered to supplement locations without permanent DMS when temporary events or work zones are active, typically cause at least 15 minutes of delay per day, and the speed limit exceeds 45 mph. 2.5. DMS shall be considered for deployment in locations upstream of known locations of recurring weather events (e.g. prone to fog, ice, reduced visibility). 2.6. In specific situations, ILCS shall be considered as a mechanism for alerting travelers to lane closures. 2.7. In specific situations, ILCS shall be considered as a mechanism for alerting travelers to advisory speeds.
3. Travelers need DMS displays to be visible and legible at posted speeds from all lanes of travel.	3.1. DMS shall be located for visibility from all lanes, preferably as close to centered between all lanes as possible. 3.2. DMS displays shall be legible at a distance that is appropriate for the roadway section it is installed, considering the local speed limit and sight distance. 3.3 DMS shall adjust brightness of displays to accommodate different ambient light conditions (e.g. day to night, solar glare). 3.4 The DMS shall have a 30-degree cone of visibility, where the intensity of the display is at least 50% of maximum brightness to an angle of 15 degrees in both directions, offset from center.

Need	System Requirement
4. Travelers need DMS to function in all Minnesota weather conditions.	4.1. The DMS shall be able to perform in extreme cold conditions experienced in Minnesota. 4.2. DMS shall function properly in extreme heat conditions. 4.3. DMS shall be constructed to function properly in harsh weather conditions and conditions where salt and other corrosive materials may be used. 4.4. DMS (and mounting structure) shall meet performance specifications as defined for the region and location of deployment. 4.5. The DMS face shall clear itself in a reasonable time if obstructed by snow and ice during a storm.
DMS Operators	
5. Operators need to be able to control the messages displayed on DMS (post and remove messages) from NTCIP compliant DMS control software from locations remote to the DMS.	5.1. The DMS shall receive and process NTCIP compliant communications describing messages to be displayed on the sign and display or remove the appropriate messages. 5.2. The DMS shall send an NTCIP compliant message to the DMS Central Control Software confirming when messages are displayed or removed from the sign. 5.3. Portable DMS shall include a mechanism for on-site control of messages displayed on the sign. 5.4. If deployed to be operated remotely, Portable DMS shall support remote message control and confirmation using the DMS control software. 5.5. The DMS shall include safeguards against cyber security attacks. 5.6. The DMS control software shall include safeguards against cyber security attacks.

Need	System Requirement
6. Operators need to be able to monitor the operational status of each DMS (what is displayed and whether the device is connected/operational) from NTCIP compliant DMS control software from locations remote to the DMS.	6.1. The DMS shall receive and process NTCIP compliant requests for current sign messages and respond with the current messages/graphics displayed on the sign. 6.2. The DMS shall perform diagnostics tests of functional components and display status to operators. 6.3. The DMS shall respond to NTCIP 1203 polls communicating number of pixel failures. 6.4. The DMS Control Software shall allow for users to perform queries using a configurable list of common queries. For example, the status of all DMS. 6.5. DMS deployments shall consider deploying nearby cameras to support remote visual verification of sign status. 6.6. If deployed to be operated remotely, Portable DMS shall respond to requests for current sign messages and status, as described for permanent DMS.
7. Operators need an interface to the DMS that enables them to select pre-defined messages, create free-text messages, post graphics to the sign, monitor the sign status, and remove messages posted.	7.1. The overall DMS System shall include a DMS control software (often a full ATMS) that enables operators to interact with the DMS. 7.2. The DMS control software shall allow operators with access rights to enter DMS messages and images through a display that shows the message as it will appear on the DMS, including color and images. 7.3. The DMS control software shall limit the operator's entry based on the capabilities of the DMS selected. For example, if the DMS does not allow multiple colors, the software shall not allow the user to select the color. 7.4. The DMS control software shall communicate the messages and formatting to the DMS using NTCIP 1203 standard. 7.5. The DMS control software shall allow users to view the locations and statuses of DMS controlled by the software. 7.6. The DMS control software shall periodically poll capable DMS for the value of the NTCIP 1203 object pixelFailureTableNumRows and generate a notification to operators if the percentage of failed pixels on a DMS device exceeds a configurable value. 7.7. Either the DMS control software shall support communication of messages to Portable DMS or a sign specific control system shall be used to enable remote control of Portable DMS.

Need	System Requirement
8. Operators need a mechanism to automatically create some DMS messages (e.g. travel times, and other pre-defined response plans).	8.1. If "time of day automated messaging" is used, the DMS control software shall allow users to configure messages to display and be removed based on time of day (e.g. "Left turn not allowed"). 8.2. If "algorithm based automated messaging" is used, the DMS control software shall allow users to configure thresholds and algorithms that trigger automated processes and message recommendations. For example, a user may set a threshold speed at which a certain DMS message is recommended. 8.3. If travel times are posted to the DMS, the DMS control software or related system shall generate travel time messages for destinations configured for each sign. 8.4. If an external system automatically determines the DMS message, the DMS control software shall be capable of interfacing to external systems to receive notices of DMS messages to post to signs. 8.5. The DMS control software shall allow operators to manually enter messages that override automatically generated messages, based on priority.
9. Operators need a library of standard messages that can be customized for a given situations to improve consistency in posted messages.	9.1. The DMS control software shall have a DMS message and images library that users with access rights can access when creating a DMS messages. 9.2. The DMS control software shall allow users to manage the message in the DMS library, including editing, adding, and deleting messages. 9.3. The DMS control software shall allow users to select messages and/or images from the library to display on the selected DMS(s). 9.4. The DMS control software may include priority values assigned to pre-defined messages to support handling of conflicting messages.
Administrators	
10. Administrators need to be able to configure signs, either remotely or at the sign.	10.1. The DMS control software shall allow users to add and delete DMS devices that can be monitored and controlled by the DMS Control Software. 10.2. The DMS shall support remote configuration of the sign, including font size, image size, and colors. 10.3. The DMS shall support local on-site configuration of the signs. 10.4. The DMS shall support local cable connectivity to laptop computers running the DMS manufacturer software to control messages displayed on the sign.

Need	System Requirement
Technicians and Installers	
11. Technicians and installers need power, communications, and a support structure to be available at the site the DMS is deployed.	11.1. DMS design shall include the approach to mounting the DMS. 11.2. DMS design shall include power connections. 11.3. DMS design shall include components to support remote communications. 11.4. DMS design shall include accessibility to the sign. 11.5. DMS design shall include sign visibility when finalizing location and installation. 11.6. DMS design shall consider whether nearby CAV roadside units (RSUs) will require direct data feeds from the DMS. 11.7. DMS design shall consider whether nearby CAV roadside units (RSUs) will benefit from shared structures, power, or communications with the DMS.
12. Technicians and installers need the DMS to adhere to appropriate safety standards, specifications, and protocols.	12.1. A professional engineer registered in the State of Minnesota shall review and approve all structural details of the complete DMS structural system. The DMS housing, fabrication methods, and the housing's attachment to its support structure should all be considered in that structural system. 12.2. The DMS shall include mounting instructions. 12.3 DMS shall include temporary or permanent components (e.g. lifting eyes) to support safe lifting, transport, and installation of the signs. 12.4 DMS shall meet current DMS specifications as approved by MnDOT or the agency/owner that is deploying/operating the DMS.
13. Technicians and installers responsible for Portable DMS deployments need complete equipment solutions suitable for roadside deployment.	13.1. Portable DMS shall include a mechanism for on-site technicians to configure the message displayed on the sign. 13.2. If controlled remotely, Portable DMS shall include communications capabilities and support NTCIP messages to control and query signs. 13.3. Portable DMS shall be installed on or part of a trailer to support movement to/from sites. 13.4. Portable DMS shall include self-sustaining power sources (e.g. battery combined with solar) or shall connect to local power connections. 13.5. Portable DMS may include GPS position determination to report their location.

Need	System Requirement
CAV Infrastructure Systems and CAVs	
14. CAV Infrastructure Systems need a mechanism to receive static and dynamic information to be relayed to the travelers.	14.1. In locations where CAV Infrastructure Systems broadcast messages to CAVs, the DMS Control Software shall generate messages containing content displayed on DMS and identify location areas where the content is relevant to drivers. 14.2. The DMS Control Software shall communicate the messages to the applicable CAV Infrastructure System. Note: this message exchange will support CAV Infrastructure Systems in communicating the "local traveler information" information flow (Roadside equipment to vehicle On-Board Equipment (OBE)).
15. CAVs may need a mechanism to communicate directly with DMS.	15.1. In situations where direct DMS to CAVs communications is operational, DMS shall generate a message conveying the message described on the DMS, in a format compatible with the two-way vehicle to roadside or cloud-based communication medium (note information flow is defined as "automated vehicle control parameters" as defined in ARC-IT). 15.2. In situations where CAV equipped vehicles communicate with DMS, the DMS (or supporting roadside unit) shall receive, process, and act upon messages from the vehicle to display messages on the sign.

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 DMS;
- Concepts for the use of DMS; 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 13 below identifies the needs/potential solutions included in the Minnesota ITS Architecture that are addressed through concepts for the use of DMS 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 DMS stakeholder need(s) that were influenced or derived based on each service package.

Table 13: Summary of Local and National ITS & CAV Architecture References Mapped to DMS Needs

MN Statewide Regional ITS Architecture: Need/Potential Solutions	ARC-IT: Service Packages	ARC-IT: Processes	DMS Stakeholder Needs Influenced by each Service Package
• ATMS05 – Provide incident and congestion information to travelers	• TM06 Traffic Information Dissemination	• Output Roadway Information Data • Process Roadway Information Data	• Need 1: Real-time travel time/ congestion notification
	• TM12 Dynamic Roadway Warning	• Control Roadway Warning System	• Need 2: Real-time non-recurring event notification
• ATMS10 – Utilize variable speed limits	• TM20 Variable Speed Limits	• Output Roadway Information Data	• Need 8: Automated message creation
• ATMS11 – Operate reversible lanes	• TM16 Reversible Lane Management	• Control Dynamic Lanes	• Need 5: Remote DMS control
• ATMS15 – Provide operating speed / travel time information to travelers	• TM06 Traffic Information Dissemination	• Output Roadway Information Data • Retrieve Traffic Data	• Need 1: Real-time travel time / congestion notification
• ATMS17 - Provide travel information on special events	• TM06 Traffic Information Dissemination	• Output Roadway Information Data	• Need 2: Real-time non-recurring event notification
• ATMS24 - Operate Freeway/Expressway / arterial DMS	• TM06 Traffic Information Dissemination	• Output Roadway Information Data	• Need 5: Remote DMS control • Need 6: DMS monitoring
• ATMS34 – Provide roadway flood warnings	• TM12 Dynamic Roadway Warning	• Control Roadway Warning System	• Need 2: Real-time non-recurring event notification • Need 13: Portable DMS functionality

MN Statewide Regional ITS Architecture: Need/Potential Solutions	ARC-IT: Service Packages	ARC-IT: Processes	DMS Stakeholder Needs Influenced by each Service Package
• ATMS36 - Implement Integrated Corridor Management (ICM) strategies	• TM06 Traffic Information Dissemination	• Output Roadway Information Data	• Need 1: Real-time travel time / congestion notification
	• TM16 Reversible Lane Management	• Control Dynamic Lanes	• Need 5: Remote DMS control • Need 8: Automated message creation
• ATMS43 – Notify travelers of snowplow operations and cleanup using DMS	• MC04 Winter Maintenance	• Roadway Maintenance Status	• Need 2: Real-time non-recurring event notification
• ATMS45 – Provide road closure information for far away closures	• TM19 Roadway Closure Management	• Process Roadway Information Data	• Need 2: Real-time non-recurring event notification
• ATMS50 – Keep drivers off the roads during winter storms	• TM19 Roadway Closure Management	• Output Roadway Information Data	• Need 2: Real-time non-recurring event notification
• MCM05 – Provide queue detection and advisory to warn traffic of a stopped queue at work zone	• MC06 Work Zone Management	• Provide Short Range Traveler Information • Operate Work Zone Devices	• Need 2: Real-time non-recurring event notification • Need 13: Portable DMS functionality
	• TM 12 Dynamic Roadway Warning	• Control Roadway Warning System	• Need 2: Real-time non-recurring event notification • Need 13: Portable DMS functionality

MN Statewide Regional ITS Architecture: Need/Potential Solutions	ARC-IT: Service Packages	ARC-IT: Processes	DMS Stakeholder Needs Influenced by each Service Package
• MCM08 – Provide dynamic late merge systems for construction / maintenance activities	• MC06 Work Zone Management	• Operate Work Zone Devices	• Need 5: Remote DMS control
• MCM10 – Provide work zone information to travelers	• MC06 Work Zone Management	• Output Roadway Information Data	• Need 5: Remote DMS control • Need 2: Real-time non-recurring event notification
• MCM11 – Notify travelers of delays or travel times through work zones	• MC06 Work Zone Management	• Provide Broadcast Data Interface	• Need 1: Real-time travel time / congestion notification
• ATMS43 – Notify travelers of snowplow operations and cleanup using DMS	• TM02 Vehicle-Based Traffic Surveillance	• Collect Vehicle Roadside Data	• Need 2: Real-time non-recurring event notification
	• MC04 Winter Maintenance	• Manage M&C Vehicle Fleet	
• MCM09 – Use GPS/GIS data to target and record replacement and repair of infrastructure	• MCO5: Roadway Maintenance and Construction	• Collect Traffic Field Equipment Fault Data	• Need 6: DMS monitoring • Need 11: DMS supporting infrastructure
• PSFT10 – Provide ability to remotely post AMBER alert information on DMS	• PS10: Wide-Area Alert	• Manage Wide Area Alerts and Advisories	• Need 2: Real-time non-recurring event notification • Need 14: CAV message receipt
	• PS10: Wide-Area Alert	• Provide Driver Information Interface	• Need 14: CAV message receipt

MN Statewide Regional ITS Architecture: Need/Potential Solutions	ARC-IT: Service Packages	ARC-IT: Processes	DMS Stakeholder Needs Influenced by each Service Package
• PSFT09 – Provide emergency/ evacuation and reentry information		• Manage Wide Area Alerts and Advisories	• Need 5: Remote DMS control • Need 8: Automated message creation
• None identified at this time	• TI07 In-Vehicle Signage	• Output In-vehicle Signage Data	• Need 14: CAV message receipt
• ATMS32 – Provide curve speed warnings	• VS05 Curve Speed Warning	• Output in-vehicle Signage Data • Provide Driver with Personal Travel Information	• Need 14: CAV message receipt • Need 8: Automated message creation
• None identified at this time	• VS14 Cooperative Adaptive Cruise Control	• Provide Driver Information Interface	• Need 14: CAV message receipt

Model Test Plan

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

Each DMS 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 DMS 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 DMS) 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 DMS. 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 DMS to verify the quality assurance / quality control and DMS 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 the field to test the actual deployment and functionality of the DMS.

Table 14: Model Test Plan for DMS

System Requirement		Testing Instructions	Type of Result	Comments / Notes
1.1	In locations that experience recurring unreliable travel times, permanent DMS shall be considered to advise travelers of travel times or delays.	Advisory requirement – no testing required	N/A	
1.2	In situations where long-term temporary events, such as work zones lasting approximately the entire construction season, are expected to create delays, Portable DMS shall be considered to advise travelers of travel times, delays or alternate routes.	Advisory requirement – no testing required	N/A	
1.3	DMS shall be located strategically to support travelers' decisions about alternate route selection to reach key downstream destinations.	Advisory requirement – no testing required	N/A	
1.4	When displaying travel times or delay information, DMS messages shall identify recognizable landmarks such as major roads or cities.	Confirm that DMS Control Software can be configured to display calculated travel times and text to describe destinations.	Pass/Fail	
1.5	Travel time displays on DMS shall be operated on regular schedules that match periods of unreliable travel times, unless replaced by higher priority messages.	Confirm that DMS Control software can support time of day / day of week scheduling.	Pass/Fail	
2.1	Agencies shall consider DMS deployments in locations upstream of areas where unplanned events impact or impede traffic at least two times per month and where alternate routes are available if drivers were aware of these events.	Advisory requirement – no testing required	N/A	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
2.2	Agencies shall consider DMS upstream of horizontal or vertical curves that prevent drivers from viewing stopped traffic in advance.	Advisory requirement – no testing required	N/A	
2.3	In rural areas, permanent DMS deployments shall be considered such that they minimize the distance between signs to the extent possible.	Advisory requirement – no testing required	N/A	
2.4	Portable DMS shall be considered to supplement locations without permanent DMS when temporary events or work zones are active, typically cause at least 15 minutes of delay per day, and the speed limit exceeds 45 mph.	Advisory requirement – no testing required	N/A	
2.5	DMS shall be considered for deployment in locations upstream of known locations of recurring weather events (e.g. prone to fog, ice, reduced visibility).	Advisory requirement – no testing required	N/A	
2.6	In specific situations, ILCS shall be considered as a mechanism for alerting travelers to lane closures.	Advisory requirement – no testing required	N/A	
2.7	In specific situations, ILCS shall be considered as a mechanism for alerting travelers to advisory speeds.	Advisory requirement – no testing required	N/A	
3.1	DMS shall be located for visibility from all lanes, preferably as close to centered between all lanes as possible.	Design - Confirm that DMS design documents describing mounting address the visibility of the sign and explored all options for centering the device on the roadway.	Content Review	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
3.2	DMS displays shall be legible at a distance that is appropriate for the roadway section it is installed, considering the local speed limit and sight distance.	Design - During the design phase, confirm that calculations based on speed limit and sight distance were used to determine the distance away from the sign that legibility is required. FAT - Confirm that the DMS displays of the typical number of lines and fonts are visible at least to the needed distance determined in the design. Field – After installation, drive the corridor in each lane of travel with a test message displayed to confirm that messages are legible.	Design -Content Review FAT - Pass/Fail Field - Pass/Fail	
3.3	DMS shall adjust brightness of displays to accommodate different ambient light conditions (e.g. day to night, solar glare).	FAT – Confirm that brightness and dimming ranges for ambient settings are functioning. Field – Confirm that the DMS is visible during night and day (bright) conditions	Pass/Fail	
3.4	The DMS shall have a 30-degree cone of visibility, where the intensity of the display is at least 50% of maximum brightness to an angle of 15 degrees in both directions, offset from center.	FAT – Confirm the brightness at 15 degree angles offset from center of the sign are at least 50% maximum brightness. Field – After deployment with test message displayed, drive the corridor in each lane to verify ability to read all portions of the sign	Pass/Fail	
4.1	The DMS shall be able to perform in extreme cold conditions experienced in Minnesota.	FAT – Confirm that a cold test was performed on the DMS.	Pass/Fail	
4.2	DMS shall function properly in extreme heat conditions.	FAT – Confirm that a heat test was performed on the DMS.	Pass/Fail	
4.3	DMS shall be constructed to function properly in harsh weather conditions and conditions where salt and other corrosive materials may be used.	Design – Confirm that the housing and exterior components are made from materials resistant to corrosion.	Content Review	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
		FAT – Confirm that exterior seams are continuously welded with no gaps. FAT – Confirm that exterior welds are free of cracks, blowholes, and irregularities.		
4.4	DMS (and mounting structure) shall meet performance specifications as defined for the region and location of deployment.	Design – Confirm that local design has been completed for mounting structure and supporting infrastructure. FAT – Confirm that DMS meet local specifications (or those below): • Display a full display at the following brightness levels, 4%, 8%, 40%, 100% (if DMS is color, confirm the brightness levels for 20 colors). • Single row and single column stepping pattern with variable dwell time, for color DMS use 10 colors (one color at a time). • Display of a large graphic image. Field – Confirm all supporting infrastructure is installed and operational (e.g. power, communications) and confirm the system is documented with supporting illustrations and figures.	Pass/Fail	
4.5	The DMS face shall clear itself in a reasonable time if obstructed by snow and ice during a storm.	Design – Confirm that the DMS is designed to self-clear ice (e.g. heat generate from the sign or other approach).	Content Review	
5.1	The DMS shall receive and process NTCIP compliant communications describing messages to be displayed on the sign and display or remove the appropriate messages.	FAT – Confirm the software used in the DMS has passed NTCIP testing. Field – Conduct test displays of messages to confirm the proper posting and removal of messages.	Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
5.2	The DMS shall send an NTCIP compliant message to the DMS central control software confirming when messages are displayed or removed from the sign.	Design – Confirm the software used in the DMS generates messages confirming the current sign display. FAT – Confirm that the software used in the DMS has passed NTCIP testing. Field – Confirm through CCTV viewing that messages posted/removed from sign are executed.	Design - Content Review FAT - Pass/Fail Field - Pass/Fail	
5.3	Portable DMS shall include a mechanism for on-site control of messages displayed on the sign.	FAT – Confirm the functionality of posting / removing sign displays at the Portable DMS.	Pass/Fail	
5.4	If deployed to be operated remotely, Portable DMS shall support remote message control and confirmation using the DMS control software.	FAT – Confirm NTCIP compliance for remote sign control. Field – Confirm the Portable DMS can be established within the DMS control software, and messages posted and removed.	Pass/Fail	
5.5	The DMS shall include safeguards against cyber security attacks.	Design – Confirm that DMS procured include current industry state of practice safeguards to prevent cyber-attacks. Field – Confirm that all recommended precautions to prevent cyber-attacks are implemented (e.g. changing default passwords, changing locks, implementing locking mechanisms as recommended, etc.	Pass/Fail	
5.6	The DMS control software shall include safeguards against cyber security attacks.	Design – Confirm that DMS control software is secured behind appropriate firewalls to prevent unwanted attacks.	Pass/Fail	
6.1	The DMS shall receive and process NTCIP compliant requests for current sign messages and respond with the	Field – Establish the DMS with the DMS control software and visually confirm that messages sent for display are displayed.	Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
	current messages/graphics displayed on the sign.			
6.2	The DMS shall perform diagnostics tests of functional components and display status to operators.	FAT – Demonstration of diagnostics tests and display of test results. Field – Confirm the DMS is performing diagnostics tests and displaying results.	Pass/Fail	
6.3	The DMS shall respond to NTCIP 1203 polls communicating number of pixel failures.	FAT – Demonstration of sending polls and messages generated reporting the number of pixel failures. Field – Confirm the DMS is responding to pixel failure poll requests. Simulate pixel failures, if possible.	Pass/Fail	
6.4	The DMS control software shall allow for users to perform queries using a configurable list of common queries. For example, the status of all DMS.	Field – Execute a variety of common queries in the DMS Control Software and confirm accuracy and completeness.	Pass/Fail	
6.5	DMS deployments shall consider deploying nearby cameras to support remote visual verification of sign status.	Advisory requirement – no testing required	N/A	
6.6	If deployed to be operated remotely, Portable DMS shall respond to requests for current sign messages and status, as described for permanent DMS.	FAT – Confirm NTCIP compliance for remote sign control. Field – Confirm the Portable DMS can be established within the DMS Control Software, and messages posted and removed.	Pass/Fail	
7.1	The overall DMS system shall include a DMS control software (often a full ATMS) that enables operators to interact with the DMS.	Design – Verify presence of DMS control software. Field – Confirm functionality of DMS control software to allow interaction with DMS.	Design - Content Review Field - Pass/Fail	
7.2	The DMS control software shall allow operators with access rights to enter DMS messages and images through a	Design – Verify presence of secure interface that allows a user to enter and preview a DMS message or image for display.	Design - Content Review	

	System Requirement	Testing Instructions	Type of Result	Comments / Notes
	display that shows the message as it will appear on the DMS, including color and images.	Field – Confirm: • Presence of a secure interface that can only be accessed by authorized users. • Ability of a user to enter DMS messages and images. • Ability of a user to preview DMS message as it will appear on the DMS, including the same color and images.	Field - Pass/Fail	
7.3	The DMS control software shall limit the operator's entry based on the capabilities of the DMS selected. For example, if the DMS does not allow multiple colors, the software shall not allow the user to select the color.	Field – Confirm the DMS control software customizes the available user options for DMS messages based on the capability of the selected DMS. • If possible, select a DMS that does not support color and attempt to enter messages with multiple colors • If possible, select a DMS with fixed number of lines and attempt to create messages with more lines	Pass/Fail Color selection fail Limited to # of lines	
7.4	The DMS control software shall communicate the messages and formatting to the DMS using NTCIP 1203 standard.	FAT – Confirm the software used in the DMS has passed NTCIP testing. Field – Conduct test displays of messages to confirm communications between DMS and NTCIP compatible DMS control software.	Pass/Fail	
7.5	The DMS control software shall allow users to view the locations and statuses of DMS controlled by the software.	Field – Confirm that users can view the current location and status of all DMS that are controlled by the DMS control software within the user interface.	Pass/Fail	
7.6	The DMS control software shall periodically poll capable DMS for the value of the NTCIP 1203 object pixelFailureTableNumRows and generate a notification to operators if	FAT – Demonstration of sending polls and messages generated reporting the number of pixel failures. Field – Confirm the DMS is responding to pixel failure poll requests and capable of sending a	Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
	the percentage of failed pixels on a DMS device exceeds a configurable value.	notification when the percentage of failed DMS pixels exceeds a specified threshold. Simulate pixel failures, if possible.		
7.7	Either the DMS control software shall support communication of messages to Portable DMS or a sign specific control system shall be used to enable remote control of Portable DMS.	Design – Confirm a communication mechanism with the Portable DMS to send messages, i.e. either via DMS Control Software or remote control. Field – Test that messages can be posted to the Portable DMS from the selected control software	Design - Content Review Field - Pass/Fail	
8.1	If "time of day automated messaging" is used, the DMS Control Software shall allow users to configure messages to display and be removed based on time of day (e.g. "Left turn not allowed").	Field – Verify user ability to configure messages and timing for display of a DMS message to be posted in an automated manner based on the time of day.	Pass/Fail	
8.2	If "algorithm based automated messaging" is used, the DMS Control Software shall allow users to configure thresholds and algorithms that trigger automated processes and message recommendations. For example, a user may set a threshold speed at which a certain DMS message is recommended.	Field – Verify user ability to configure thresholds and algorithms that initiate a DMS message to be posted in an automated manner.	Pass/Fail	
8.3	If travel times are posted to the DMS, the DMS control software or related system shall generate travel time messages for destinations configured for each sign.	Field – Verify connection of one or more DMS to system and proper configuration for posted travel time messages on the DMS. Field – Verify travel times posted as computed	Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
8.4	If an external system automatically determines the DMS message, the DMS control software shall be capable of interfacing to external systems to receive notices of DMS messages to post to signs.	Field – Verify DMS control software interface with external systems receives notification whenever the external system posts a DMS message.	Pass/Fail	
8.5	The DMS control software shall allow operators to manually enter messages that override automatically generated messages, based on priority.	Field – Verify operator ability in DMS control software to override automatically generated messages by creating a message with higher priority than automatically generated messages (e.g. travel times), verify that the operator entered message overrides the travel times. Field – Verify that operator entered DMS messages with lower priority than automated messages do not override the display of the automated message (e.g. Public service announcements should not override travel times).	Pass/Fail	
9.1	The DMS control software shall have a DMS message and images library that users with access rights can access when creating a DMS messages.	Design – Verify inclusion of secure library for messages and images. Field – Verify security features to allow access only to users with credentials. Verify library can store and be queried for specific images and messages for a DMS.	Design - Content Review Field - Pass/Fail	
9.2	The DMS control software shall allow users to manage the message in the DMS library, including editing, adding, and deleting messages.	Field – Confirm user ability to create, edit, and delete messages in the library using DMS control software.	Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
9.3	The DMS control software shall allow users to select messages and/or images from the library to display on the selected DMS(s).	Field – Confirm user ability to select items from the library. Confirm selected items are displayed on DMS.	Pass/Fail	
9.4	The DMS control software may include priority values assigned to pre-defined messages to support handling of conflicting messages.	Advisory requirement – no testing required	N/A	
10.1	The DMS control software shall allow users to add and delete DMS devices that can be monitored and controlled by the DMS Control Software.	Design – Include software capability to add and delete DMS. Field – When adding a new DMS, attempt to add the DMS to be controlled by the DMC control software to verify the ability of the DMS to connect. Field - When adding a DMS control software, attempt to connect to one or more existing DMS and establish control and monitoring capability.	Design - Content Review Field - Pass/Fail	
10.2	The DMS shall support remote configuration of the sign, including font size, image size, and colors.	Design – Confirm interface and components to allow remote configuration, including font size, image size, and colors. FAT – Confirm functionality of components allowing for remote configuration, including font size, image size, and colors. Field – Confirm ability to configure installed DMS using the DMS control software, including font size, image size, and colors.	Design - Content Review FAT - Pass/Fail Field - Pass/Fail	
10.3	The DMS shall support local on-site configuration of the signs.	Design – Confirm interface and components to allow for on-site configuration.	Design - Content Review	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
		FAT – Confirm functionality of interface and components that allow for on-site configuration.	FAT - Pass/Fail	
10.4	The DMS shall support local cable connectivity to laptop computers running the DMS manufacturer software to control messages displayed on the sign.	Design – Confirm interface and components to allow for on-site configuration. FAT – Confirm functionality of interface and components that allow for on-site configuration by connecting a laptop to the DMS and using the vendor provided control software to perform configuration.	Design - Content Review FAT -Pass/Fail	
11.1	DMS design shall include the approach to mounting the DMS.	Design – Confirm installation considerations are included in design.	Content Review	
11.2	DMS design shall include power connections.	Design – Confirm presence of power connections for external sources or self-sustaining power units.	Content Review	
11.3	DMS design shall include components to support remote communications.	Design – Confirm presence of components for remote communications.	Content Review	
11.4	DMS design shall include accessibility to the sign.	Advisory requirement – no testing required	N/A	
11.5	DMS design shall include sign visibility when finalizing location and installation.	Advisory requirement – no testing required	N/A	
11.6	DMS design shall consider whether nearby CAV RSUs will require direct data feeds from the DMS.	Advisory requirement – no testing required	N/A	
11.7	DMS design shall consider whether nearby CAV RSUs will benefit from shared structures, power, or communications with the DMS.	Advisory requirement – no testing required	N/A	
12.1	A professional engineer registered in the State of Minnesota shall review	Design – Confirm professional engineer review.	Content Review	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
	and approve all structural details of the complete DMS structural system. The DMS housing, fabrication methods, and the housing's attachment to its support structure should all be considered in that structural system.			
12.2	The DMS shall include mounting instructions.	Design – Confirm presence of mounting instructions with deliverables.	N/A	
12.3	DMS shall include temporary or permanent components (e.g. lifting eyes) to support safe lifting, transport, and installation of the signs.	FAT – Confirm presence of components to support safe movement and installation.	Pass/Fail	
12.4	DMS shall meet current DMS specifications as approved by MnDOT or the agency/owner that is deploying/operating the DMS.	Design – Confirm that local specifications have been developed or acquired from other agencies and approved for use in final acceptance. Design- Confirm that the local specifications of the deploying/operating agency/owner are met. FAT – Confirm that DMS meet local specifications.	Design - Content Review Design - Content Review FAT - Pass/Fail	
13.1	Portable DMS shall include a mechanism for on-site technicians to configure the message displayed on the sign.	FAT – Confirm mechanism at the Portable DMS to configure the message display.	Pass/Fail	
13.2	If controlled remotely, Portable DMS shall include communications capabilities and support NTCIP messages to control and query signs.	FAT – Confirm NTCIP compliance for remote sign control to control and query Portable DMS. Field – Confirm communications with the Portable DMS to query the display, and post	Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
		and remove messages from an NTCIP compliant DMS Control Software.		
13.3	Portable DMS shall be installed on or part of a trailer to support movement to/from sites.	Design – Confirm Portable DMS is installed on or part of a trailer configuration that is safe for road travel. FAT – Confirm the trailer is tested for safe road travel.	Design - Content Review FAT - Pass/Fail	
13.4	Portable DMS shall include self-sustaining power sources (e.g. battery combined with solar) or shall connect to local power connections.	Design – Confirm desired power source is present, i.e. self-sustaining or power connection. FAT – Confirm Portable DMS self-sustaining power source is functional, or that a power connection is present.	Design- Content Review FAT - Pass/Fail	
13.5	Portable DMS shall include GPS position determination to report their location.	FAT – Confirm GPS capabilities are present. Field – Confirm GPS positioning accuracy.	Pass/Fail	
14.1	In locations where CAV infrastructure systems broadcast messages to CAVs, the DMS control software shall generate messages containing content displayed on DMS and identify location areas where the content is relevant to drivers.	Design – Confirm CAV message generation capabilities. Field – Demonstration of DMS control software ability to generate a CAV message in a standard format that conveys the message described on the DMS and the location areas where the content is relevant to drivers.	Design - Content Review Field - Pass/Fail	
14.2	The DMS control software shall communicate the messages to the applicable CAV infrastructure system. Note: this message exchange will support CAV infrastructure systems in communicating the “local traveler	Design – Confirm ability to transfer CAV messages. Field – Confirm DMS control software can communicate the generated CAV message to CAV Infrastructure System in the field.	Design - Content Review Field - Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
	information" information flow (Roadside equipment to vehicle OBE).			
15.1	In situations where direct DMS to CAVs communications is operational, DMS shall generate a message conveying the message described on the DMS, in a format compatible with the two-way vehicle to roadside or cloud-based communication medium (note information flow is defined as "automated vehicle control parameters" as defined in ARC-IT).	Design – Confirm DMS CAV communications and processing capabilities. FAT – Demonstration of DMS or supporting roadside unit ability to: • Generate a CAV message in a standard format that conveys the message described on the DMS • Communicate the generated CAV message to equipped vehicle systems via one or more standard communications mechanisms. Field – Confirm with one or more on-board devices that the DMS or supporting roadside unit is able to: • Generate a CAV message in a standard format that conveys the message described on the DMS • Communicate the generated CAV message to equipped vehicle systems via one or more standard communications mechanisms.	Design - Content Review FAT - Pass/Fail Field - Pass/Fail	
15.2	In situations where CAV equipped vehicles communicate with DMS, the DMS (or supporting roadside unit) shall receive, process, and act upon messages from the vehicle to display messages on the sign.	Design – Confirm DMS CAV communications and processing capabilities. FAT – Demonstration of DMS or supporting roadside unit: • Receiving CAV messages in standard formats.	Design - Content Review FAT - Pass/Fail	

System Requirement		Testing Instructions	Type of Result	Comments / Notes
		• Processing and retaining multiple CAV messages to parse out various data elements. • Acting on received CAV messages, e.g. communicating summary data to MnDOT or generate and post a DMS message. Field – Confirm with one or more on-board devices that the DMS or supporting roadside unit is able to: • Receive CAV messages in standard formats. • Process and retain multiple CAV messages. • Act on received CAV messages, e.g. communicating summary data to MnDOT or generate and post a DMS message.	Field - Pass/Fail	