TSMO
TRANSPORTATION SYSTEMS MANAGEMENT & OPERATIONS

Michigan Department of Transportation

Real-Time Warning/Variable Speed Limit Abbreviated Concept of Operations Document

CAMBRIDGE SYSTEMATICS

February 2022

1. Report No.	2. Government Accession No.	3. MDOT Project Manager
1A	N/A	Steven J. Cook, P.E.

4. Title and Subtitle	5. Report Date
Michigan Department of Transportation Real-Time Warning/Variable Speed Limit Abbreviated Concept of Operations Document	February 2022
	6. Performing Organization Code N/A
7. Author(s) S. Cook, R. Nelson, A. Danczyk, G. Leao, E. Flanigan	8. Performing Organization Report No. N/A
9. Performing Organization Name and Address Michigan Department of Transportation 6333 Lansing Road Lansing, MI 48917	10. Work Unit No. (TRAIS) N/A
	11. Contract or Grant No. N/A
12. Sponsoring Agency Name and Address Michigan Department of Transportation 6333 Lansing Road Lansing, MI 48917	13. Type of Report and Period Covered Final Report, 04/2021 to 02/2022
	14. Sponsoring Agency Code N/A

15. Supplementary Notes

Conducted in cooperation with the American Association of State Highway and Transportation Officials and the U.S. Department of Transportation.

16. Abstract

This document describes the Concept of Operations (ConOps) for expanding the Michigan Department of Transportation's (MDOT) Real-Time Warning (RTW) and Variable Speed Limit (VSL) program. As part of MDOT's Road Weather Management (RWM) program, RTW and VSL systems serve as one application for providing motorists with necessary weather-related insights to make informed travel decisions. MDOT has deployed RTW/VSL applications to date, and is looking to capture best practices nationally to develop a sustainable business case for continued expansion of these systems. The purpose of this document is to outline a framework for proactively identifying needs for RTW/VSL and deploying appropriate countermeasures to improve traffic operations.

This document supports one of the strategies that is part of larger Road Weather Management solutions. Although focused on Michigan applications and needs, this document intends to support the American Association of State Highway and Transportation Officials (AASHTO) Road Weather Management Community of Practice by forming a roadmap from which other interested states and transportation organizations can use to support their program.

17. Keywords	18. Distribution Statement
Road Weather Management, Real-Time Warnings, Variable Speed Limits, Concept of Operations, Intelligent Transportation Systems, Transportation System Management and Operations	No restrictions. This document is available to the public through the Michigan Department of Transportation.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	32	N/A

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1.0 Introduction

1.1 Document Purpose

This document describes the Concept of Operations (ConOps) for expanding the Michigan Department of Transportation's (MDOT) Real-Time Warning (RTW) and Variable Speed Limit (VSL) program. As part of MDOT's Road Weather Management (RWM) program, RTW and VSL systems serve as one application for providing motorists with necessary weather-related insights to make informed travel decisions. MDOT has deployed RTW/VSL applications to date, and is looking to capture best practices nationally to develop a sustainable business case for continued expansion of these systems. The purpose of this document is to outline a framework for proactively identifying needs for RTW/VSL and deploying appropriate countermeasures to improve traffic operations.

This document supports one of the strategies that is part of larger Road Weather Management solutions. Although focused on Michigan applications and needs, this document intends to support the American Association of State Highway and Transportation Officials (AASHTO) Road Weather Management Community of Practice by forming a roadmap from which other interested states and transportation organizations can use to support their program.

1.2 Background

MDOT and other state transportation agencies have employed Intelligent Transportation Systems (ITS) over several decades to help operate the transportation system. Among the many solutions offered by ITS, one core tenant is the ability to provide drivers with critical, useful information from which they can make informed travel decisions. Advanced notice of travel-specific considerations—when deployed in a strategic, thoughtful manner—has been demonstrated over time to provide benefits that far outweigh the costs.

Road weather challenges continue to be a major cause of traffic-related crashes in Michigan and elsewhere. Studies reveal that it can account for 25 percent of non-recurring traffic delays, impacting the economy by $10 billion per year.[1] In many situations, the cause of the weather-related issue is visible to the driver (e.g., a blizzard), and the driver may benefit from further information (e.g., a roadside message warning of treacherous conditions) to take corrective action. In other situations, the cause of the weather-related issue is not visible to the driver (e.g., an isolated icy patch of pavement), and the driver may benefit from any information of the concern they cannot see. In either case, the presence of enhanced information on travel conditions aids their ability to make informed travel decisions.

Road Weather is a Major Cause of Traffic-Related Crashes

Approximately 21 percent of nationwide vehicle crashes are weather-related, equating to over 5,000 fatalities annually, based on National Highway Traffic Safety Administration (NHTSA) data between 2007 and 2016.

1 U.S. DOT, "How Do Weather Events Impact Roads?" https://ops.fhwa.dot.gov/weather/q1_roadimpact.htm.

While many types of weather-related issues affect the road environment, many can be categorized into discrete topic areas. Table 1 outlines some of the weather-related challenges that MDOT and other transportation agencies face.

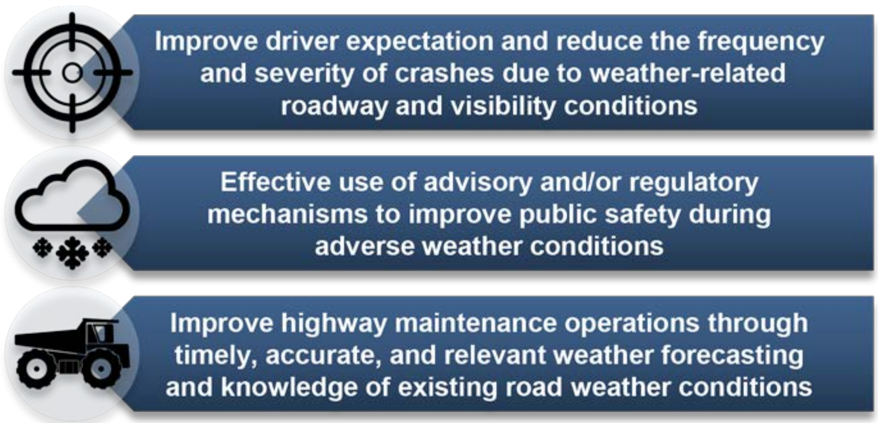
Table 1. Road Weather Event Details and Types

Road Weather Challenge	Details	Michigan Example
Limited Visibility	Limited visibility decreases a driver's sightlines and their ability to react and take corrective actions, such as maintaining their lane or stopping for slow-moving traffic. In Michigan, fog and blowing snow are the primary weather event that limits visibility, but heavy precipitation or dust storms (such as in the southwestern United States) can also create this challenge.	Fog, Heavy Rain, Blowing Snow
Inclement Pavement Conditions	Inclement pavement conditions decrease a driver's ability to stop as they would under normal conditions, as well as reduces ease of maneuverability. In Michigan, precipitation (i.e., hydroplaning) and winter ice are primary weather events that create inclement pavement conditions. Other parts of the United States likely experience the same. In certain topographies or microclimates, inclement pavement conditions can sometimes appear without any advance notice, such as if a driver goes around a curve that is blocked from sunlight and is icy.	Icy road, slippery rain conditions (hydroplaning), black ice
Inclement Meteorological Conditions	Inclement meteorological conditions present hazards to the driver's vehicle that may disrupt their operation, causing the driver to lose control. In Michigan (particularly on the Mackinac Bridge), high winds are a primary weather event that threatens travelers' abilities to maneuver their vehicles, particularly high-profile vehicles like trucks. Drifting snow can also be a challenge, either by making it difficult to know where the travel lane is or by creating inclement pavement conditions (e.g., ice). Other parts of the United States also experience these types of challenges.	High winds, drifting snow
High-Risk Meteorological Events	High-risk meteorological events include major storms that put the driver's ability to control their vehicle at risk, often creating other challenges like limited visibility or inclement pavement conditions. Whereas inclement meteorological conditions often permit a trip to continue so long as the driver manages the situation, high-risk meteorological events are situations where any travel is particularly risky. In Michigan, this primarily includes widespread blizzards or tornadoes. In other parts of the country, this may include massive flooding or hurricanes. These events are generally visible when they do occur, and are often managed by providing drivers with advanced notice to take corrective action and get off the road. As these events can occur in random geographies, it is difficult to plan a corridor-specific advisory system for them because their impacts can occur over a large area.	Blizzard, tornado, flooding

1.3 System Overview

RWM technology systems aim to mitigate the impacts weather has on the road system and the environment. RWM solutions encompass applications that include information systems for notifying motorists of road weather hazards, automated treatment systems to apply countermeasures to sensitive infrastructure (e.g., de-icing systems on bridges), and inform on plowing/salting operations. This may be done through a combination of roadside equipment, data services, and information distribution systems, which are discussed in greater detail later in this ConOps.

This ConOps focuses exclusively on the RTW and VSL applications of RWM programs, based on recommendations made at the TSMO365 Peer Exchange in June 2019 to focus on these topics as priority action items to advance the state of the practice. RTW/VSL systems are information systems, utilizing weather, traffic, and road condition data to warn of adverse conditions in a timely and specific manner. When thoughtfully designed, they provide motorists and/or transportation managers with the necessary insights to make informed decisions. Examples include advance notification of an upcoming weather hazard (e.g., heavy snow ahead) or location-based notification of an unseen hazard (e.g., ice on bridge). RTW/VSL systems are often designed with a degree of customization, allowing for multiple use cases both for weather and other traffic management applications when weather is not an issue. MDOT currently employs RTW/VSL solutions as part of its ITS program.



Based on feedback gathered through the TSMO365 Peer Exchange, subsequent AASHTO RWM Community of Practice listening sessions, and the NCHRP 03-142 G-11 research statement titled “Evaluating the Impacts of Real-Time Warnings and Variable Speed Limits on Safety and Travel Reliability During Weather Events,” it is apparent that RTW/VSL strategies are not boilerplate deployments. Different states with RTW/VSL had different needs, opportunities, and challenges when deploying their systems, and the technology solutions used had differences in terms of equipment and process. This ConOps aims to capture those varying motivations, identify how different applications fit in the overall RTW/VSL process, and illustrate how and when those solutions could be employed in Michigan.

1.4 References

This ConOps is supported by previous work undertaken for RTW:

- U.S. DOT, Guidelines for the Use of Variable Speed Limits in Wet Weather, FHWA-SA-12-022, August 2012.
- U.S. DOT, Michigan Department of Transportation (MDOT) Weather Responsive Traveler Information (Wx-TINFO) System Implementation Project, FHWA-JPO-16-323, January 2016.
- National Operations Center of Excellence, Michigan Department of Transportation Escanaba River Bridge Deck Warning System. June 2020.
- U.S. DOT, Field Test of Variable Speed Limits in Work Zones (In Michigan). Final Report RC-1467. Prepared By Michigan Department of Transportation and Michigan State University. September 2003.
- MDOT, Weather Responsive Traveler Information System (Wx-TINFO) Implementation Concept of Operations. September 2014.
- MDOT, Michigan Mobility 2045 Transportation Plan. November 2021.
- AASHTO Community of Practice (CoP) on Road Weather Management (RWM). Listening Session. April 22, 2021.
- AASHTO Community of Practice (CoP) on Road Weather Management (RWM). Listening Session. November 9, 2021.

2.0 Current System and Situation

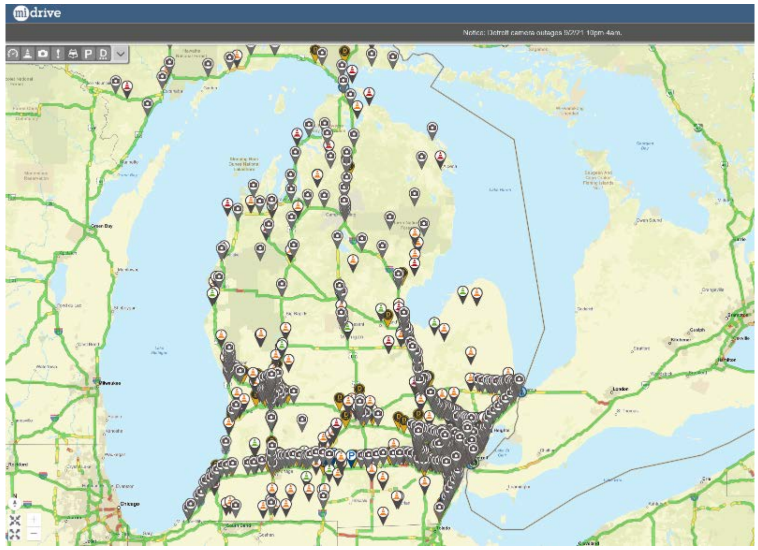
2.1 Description of Current System and Situation

MDOT employs a robust statewide ITS program to better operate the state-owned road network. Among the applications used, several RTW/VSL applications have been operational for several years. These applications are highlighted as the current systems in place, from which an RTW/VSL expansion could be informed for best practices.

Real-Time Warning System—Static Signs with Activated Flashing Beacons—This application activates a flashing beacon over a warning sign to inform motorists in real-time when icy or inclement pavement conditions are present. Sensors near the site monitor pavement conditions and, when slippery conditions are present or likely, send a signal to a sign field controller that activates the flashing beacon(s). During non-active periods, the static warning message remains and, due to being only a warning message, is not considered to be in conflict the other messaging or incorrect. MDOT has installed several systems around the state, including a Bridge Deck Warning System on I-75 over Charles Brink Road and on I-75 over Trowbridge Road in the North Region. Other similar systems provide activated beacons for traffic or safety concerns, such as queue warnings or curve speed warnings.

Real-Time Warning (Dynamic Message Signs)—MDOT operates Dynamic Message Signs (DMS) at various locations throughout the state that receive road, weather, and traffic messages to help motorists make informed decisions. The default message for these signs is often a distance-based travel time to destinations along the corridor (e.g., I-496 10 Miles 11 Minutes), utilizing travel time data provided by other systems; some DMS also support automated congestion messaging, where speed data is used to provide messages regarding stopped or slow traffic ahead. These DMS are currently used to display relevant weather-related messages that are reported to the overseeing Traffic Operations Center (TOC) that controls the sign. Often, these are for regional weather events, such as "Winter Weather Warning," as opposed to specific local issues, although some regions utilize their DMS to be triggered by local environmental sensor data. MDOT's Southwest Region is currently developing a weather-responsive advisory system along I-94 in Van Buren County that will utilize DMS to post advisory speed and roadway condition information (e.g., slippery roads ahead) along the corridor. This system will utilize a combination of environmental sensor stations (ESS), real-time traffic speeds and operation, and other inputs to inform an automated decision-tree that will post messages. Messages will be posted on DMS that are installed every 5 miles to provide frequent updates

through this winter weather-related high-crash area. TOC operators will be aware of posted messages and can override based on field observations. This system is anticipated to be fully functional in 2022 or 2023.



Real-Time Warning (Advanced Traveler Information)—MDOT operates Mi Drive as its primary Advanced Traveler Information System for providing relevant travel conditions across Michigan. Visitors to this public-facing system can view CCTV camera images, read DMS messages at specific signs, see snowplow locations (when operating), and receive general information. While this system is primarily utilized for advanced trip planning, it can also provide real-time warnings on inclement conditions.

Variable Speed Limits—MDOT has utilized VSL as part of the U.S.-23 FlexRoute project, which installed overhead Active Traffic Management gantries along U.S.-23 from M-14 to M-36/9 Mile Road just north of Ann Arbor. Similarly, as mentioned earlier, MDOT's Southwest Region is exploring use of advisory speed limits on DMS in coordination with a RTW message. The current practice by MDOT is to consider variable speed limits in general practice as advisory.

Other services exist for pushing RTW messages to motorists that are not controlled by MDOT. For example, emergency notification systems can push relevant messages directly to a motorist's cell phone based on their geographic location, but these types of notifications are generally reserved for extremely critical events (e.g., tornado or thunderstorm warning, AMBER alert, other public safety notifications), and are seldom relevant only to just RWM.

2.2 Current System Stakeholders and Actors

Several relevant stakeholders are involved for RWM in Michigan.

MDOT—As infrastructure owner-operator for state-owned public roads in Michigan, MDOT is responsible for building, operating, and maintaining the state highway system in the interest of public safety and mobility.

- MDOT operations planners and engineers are responsible for coordinating annually with the regions to identify candidate project sites for RWM strategies, prioritizing resources, establishing the concept for operations, coordinating with internal and external stakeholders, and providing support for the system's lifecycle.

- MDOT operations staff, in addition to managing the general traffic incident management program, are responsible for overseeing operations of the centrally managed RTW/VSL systems on Michigan roads. MDOT operations staff in the
- TOCs review recommendations made either by the system or via field reports in order to issue response plans, and they are responsible for making sure messaging is properly delivered to the public.
- MDOT's ITS Program Office is responsible for maintaining ITS field assets in working order. In addition to routine maintenance (e.g., camera cleaning, sensor count checks, etc.), the program office staff manages contracts with vendors that are responsible for responding to devices that go offline within a designated timeframe.

Law Enforcement—As the agency responsible for enforcing laws, the Michigan State Police is the primary law enforcement agency on the state-owned highway network. Michigan State Police's responsibilities include responding to weather-related incidents to help manage safe travel along the corridor.

Other Government Organizations—Road weather management is dealt with elsewhere in Michigan by other agencies, such as counties or municipalities. Local law enforcement has similar responsibilities for managing incidents on the local road network. MDOT contracts with local agencies through its Local Agency Program to support maintenance safety and mobility improvements. Other agencies—such as the National Weather Service—collects and distributes the weather data to support these management activities.

2.3 Support Environment

Existing RTW/VSL assets are supported as part of the MDOT ITS programs, which are maintained by the MDOT regions. For most instances, the regions utilize an ITS maintenance contractor to maximize the uptime of devices, such as providing troubleshooting for a malfunctioning device or performing scheduled routine maintenance for device upkeep.

2.4 Operational Policies and Constraints

MDOT's operational policies for RTW and VSL trend towards using automation where possible in order to minimize the workload on operations staff, but similarly acknowledging that more elaborate systems may require some operator verification to avoid incorrect messages from being posted. Since most RTW system are local systems composed of static signs with activated flashing beacon devices, automated operation is easy to achieve through use of a calibrated field controller that activates when the sensors report the condition in question. Since the information on the static warning sign remains relevant at all times and the flashing beacons are viewed as a tool to help draw more attention to the sign, these devices are able to activate automatically because an incorrect activation would not substantially impact sign credibility with the driver. For example, activated flashing beacons over a "Bridge May Be Icy in Winter" warning sign on a hot summer day will be incorrect, but a driver will likely recognize that the warning sign is for their discretion.

The I-94 weather-responsive advisory system is proposed to utilize automated operation. The MDOT Advanced Traffic Management System (ATMS) will receive a myriad of information from fixed sensors, mobile data sources, and other weather service and, through a logic and decision tree that evaluates these inputs, recommend a message to the operator (which may include text and/or an advisory speed limit graphic). Preliminary thresholds on the logic and decision tree have been identified and will continue to be refined as the system is implemented.

3.0 Justification for and Nature of Changes

Road weather incidents continue to be a safety challenge for MDOT. Despite a growing number of safety features in vehicles, crash rates have remained steady over the last decade. Motorists continue to benefit from real-time notifications of a potential hazard, allowing them to make informed driving decisions to better travel. MDOT's existing RTW/VSL program provides support in specific areas of the state, but many other areas exist around Michigan that experience weather-related impacts and could benefit from an RTW or VSL deployment.

3.1 User Needs

MDOT has developed the Michigan Mobility 2045 plan to serve as the state's long-range transportation plan. Six goals and objectives were identified as motivations for the overall strategic direction of transportation investment in Michigan, which also informs wide-ranging transportation projects and specific user needs in the context of a RWM program. The AASHTO Road Weather Management Listening Session in April 2021 augmented these needs and motivations, with other states with RTW and VSL programs providing insight on what drove their program. These two perspectives have been fused together to formulate high-level user needs for expanding MDOT's RWM program. The second AASHTO Road Weather Management Listening Session, held in November 2021, vetted these user needs with the agencies and augmented based on feedback and additional insights.

MDOT's User Needs are described in Table 2.

Table 2. High-Level User Needs

No.	User Need
UN-1	Need to provide motorists reliable, accurate, and timely real-time warnings of inclement meteorological conditions that limit visibility.
UN-2	Need to provide motorists reliable and timely advanced notification of inclement pavement conditions.
UN-3	Need to provide motorists reliable and timely advanced notification of inclement meteorological condition that are hazardous to vehicle operation.
UN-4	Need to provide motorists reliable and timely advanced notification of high-risk meteorological events that are hazardous to vehicle operation.
UN-5	Need to improve safety in areas that are prone to crashes and incidents due to road weather events.
UN-6	Need to operate a proposed notification system in a manner that provides reliable messaging while reducing operator workload, such as through use of decision-tree recommendations or automation.
UN-7	Need to support other traffic operations information, such as informing motorists of work zones, traffic incidents, and slow speed advisories.
UN-8	Need to provide specific speed-related operational changes to help encourage motorists to collectively reduce speed when necessary for inclement travel conditions.
UN-9	Need to improve the efficiency and effectiveness of highway maintenance operations through proper forecasting and reporting of existing road weather conditions.

No.	User Need
UN-10	Need to share data with the public and third-party data service providers to increase data accessibility and opportunities for use.
UN-11	Need to integrate new ITS elements in the larger ITS program.
UN-12	Need to encourage alternate route use or trip avoidance when inclement conditions are hazardous to motorists on a particular route.
UN-13	Need to utilize solutions capable of having a sustainable operations and maintenance models for preserving system accuracy and reliability.
UN-14	Need to collect performance measures to demonstrate value and return-on-investment of technological systems.

3.2 Description of Desired Changes

In order to further achieve the goals identified in Michigan Mobility 2045, MDOT is considering expansion of its RTW/VSL program as a countermeasure to help fill gaps in coverage. This expansion will build upon the success of the existing RTW/VSL program, but utilize lessons learned from peer agency states with successful RTW/VSL programs that have successfully served their road users. Each state that participated in the AASHTO Road Weather Management Listening Session in April 2021 identified variations in their approach and motivations. When outlining the findings from that session, the second Listening Session in November 2021 allowed states to add additional considerations that they felt were worth noting. As part of desired changes to the RTW/VSL program, MDOT aims to consider these variations as an opportunity to make the applications work better and more widely serve motorists. Key considerations for desired changes are outlined in Table 3.

Table 3. Considerations for Desired Changes

Consideration	Details
Deploy RTW/VSL where purpose and need exists	Peer states identified a purpose and need for RTW and/or VSL prior to deployment. This was often gathered through internal and external stakeholder engagement, which often included buy-in from operations, maintenance, and law enforcement personnel. Engineering studies are valuable to help support feasibility of a proposed operational improvement and assist in developing operational parameters (e.g., threshold speeds for VSL).
Track and document successes or (as applicable) failures.	Peer states tracked the observed improvements after deployment to validate the application's successes or failures. These tracked outcomes were used for reporting purposes and to enhance the quality of the system. For example, some peer states used their tracked outcomes to generate a Qualified Products List (QPL) to help vendors better meet requirements.
Evaluate the availability of supporting services for all elements of the system, namely reliable power and network communications.	Peer states noted that successful RWM systems—like all ITS assets—need reliable electrical power service and access to network communication systems, which can be challenging in remote parts of the road network. They indicated that these elements often were overlooked during design, and tended to become problems later (e.g., high cost to extend service, use of an unreliable alternative such as solar power, etc.). Giving these elements consideration early in the planning and design processes can help mitigate some of the problems, such as identifying the need for backup power to be scoped into the design.

Consideration	Details
Determine preference toward field-managed or centrally managed systems.	Peer states highlighted that some applications benefit from real-time monitoring, whereas other field-managed systems could operate on their own. For example, “Ice on Bridge” with activated flashing beacons may be so remote and out of communications service that automated local activation without oversight from a TOC is beneficial.
Evaluate automated activation versus manual (operator) activation	Many peer states used different activation strategies. Simpler systems (e.g., “Ice on Bridge”) generally were activated automatically in the field. More complex systems (e.g., VSL on highway) had systems that provided decision-tree recommendations based on data, but ultimately had to be confirmed and activated by an operator at the TOC.
Review the proposed algorithm that issues recommendations (either to operator or to field equipment).	Peer states used different algorithms for activating RTW and VSL messages. A key takeaway was to review the inputs, the decision-tree processes, and other outcome selections with relevant stakeholders to confirm that the system is doing what it should.
Explore whether messaging is advisory signage or regulatory signage.	Some messages can be set up as advisory or regulatory, particularly on DMS that show a sign image or on VSL. Many peer states use advisory signage due to being easier to implement from a policy perspective. Regulatory signage offers a stronger enforcement element in terms of mandating compliance, but often is more complicated by requiring specific laws, policies, and procedures to be adopted at the state legislature and among a wide group of stakeholders.
Conceptualize the preferred messaging infrastructure	Most peer states provide RTW and VSL notifications on a road sign, either static or dynamic. Highway Advisory Radio (HAR) was used for certain applications. Advanced Traveler Information System (ATIS) is also another information distribution resource, although that is used more for pre-trip planning. Other emerging technologies—namely vehicle-to-infrastructure solutions—may be able to send digitized messages over-the-air to a vehicle’s onboard equipment to notify the driver.
Evaluate opportunities to support other traveler information services	Some RTW/VSL applications can be utilized for both road weather applications and traffic management applications. For example, a DMS can notify of either inclement weather in the winter or a multi-vehicle incident in the summer. When both occur simultaneously, standard operating procedures must be in place to determine which message gets the priority and is ultimately distributed, or how several messages can be concatenated.
Determine the necessary level of field verification	Verification includes both confirmation of the reported weather as well as confirmation that the correct message has been posted in the field. Many peer states with verification processes utilize CCTV camera or in-field maintenance personnel to accomplish this.

Consideration	Details
Determine the methodology for removing a message at the right time	In addition to putting the correct message out to drivers, it is equally important to know when to appropriate remove the message. Many ATMS platforms utilize automated tools to notify operators of and/or remove messages that may not be relevant due to time. When systems are informed by various data services (e.g., National Weather Service, field equipment, etc.), establishing the proper thresholds and time requirements for removal is important to avoid having an outdated message show on the signs. As an example, some agencies that have RWM systems for high wind warnings will automatically remove a message after a period of time has elapsed since the last reported wind gust. In Michigan, some road weather messages are only automatically posted when sensed for at least 2 minutes, and only removed when not detected for at least 2 minutes.
Coordinate with stakeholders regularly to find opportunities for the system to benefit their activities	RTW and VSL systems can support other stakeholders, particularly those who work in the field for construction or response to weather-related incidents (maintenance, first responders, law enforcement etc.). Coordination with these stakeholders ensures that the system is working collaboratively.
Identify sustainable operations and maintenance funding models.	RTW and VSL systems require ongoing operations and maintenance funding to continue providing operations in the future. Many ITS programs struggle to secure long-term funding, so it is critical to identify the ongoing lifecycle funding source during the planning and design phase. Additional considerations should be given for evolving technology over the long-term, and how that can be factored into cost.

3.3 Assumptions and Constraints

3.3.1 Assumptions

- **MDOT's ITS program remains in place—**The ITS program serves as the primary framework in which many RTW/VSL services can operate. This program provides a network architecture to facilitate real-time communications between field and center and a central processing software to process weather data. Local field devices are supported by the ITS program's maintenance contract. Removal of this program would make RTW/VSL operations and long-term maintenance more challenging.
- **The necessary equipment is deployed to allow accurate messaging—**MDOT will deploy the equipment that can provide the data types necessary to produce the data that can facilitate proper messaging, regardless of if processed by algorithm or via manual activation. For example, an ice warning system will have the necessary detection hardware to detect ice.

3.3.2 Constraints

- **Weather monitoring is limited—**Weather events impact a wide area. While regional meteorological services do a good job at identifying broad issues (e.g., precipitation, etc.), some of the more specific conditions that create inclement travel conditions must be measured locally at a site or along a specific corridor (e.g., I-94 in the Southwest Region gets lake effect snow squalls and whiteout conditions from Lake Michigan, whereas other parts of the state may not). Road Weather Information Systems (RWIS) can help assess these measurements, but their coverage is limited due to requiring specialized field equipment at many sites and its ability to only measure environmental weather conditions near the site.

Distances between ESS create weather data gaps, which limit an operator's knowledge of specific localized roadway conditions. Density of ESS architecture for better coverage may be limited by financial and operational resources. Additionally, messaging infrastructure can be limited, as posting messages too far in advance of conditions that rapidly change can impact the message's credibility.

- **External limitations on system operation—**RTW/VSL systems can be centrally- or locally-operated, depending on the application. Centrally operated applications can collect and distribute information across a wide area but require access to a reliable communications network in order to exchange data. Communications network coverage—including wireless options like cellular—is not always available.
- **Reliance on Driver Compliance—**Even though the message may inform a driver of an inclement travel condition and propose a driver action (e.g., "Low Visibility—Turn Headlights On"), it relies on drivers to take the necessary action that may help improve safety along a roadway corridor. Drivers may elect to take no corrective action and still result in a crash. This is true even in VSL environments with regulatory requirements.

4.0 Concept for the Proposed System

4.1 Description of the Proposed System

These RTW/VSL strategies utilize technological processes to provide service to motorists. Technological processes follow a general framework that is used to establish a successful ITS program. It requires 1.) a means to collect data; 2.) a means to process the data, and 3.) a means to distribute that data to the targeted user group.

4.1.1 Information Collection from Field

Systems and technology components that collect data focus on reporting relevant meteorological conditions for travel, either at a regional or local level. Table 4 outlines relevant RWM data collection components. These components are based on those currently used by MDOT’s RTW/VSL program, those utilized by peer states as part of their RTW/VSL program, and those that are known in the industry as potential opportunities to collect data. A scale of coverage is provided to each component to help convey the expected degree of data that could be collected.

Table 4. Information Collection Components

Information Collection Component	Data Collection Scale	Details
RWIS	Local	RWIS includes ESS in the field to measure atmospheric, pavement, and/or water level conditions. Strategically deployed RWIS can monitor local conditions, such as in areas with micro-climate concerns or sensitive bridge infrastructure that freezes before the road. Roadside RWIS refer to either permanent or temporary (i.e., trailer-mounted) weather station sites that collect meteorological data at a single geographical position along a corridor.
Mobile Road Weather Information Systems	Local/Regional	“Mobile” RWIS is a similar ESS that is attached to a moving vehicle, allowing readings to be collected across an expanded area. Most mobile RWIS systems are physical weather devices attached to fleet vehicles, such as maintenance vehicles or snow plows, but can include data services that are published through a fleet Computer-Aided Dispatch / Automatic Vehicle Location (CAD/AVL) system (e.g., plow blade up/down, salt spreader on/off) or video images from mobile equipment (e.g., front-facing CCTV cameras on plow vehicles). While “mobile” RWIS generally collects less data than fixed-site RWIS, it can offer meteorological readings over a wider area, depending on the route in which the vehicle drives.

Information Collection Component	Data Collection Scale	Details
Third-party Meteorological Data	Regional	**National Weather Service:** The National Weather Service is an agency of the United States Government tasked with providing weather forecasts, warnings of hazardous weather, and other weather-related information services. The NWS monitors weather stations across the United States and provides forecasts and warnings on inclement weather conditions. It is one of many services that provides widespread weather information that is relevant to travelers. NWS provides publicly available data feeds on meteorological conditions. **Automated Weather Observation System (AWOS) and Automated Surface Observing System (ASOS):** An AWOS station collects and broadcasts key meteorological data, typically winds, temperature/dewpoint, density altitude, visibilities, and cloud ceilings. It is managed by the Federal Aviation Administration (FAA). An ASOS station collects similar meteorological data, but is managed, maintained, and controlled by the National Oceanic and Atmospheric Administration (NOAA). Both systems are largely automated, but may include human observer monitoring by the owner agency when visibilities are reduced. **Great Lakes Buoys:** NOAA and a few other agencies maintain a network of buoys that are deployed in Lake Michigan to gather temperature, barometer, and other meteorological data collection. These buoys provide insight on conditions over the water, which often translates into meteorological events in Michigan due to lake proximity. **Other Services:** Similar to NWS, third-party meteorological services have emerged as a data resource for meteorological data. These private-sector services often collect weather data from a myriad of sources and provide their own customer-focused weather reports. Some of these services may require a fee to access data on a regular basis. Other types of service, such as a Maintenance Decision Support Service (MDSS), may be separate third-party tool housed within a transportation agency that can provide additional forecasts, such as road condition forecasts for snow management operations or combined data resources from several weather resources (e.g., radar, ASOS/AWOS, ESS, snowplow mobile AVL weather data, etc.)
CCTV Cameras	Local	CCTV cameras in the field allow for remote viewing of a particular geographic location. While CCTV cameras are often used for monitoring traffic-related incidents or congestion, they also provide a remote view of the roadway to help visually inform operators of certain inclement conditions, such as heavy rain or snow events helping to validate local weather condition state.
Traffic Sensors	Local	Traffic sensors provide volume, occupancy, and speed data for a particular reporting area, often on a lane-by-lane basis. Field equipment provides real-time traffic operations data at a particular site. While this does not specifically generate meteorological data, real-time traffic data can indicate where traffic is not operating as it normally would, such as due to a weather-related issue.

Information Collection Component	Data Collection Scale	Details
Crowdsourced Reporting	Local/Regional	With the rise of personal mobile devices, new tools have made it possible for citizens to report weather observations. Mobile applications, notably Waze, rely on drivers to report observed incidents and other traffic-related issues. By crowdsourcing a consistent report, the application developers feel confident that the reported event can be accurately shared with other users. While this has many uses, it's role as a weather data collection tool on roadways is not recommended, as single reports are often limited in usefulness and accuracy, and it may distract drivers who should otherwise be focusing on the road.
Public-Sector Connected Vehicle (vehicle-to-infrastructure) Data	Local/Regional	The United States Department of Transportation (U.S. DOT) Intelligent Transportation System Joint Program Office's (ITS-JPO's) Connected Vehicle (CV) program applications include an enabling system on Connected Vehicles called a Vehicle Data Translator (VDT), which ingests CV data that is tied to weather-related observations. For example, windshield wiper status to infer precipitation or anti-lock brake system (ABS) activation to infer road friction. This component is currently a prototype, as the vehicle-to-infrastructure communication program has not been adopted and a very limited number of connected vehicles are currently on Michigan roads.
Private-Sector Connected Vehicle Data	Local/Regional	Some data service providers are gathering vehicle-reported data for use in traffic management applications. These data service providers utilize data collected by the vehicle's onboard systems and reported out through its cellular connection. For example, Waycare is one data service provider that collects real-time vehicle reports of "hard braking" events, which is processed through proprietary algorithms and reported to subscribers as potential spot-specific incident locations. These services may require a fee to access data on a regular basis.

4.1.2 Information Processing

Systems and technology components that process data receive the data that is collected and determine if a warning is necessary. For automated components, the notification is issued based on certain criteria being met and distributed without the need for operator intervention. For manual components, the notification is also issued based on certain criteria being met, but a human operator is notified to confirm that the message should be sent. Table 5 outlines relevant RWM data processing components.

Table 5. Information Processing Components

Information Processing Component	Data Collection Scale	Details
Local Field Controller	Local	Local field controllers are basic devices—often some type of programable logic controller—that activate in response to pre-defined criteria being met. These controllers are often located in field cabinets and support a local RWM strategy, such as a RWIS that collects data and notifies drivers of inclement conditions via a flashing beacon sign. Local field controllers may operate in isolation with pre-programmed decision-tree logic, but others may have a communications network connection that provides status information to a central monitoring system.
Central Software	Regional	Central software refers to software that resides in MDOT's central system, often part of the ATMS in the TOC. This software receives data from the field and recommends messaging in response to a certain event. Messages may be distributed to remote field devices either automatically or manually through a TOC operator's validation.
Weather Responsive Traveler Information System (Wx-TINFO)	Regional	Wx-TINFO is a weather data aggregator that collects meteorological data from the sources above to create a single, comprehensive application. It runs this data through a quality assurance check and analyzes it through a logic/decision tree to uncover pertinent, accurate weather information. These weather conditions are automatically generated and provided to the ATMS for use. Wx-TINFO is a key input for the weather-responsive advisory system that is proposed for I-94. It serves as a supporting processor for the MDOT central software.

4.1.3 *Information Distribution*

Systems and technology components that distribute information that helps motorists make informed decisions. Table 6 outlines relevant RWM information distribution components.

Table 6. Information Distribution Components

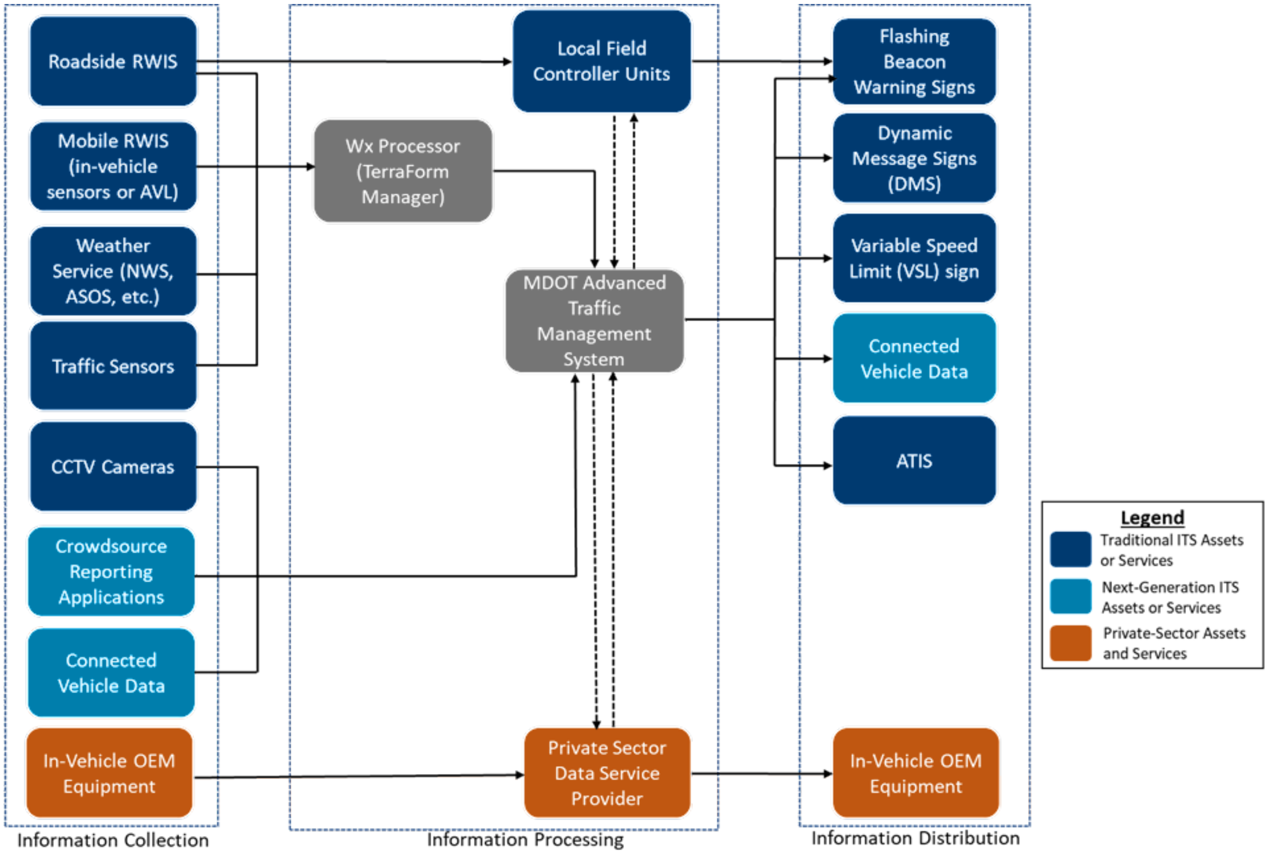
Information Collection Component	Data Collection Scale	Details
Static Sign with Flashing Beacons	Local	Static regulatory or warning signs are equipped with flashing beacons that activate when triggered by the proposed system. The static sign remains relevant when the flashing beacons are not active, but activation of those beacons helps draw additional attention to the messaging. Activated beacons helps inform the driver of an active warning.
Dynamic Message Sign	Local/Regional	Dynamic Message Signs are activated to show a RTW message when triggered by the proposed system. The DMS posts the message that is received or is called from its library of fixed messages. DMS allows customizable messages to be selected, based on the specific need. These messages help inform the driver of an active warning and the need to be alert.

Information Collection Component	Data Collection Scale	Details
VSL Sign	Regional	Variable Speed Limit Signs have a dynamic component that allows speed limits to be changed. VSLs can either be a static sign with changeable numerals or a full dynamic message sign. VSLs publish a speed limit as either an advisory recommendation or as a regulatory requirement, depending on state regulations. Reduction in speeds help inform the driver of an inclement condition that may warrant a slower travel speed.
Public-Sector Connected Vehicle (vehicle-to-infrastructure) Data	Local/Regional	The U.S. DOT ITS-JPO's CV program applications include an enabling system on Connected Vehicles called a Motorist Advisories and Warnings (MAW), which broadcasts CV data that is tied to road weather. Depending on the placement and design of roadside units, this CV data could provide geofenced notifications of weather-related concerns, similar to if a roadside sign or DMS was present. This component is currently a prototype, as the vehicle-to-infrastructure communication program has not been adopted and a very limited number of connected vehicles are currently on Michigan roads.
Private-Sector Connected Vehicle Data	Local/Regional	Many in-vehicle infotainment systems provide navigation systems that receive real-time traveler information from private-sector traffic data service providers. By providing RTW/VSL information to these third-party data service providers, the information could be distributed to in-vehicle information systems in geofenced areas.
ATIS	Regional	ATIS, including Mi Drive and third-party traveler information services, provide widespread information for travel conditions. In the absence of a locally reported issue from a device, ATIS generally reports on regional conditions and provides widespread advisories for drivers to make informed decisions.

4.1.4 Conceptual Architecture

Figure 1 illustrates the conceptual architecture for a proposed RTW/VSL program. While recognizing that not every component must be deployed in order to have an effective system, all components are shown to help illustrate their placement and role in the system. Many combinations can be paired together to build a successful RTW/VSL system.

Figure 1. Conceptual Architecture



4.2 Stakeholder and Actors of the Proposed System

Many stakeholder types that support existing RWM in Michigan are maintained, while new stakeholder groups may be added based on geographic expansion.

MDOT—As infrastructure owner-operator for state-owned public roads in Michigan, MDOT is responsible for building, operating, and maintaining the state highway system in the interest of public safety and mobility.

- MDOT planners and engineers remain responsible for identifying candidate project sites for RWM strategies, prioritizing resources, establishing the concept for operations, coordinating with internal and external stakeholders, and providing support for the system's lifecycle.
- MDOT operations staff remain responsible for overseeing operations of the RTW/VSL, if designed to be processed through a TOC. Even if response plans are automatically activated, the MDOT operations staff will be responsible for confirming status of activation and that everything is showing properly to the public.
- MDOT's maintenance staff remain responsible for maintaining field assets in working order, often utilizing an ITS maintenance contractor to complete the actual work. In addition to routine maintenance (e.g., camera cleaning, sensor count checks, etc.), maintenance staff are responsible for responding to devices that go offline within a designated timeframe.

Law Enforcement—As the agency responsible for enforcing laws, the Michigan State Police is the primary law enforcement agency on the state-owned highway network. Michigan State Police's responsibilities include responding to weather-related incidents to help manage the incident. If regulatory signage is utilized (i.e., regulatory VSL), Michigan State Police is responsible for enforcing those reduced speed limits, as well as enforcing instances where drivers are traveling too fast for inclement conditions (i.e., advisory VSL).

Other Government Organizations—Road weather management is dealt with elsewhere in Michigan by other agencies, such as counties or municipalities. Local law enforcement has similar responsibilities for managing incidents on the local road network. MDOT supports local agencies through its Local Agency Program to help fund safety and mobility improvements

4.3 Support Environment

Assets for RTW/VSL are supported as part of the MDOT ITS program, which are maintained by the MDOT regions. The regions utilize their local maintenance staff or an ITS maintenance contractor to maximize the uptime of devices, such as providing troubleshooting for a malfunctioning device or performing scheduled routine maintenance for device upkeep.

4.4 Operational Policies and Constraints

MDOT's operational policies for RTW and VSL vary depending on the equipment that is being utilized. For the real-time warning static signs with activated flashing beacons, these remote devices are calibrated in the field to activate automatically when a condition is detected. Since the information on the static warning sign remains relevant at all times and the flashing beacons are viewed as a tool to help draw more attention to the sign, these devices are able to activate automatically because an incorrect activation would not substantially impact sign credibility with the driver. For example, activated flashing beacons over a "Bridge May Be Icy in Winter" warning sign on a hot summer day is incorrect, but a driver will likely recognize that the warning sign is for their discretion.

For RTW or VSL on DMS, MDOT may use automation or a human operator to approve the messaging prior to being posted on the roadside. MDOT's ATMS has a library of "canned" messages that are recommended to an operator based on certain conditions. For the I-94 weather-responsive system, the MDOT ATMS receives a myriad of information from fixed sensors, mobile data sources, and other weather service and, through a logic and decision tree that evaluates these inputs, recommends a message that is automatically pushed to the field. Other deployments may require operator confirmation, particularly ones that are more high-profile to the public or have a greater risk factor of publishing the wrong message. In such manual cases, the operator must approve the message before the ATMS may post the message on the DMS. Manual approval, while increasing workload, helps reduce the chance of an incorrect message being sent to the field, which will have a greater impact on sign credibility with the driver. For example, a DMS that says "Slippery Roads, Reduce Speed" with an advisory speed of 35 mph on a hot summer day will be incorrect, but the driver will likely view this as an unreliable system and ignore it in the future.

5.0 Operational Scenarios/Use Cases

This section discussed operational scenarios that are relevant to MDOT's proposed RTW/VSL system. These operation scenarios each focus on one type of road weather events that were highlighted earlier in Table 1, utilizing a combination of components, technologies, and equipment to demonstrate how they would play a role in the proposed system. Inclusion of a particular component does not require MDOT to use that component as part of the final system, but aims to illustrate how it could be used as part of a comprehensive system.

Figure 2. Example of a winter weather crash event

5.1 Limited Visibility

A motorist is traveling on I-94 in Michigan, where MDOT has deployed its weather-responsive advisory system in response to high crash rates during weather events. This advisory system includes many fixed-site RWIS at locations along the corridor, as well as some temporary trailer-mounted RWIS sites that augment the coverage. In addition to various traffic speed detectors and CCTV cameras, the corridor is also instrumented with dual DMS in the median (one for each travel direction).

On this day, several roadside RWIS report meteorological conditions that are consistent with heavy fog. The RWIS report these conditions via wireless link to MDOT's ATMS, which—coupled with other data feeds from credible meteorological sources that suggest the same—reviews its pre-programmed decision tree to determine an automated response. The decision tree leads to a recommendation to automatically initiate an advisory DMS message to motorists of limited or low visibility, as well as recommend a reduced advisory speed limit. DMS that are both in advance and within the affected area immediately activate, posting a message of "LOW VISIBILITY AHEAD" with a graphical advisory speed limit of 45 mph. The motorist who is traveling on I-94—not yet having encountered the fog—sees the sign and elects to drive more cautiously in anticipation of limited visibility.

Operators at the MDOT TOC are informed of the automated message activation and, using the cameras, they visually confirm that fog is present along the corridor between their other tasks. Local law enforcement may be notified to monitor for potential incidents along the corridor where fog is reported.

5.2 Inclement Pavement Condition

During winter, motorists enjoy driving along the M-28 in the upper peninsula to see stunning views of Lake Superior. MDOT's plow crews work feverishly to keep the roads clear after every snowfall so motorists have a clear way to travel. Even though the winter sun can keep the road surface warm, several segments have larger hills that obstruct the sunlight. When the air and ground temperature are just right, these shadowed areas experience slippery or icy pavement surfaces, even though the rest of the road that sees sunlight is without ice. Motorists who fail to realize that the shadowed portions are icy tend to crash, especially when curves are present.

A motorist traveling along M-28 is about to encounter an icy curve that is in the shade of a large hill. Fortunately, MDOT installed an RWIS at this particular curve to monitor for pavement condition. The sensors report that the road surface temperature is consistent with icy conditions, so a field processor activates a flashing beacon on an upstream warning sign that reads "Icy Curve Ahead When Flashing." The field processor is configured to continue monitoring the road surface and deactivate the flashing beacon once 30 minutes has passed since the last report of icy conditions. The motorist sees the sign and flashing beacon, recognizes the issue at hand, and slows down to avoid entering the curve at too high of a speed.

MDOT employs many RWIS around the state. Some are designed to be field-managed without network communication links, meaning they activate and deactivate in accordance with preset parameters in their field processors without informing MDOT. Others are designed to have network communication links, operating nearly the same way, but providing performance reporting and real-time activation status back to MDOT. MDOT is able to utilize these real-time links to verify the device is operating and, when an issue is reported by the device, dispatch maintenance to make the necessary repairs.

Recognizing that slippery or icy patches can be anywhere along M-28, MDOT subscribes to a third-party data service provider that is able to monitor and report hard braking events in real time. Vehicles with onboard navigation and infotainment systems actively capture driving behavior and report it back to the OEMs and third-party data service provider via the vehicle's cellular connection. The third-party data service provider provides MDOT with map-based locations of where hard-braking events have been recently reported along M-28 and other highways. Depending on the frequency of occurrence, MDOT TOC operators may make a judgment call to post an advisory message of ice if weather conditions—along with the hard braking events—suggest that ice may be an issue.

5.3 Inclement Meteorological Conditions

While the Mackinac bridge often comes to mind as an area that experiences high winds, many other interstate highways throughout Michigan can experience high winds at certain times of the year. These events can be particularly risky for high-profile vehicles, such as semi-trucks, that lose control when hit by a gust of strong winds.

On a particular day, a high-altitude frontal system is passing over Michigan and causing heavy winds along the surface. The National Weather Service reports this to MDOT, whose operators promptly publish a wind warning on DMS across the state. Roadside RWIS stations around the state reinforce reports given by the National Weather Service, indicating heavy directional winds with significant gusts. MDOT is also piloting mobile RWIS on several fleet maintenance vehicles—when the vehicles are parked, the mobile RWIS is able to collect additional wind readings at spot locations around the state, helping further inform of the windstorm's extent.

While the DMS—located along major travel corridors—help motorists make informed decisions, several sections of I-75 lack DMS coverage. As part of an innovative safety corridor initiative, MDOT has deployed connected vehicle roadside devices that can communicate safety warnings via Connected Vehicle communication protocols along I-75. Vehicles that are participating in this pilot project—which includes several automotive OEMs and trucking companies that travel frequently to northern Michigan—are able to receive in-vehicle alerts of heavy winds from these connected vehicle roadside devices.

Additionally, MDOT has elected to publish weather alert data as part of a data feed that is available to public as an information resource. Several automotive OEMs have received this data as part of their navigation services, and provide this alert on dashboards of vehicles that have in-vehicle navigation sources.

5.4 High-Risk Meteorological Events

Michigan often experiences large winter storms that create several inclement conditions, where drivers would be safest if postponing their trip. For drivers that have already departed on their trip or must make the trip, additional reminders of the severity of the weather can help encourage safe behavior.

In this particular situation, a large winter storm is striking southern Michigan, impacting Ann Arbor and Detroit with heavy snowfall and gusty winds. MDOT has been monitoring this storm through meteorological data feeds provided by the National Weather Service and other third-party weather forecasting groups to which MDOT subscribes. Upon issuance of a Winter Storm Warning, immediately post notifications of the warning on DMS in the affected area.

The snow begins to fall and travelers along the U.S.-23 FlexRoute reduce speed. MDOT monitors the speed reduction through traffic monitoring equipment and, recognizing that the average travel speed is now 35 mph, elects to publish a 35-mph advisory speed limit on the VSLs along that corridor. Depending on the configuration of the FlexRoute system, some of these proposed advisory speeds may be generated by the system or automatically deployed. Where DMS are available, the Winter Storm Warning message is posted to help reinforce the reduced speed limits. To the west, the I-94 weather-responsive advisory system observes speed reductions and reports of blowing snow, which automatically activates a similar message on the DMS along with a reduced advisory speed. MDOT publishes the advisories on Mi Drive to help inform other motorists who may be embarking on a trip.

Additionally, MDOT has elected to publish weather alert data as part of a data feed that is available to public as an information resource. Several automotive OEMs have received this data as part of their navigation services, and provide this alert on dashboards of vehicles that have in-vehicle navigation sources. Those motorists are aware of the high-risk meteorological event and, even if already witnessing it, are further reinforced to drive cautiously.

5.5 Motorist Trip Planning

While most envision snow as being a widespread event, lake-effect snow often can create treacherous travel conditions at specific segments along certain highways, but leave other nearby routes untouched. Along the eastern shores of Lake Michigan, one such storm is dropping heavy snowfall on some key north-south routes, but leaving other routes with only a minor dusting.

For this particular storm, many motorists realize before they commence on a trip that some roads may be treacherous, even with MDOT conducting ongoing plow operations. They consult the Mi Drive website to gain insights on road conditions. In addition to road conditions reported on the website, which are informed by the various weather stations and services used in that region, the website informs them of current snowplow locations and provides a near real-time camera image of road conditions where the snowplows are operating. This visual coverage provides additional insight into real-world conditions to help the motorists make informed decisions about their trips.

With this information in hand prior to even starting their trips, motorists can review their available options for their trip. Depending on their preferences, they may elect to 1.) postpone the trip altogether, 2.) delay the start of the trip until conditions have improved, 3.) use an alternative route where conditions are more favorable, or 4.) commence on the original trip with additional insights. Regardless of the decision, the supporting system allows them to be informed of conditions before they are encountered, helping encourage safe travel behavior.

6.0 Summary of Impacts

Expanding the RTW/VSL program will provide impacts among primarily the traveling public, the agency, and operations staff, but will provide extended impacts to other Government agencies and communities through which state-owned routes pass. Many of these impacts stem from the outcomes that are expected from a real-time warning system, including safer roads and informed decision-making by drivers. Agencies and operations staff responsible for the system will see an increased workload that likely is augmented to their existing traffic operations and ITS programs.

Figure 3. Example Project Purpose for the I-94 Weather-Responsive Advisory System

6.1 Traveling Public

Expanding the coverage of RTW and VSL solutions, where appropriate, will increase awareness of hazardous conditions that may go undetected by a driver. For local applications that notify of a particular issue, real-time alerts will allow drivers to make informed decisions and take the necessary action to respond to the hazardous condition before encountering a risky situation. For regional applications, providing advanced information on hazardous conditions, as well as reinforcing the need to take corrective action in the midst of the hazard, will encourage drivers to take the necessary steps to drive cognizant of the weather.

6.2 Agency

Expanding the coverage of RTW and VSL solutions, where appropriate, will help improve road safety on the state-owned road network, which has direct impacts on mobility. These improvements will help MDOT better achieve the goals outlined in Michigan Mobility 2045. Increasing coverage will allow MDOT to showcase this safety program to the public and help encourage drivers to drive carefully during inclement weather. These systems will also allow agencies to provide more outreach and awareness, so that the public better understands why they are there and the benefit they provide. Public education will engage them to take action when advisories are posted, helping to improve safety and reduce potential incidents.

Increasing the coverage will require operational/capital funding to support deployment, as well as expand the maintenance requirement across the state. MDOT will need to work across regions to expand this program, ensuring that sufficient support is offered to maximize the uptime and usefulness of new devices.

6.3 Operations Staff

MDOT operations staff may see increased responsibilities, depending on the system deployed. Larger RTW and VSL applications, primarily those that utilize gantries or large DMS, may require operator review prior to message initiation, as well as ongoing verification that the correct message is being presented. Operations staff may need to monitor the ongoing weather event and update the message as conditions change, based on weather reports, observations, or data feeds. This will be in addition to their current traffic management responsibilities. Location-specific data from sensors will aid in reducing the effort for operators to discern which sign locations should receive a weather alert, but increased responsibilities should still be anticipated and planned when deploying or expanding a system.

7.0 Analysis of the Proposed System

7.1 Benefits, Disadvantages, and Limitations

7.1.1 Benefits

- **Improved road safety—**Traveler information has been demonstrated to improve safety, particularly in areas with high crash rates due to poor driver judgment. Motorists that are informed of a hazard will drive more safely, reducing the number of crashes and fatalities, insurance costs, and societal impacts that come with crashes.
- **Better travel time reliability—**Drivers who are informed of inclement conditions can redefine expectations for arrival time, potentially even adding extra travel time by leaving earlier or postponing the trip entirely. Establishing travel expectations due to inclement conditions can help discourage bad driving behavior that occurs when motorists perceive that they are running late.
- **Environmental Sustainability—**RTW/VSL systems can inform of inclement weather areas, allowing transportation managers to strategize their chemical applications where the system reports issues in lieu of unnecessary widespread coverage.
- **Supportive of Other Applications—**RTW/VSL systems are ITS applications that can be utilized for other non-RWM needs.
  - » DMS can be utilized to advise of other traffic issues, such as an incident.
  - » VSL can be utilized to advise of other non-weather motivations to slow traffic, such as for short-term roadside maintenance activities.
  - » Roadside RWIS can be utilized to inform weather models for non-transportation applications.
- **Scaled Investments—**RTW/VSL systems can be standalone or corridor-wide applications, depending on the need. When funding is limited, options remain available.

7.1.2 Disadvantages and Limitations

- **Reliance on driver compliance—**Traveler information is only useful if drivers are receptive to messaging. If RTW/VSL messages are ignored, some benefits may not be realized.
- **Equipment accuracy—**Weather is difficult to predict, especially when meteorological equipment is not accurate. Procuring reliable meteorological equipment with the appropriate accuracy levels is important to reduce false positives or false negatives. Properly maintaining this equipment is also necessary to ensure it remains calibrated and operational. Frequent testing may be necessary to confirm that field-managed systems (e.g., closed-loop flashing beacon systems) that cannot report device failures are continuing to activate and operate properly.
- **Geographic Coverage Challenges of Spot-Specific Applications—**Spot-specific monitoring sites (e.g., RWIS near bridge to monitor for ice and activate warning beacons) require investment of equipment at each site in order to be effective. Since this is more costly of an investment than systems that monitor over a larger area, deploying them requires more resources.

- **Appropriate Device Placement—**Messaging devices cannot be placed anywhere, as ensuring motorist attention requires strategic placement along the corridors (e.g., messaging devices must be in areas with good sightlines for motorists to read messages, messaging devices should be adequately spaced apart to avoid information "overload" from other signing, etc.). These limitations reduce the number of eligible sites for devices.

7.2 Alternatives and Tradeoffs Considered

- **"Do Nothing" Approach—**This alternative maintains the status quo. MDOT may continue to utilize existing RTW/VSL applications, but elects not to construct any new sites. Drivers in areas without RTW/VSL applications continue to have the same crash rates and mobility challenges during weather events, which incurs economic and societal costs as a result. This alternative is not recommended because it passes on an opportunity to help meet the goals and objectives defined in Michigan Mobility 2045 of enhancing safety, utilizing a solution that has demonstrated benefits that outweigh its costs.
- **Utilize crowdsourced data instead of purchasing meteorological detectors—**This alternative considers use of crowdsourced weather data in lieu of MDOT investing in RWIS. Crowdsourced data has been a prevalent topic in the transportation industry, where travelers report their observations on a platform that is visible to transportation managers. Waze is cited as the most common example, where users can report traffic, law enforcement activity, and other events, but city services like 311 are also crowdsourced data services. While crowdsourced data offers promise of low-cost methods for identifying transportation issues, this alternative is not recommended as a primary form of data collection because crowdsourced reporting—especially in real-time warning applications—is not properly vetted. While a user may perceive and report an icy road, no guarantees exist that an untrained crowdsourced reporter can properly assess that a hazard is present, which can strain system credibility if an alert of an icy road is then reported to the public when none exists. Instead, transportation agencies have used crowdsourced data as a secondary data source to aid in operations—for example, some TOCs utilize Waze to find out where traffic incidents are reported, but then utilize their CCTV cameras and emergency traffic patrols to confirm sighting of an incident prior to reporting it on their DMS.
- **Utilize in-vehicle systems to issue alerts rather than invest in roadside signing—**This alternative considers use of CV Onboard Units (OBUs) as an information platform in lieu of investing in roadside signing with beacons, DMS, VSL, or other activated signage. Alerts would be activated in-vehicle for the driver's awareness, utilizing geofenced notifications to prevent irrelevant alerts that apply to other areas. While costly investment and maintenance of roadside signing would be reduced, this alternative is not recommended because many drivers do not have these information platforms in their vehicle and continue to rely on roadside signs for information. To date, the National Highway Traffic Safety Administration (NHTSA) has not mandated CV equipment in fleet vehicles, which means that fewer than one (1) percent of vehicles on Michigan roads in 2021 have the necessary vehicle-to-infrastructure communications systems. Many newer vehicles have in-vehicle navigation and infotainment systems that receive traffic and incident data, which could receive a geofenced alert on road conditions, but not all Michigan drivers can afford to have this feature in their vehicle. These options may bode well as secondary information distribution services, but ultimately roadside signing remains as a strong primary resource that is equitable among all eligible drivers.

8.0 System Requirements

System requirements are specifications that a proposed system must meet in order to address user needs. In the context of the systems engineering V-diagram, system requirements are utilized to later verify that the proposed system has been built as intended, often demonstrating through system acceptance testing. They are an important step for demonstrating that all requirements have been met (or otherwise documented and agreed-to where not met) prior to advancing to full system validation.

At a high level, system requirements define:

- What the system is to accomplish (functional requirements);
- How well the system is expected to perform its functions (performance requirements);
- Which external systems the system is expected to interface with (interface requirements);
- What are the necessary data elements of the system (data requirements);
- Under what conditions will the system have to work to meet its performance goals (non-functional requirements); and
- What is needed to sustain the operation of the system (enabling requirements).

System requirements, which are presented in Table 7 through Table 10, are subdivided among the information collection, information processing, and information distribution actions that occur for the proposed system, as well as inclusion of requirements essential for infrastructure that supports the RTW/VSL system. Each requirement specifies the type and identifies which user needs are met by establishing the requirement.

Table 7. Information Collection System Requirements

Req ID	Requirement	Type	User Need Traceability
C-1	The RTW/VSL system shall be informed by local weather, regional weather, traffic speeds, or other situational information as relevant to the application.	Data	UN-1, UN-2, UN-3, UN-4
C-2	Roadside equipment that monitors road surface conditions shall be capable of measuring relevant and accurate meteorological data, such as surface temperature, moisture, icing, salinity, or other measures, as dictated by the application.	Functional	UN-1, UN-2
C-3	Roadside equipment that monitors local weather conditions shall be capable of measuring relevant and accurate meteorological data, such as temperature, wind, humidity, precipitation, or visibility, as dictated by the application.	Functional	UN-1, UN-2, UN-3
C-4	Mobile equipment that monitors road surface conditions shall be capable of measuring relevant and accurate meteorological data, such as surface temperature, moisture, icing, salinity, or other measures, as dictated by the application.	Functional	UN-1, UN-2
C-5	Mobile equipment that monitors local weather conditions shall be capable of measuring relevant and accurate meteorological data, such as temperature, wind, humidity, precipitation, or visibility, as dictated by the application.	Functional	UN-1, UN-2, UN-3
C-6	Traffic sensors shall be capable of providing accurate traffic speeds, volumes, and occupancies.	Performance	UN-5
C-7	CCTV cameras shall be deployed at strategic locations along a corridor with an RTW/VSL application to provide remote visual monitoring of traffic and roadway conditions, as well as verification of message activation.	Functional	UN-5, UN-11
C-8	Third-party meteorological data shall meet or exceed a reasonable accuracy level.	Performance	UN-1, UN-2, UN-3, UN-4
C-9	Third-party traffic data that monitors corridor vehicle speed shall meet or exceed a reasonable accuracy level.	Performance	UN-1, UN-2, UN-3, UN-4, UN-5, UN-8, UN-13

Table 8. Information Processing System Requirements

Req ID	Requirement	Type	User Need Traceability
P-1	The RTW/VSL system shall be able to receive a variety of relevant data input types, including traffic data, weather data, and other road data for public and/or private data sources.	Data	UN-6
P-2	The RTW/VSL system shall be able to receive data from MDOT and external third-party data service providers.	Interface	UN-10, UN-11
P-3	The RTW/VSL system shall be capable of processing one or more data input or input type.	Interface	UN-6
P-4	The RTW/VSL system shall be capable of setting custom thresholds for each unique data input.	Functional	UN-6
P-5	The RTW/VSL system shall be capable of using a decision tree service that can receive multiple inputs.	Functional	UN-6
P-6	The RTW/VSL system shall activate a notification when one or more data inputs cross their thresholds, or a decision tree series of actions results in a notification.	Functional	UN-6
P-7	The RTW/VSL system shall allow either automated activation or manual activation of a notification as part of its design.	Functional	UN-6
P-8	The RTW/VSL system shall have configurable timing elements that establish a minimum activation time, based on the last triggered event when a threshold is met or exceeded.	Functional	UN-1, UN-2, UN-3, UN-4, UN-6
P-9	The RTW/VSL system shall activate one or more applications to distribute information (e.g., DMS, VSL, etc.), based on what is programmed into the response action.	Functional	UN-1, UN-2, UN-3, UN-4
P-10	The RTW/VSL system should allow notifications to be sent to MDOT data portals for use, either by public-facing MDOT resources or third-party data service providers.	Interface	UN-9, UN-10
P-11	The RTW/VSL system shall have an architecture that allows for standalone closed-loop operation or integration into a larger central system.	Functional	UN-13
P-12	The RTW/VSL system should allow an operator to override an automated message.	Functional	UN-1, UN-2, UN-3, UN-4, UN-6
P-13	The RTW/VSL system shall be able to adjust and operate as intended if a device and/or sensor/input is unavailable	Enabling	UN-6, UN-13
P-14	The RTW/VSL system shall be able to store and export historical records of input and outputs generated in order to support post-deployment benefit-cost assessments, system calibration, and other evaluations.	Data	UN-11, UN-13, UN-14

Table 9. Information Distribution System Requirements

Req ID	Requirement	Type	User Need Traceability
D-1	The RTW/VSL system should be capable of activating a flashing beacon on a roadside sign.	Functional	UN-1, UN-2, UN-3, UN-4
D-2	The RTW/VSL system should be capable of activating a DMS with a pre-selected message.	Functional	UN-1, UN-2, UN-3, UN-4
D-3	DMS messages shall convey a reason for the real-time warning and an action message for drivers to take.	Functional	UN-5
D-4	VSL messages posted on DMS shall be accompanied by a message that explains the reason for the reduced speed.	Functional	UN-8
D-5	The RTW/VSL system should be capable of activating a standalone VSL with a pre-selected posted speed limit.	Functional	UN-8
D-6	The RTW/VSL system should be capable of publishing notifications on MDOT's Mi Drive traveler information website.	Functional	UN-10
D-7	The RTW/VSL system should have the capability to communicate messages and/or data to third-party systems.	Functional	UN-10
D-8	The RTW/VSL system shall provide messaging that is easily understood by and familiar to the traveling public.	Non-Functional	UN-5
D-9	The RTW/VSL system shall provide messaging that is capable of following existing MDOT messaging guidelines.	Non-Functional	UN-1, UN-2, UN-3, UN-4
D-10	The RTW/VSL system shall provide signing that complies with the Michigan Manual on Uniform Traffic Control Devices (MMUTCD).	Non-Functional	UN-1, UN-2, UN-3, UN-4
D-11	The RTW/VSL system shall provide signing infrastructure that complies with relevant Michigan DOT standards and special details.	Non-Functional	UN-1, UN-2, UN-3, UN-4
D-12	The RTW/VSL system should help inform of alternate routes that may avoid the advisory event, where relevant and useful to motorists.	Functional	UN-12
D-13	The RTW/VSL system should allow message distribution assets to be utilized for other non-related traffic management applications.	Functional	UN-7, UN-11
D-14	The system should have appropriate spacing and frequency of signing/messaging to support the intended application.	Performance	UN-5, UN-11, UN-13

Table 10. Supporting Infrastructure System Requirements

Req ID	Requirement	Type	User Need Traceability
I-1	The RTW/VSL system shall comprehensively have good uptime reliability that meets or exceeds requirements established for other comparable ITS programs.	Performance	UN-13
I-2	The RTW/VSL system shall have individual components that have good uptime reliability that meets or exceeds requirements established for other comparable ITS programs.	Performance	UN-13
I-3	The RTW/VSL system shall utilize reliable network communications that allows data to be collected, processed, and distributed in a timely manner.	Enabling	UN-13
I-4	All components that make up the RTW/VSL system shall be equipped with reliable power service.	Enabling	UN-13
I-5	The RTW/VSL system shall be designed in a manner that allows for routine maintenance and upkeep to preserve operational performance.	Enabling	UN-13
I-6	The RTW/VSL system shall operate without degradation with all devices reporting data and all distribution methods being utilized at the same time.	Non-functional	UN-13
I-7	The RTW/VSL system shall allow calibration (at an equipment or system level) to help refine system operational performance and reliability.	Non-functional	UN-6
I-8	The RTW/VSL system shall have a definable maintenance plan for undertaking routine maintenance activities.	Non-functional	UN-13
I-9	The RTW/VSL system shall be of a design that can be supported by an operations and maintenance funding program.	Non-functional	UN-13

Appendix A. Acronyms List

AASHTO	American Association of State Highway and Transportation Officials
ABS	Anti-Lock Brake System
ASOS	Automated Surface Observing System
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System
AVL	Automatic Vehicle Location
AWOS	Automated Weather Observation System
CAD	Computer-Aided Dispatch
ConOps	Concept of Operations
CoP	Community of Practice
CV	Connected Vehicle
DMS	Dynamic Message Sign
ESS	Environmental Sensor Station
FAA	Federal Aviation Administration
HAR	Highway Advisory Radio
ITS	Intelligent Transportation System
ITS-JPO	Intelligent Transportation Systems Joint Program Office
MAW	Motorist Advisories and Warnings
MDSS	Maintenance Decision Support Service
MDOT	Michigan Department of Transportation
MMUTCD	Michigan Manual on Uniform Traffic Control Devices
NHTSA	National Highway Traffic Safety Administration
NOAA	National Oceanic and Atmospheric Administration
OBU	Onboard Units
QPL	Qualified Products List
RTW	Real-Time Warning
RWIS	Road Weather Information System
RWM	Road Weather Management
TOC	Traffic Operations Center
U.S. DOT	United States Department of Transportation
VDT	Vehicle Data Translator
VSL	Variable Speed Limit
Wx-TINFO	Weather Responsive Traveler Information

TSMO

TRANSPORTATION SYSTEMS MANAGEMENT & OPERATIONS

CAMBRIDGE
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