Road Weather Information System

Strategic Plan

FINAL

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Prepared with support from

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1 OVERVIEW

1.1 Purpose of the Document

In 2007, Michigan Department of Transportation (MDOT) began a widespread deployment of a Road Weather Information System (RWIS), beginning in the Upper Peninsula. Through a series of strategically placed Environmental Sensor Stations (ESS) in remote rural areas, the RWIS was intended to help better identify inclement weather and adverse road conditions at critical locations that do not often receive monitoring in order to more efficiently deploy and prioritize maintenance needs and provide improved traveler information to motorists. MDOT has continued the deployment of fixed ESS assets throughout the state to meet local stakeholder needs and challenges. Newer trends in the data acquisition of road weather information have allowed MDOT to collect, process, and disseminate in variety of methods. The availability of road weather information on mobile assets such as snow plow vehicles, traditional vehicles with on-board communications, and from service providers that use crowd sourced data or probes, have enhanced road weather information that is available to stakeholders.

As MDOT plans the next 5 years of effective deployment of technologies and services for the RWIS program, an assessment of all existing and available resources is critical to determine the most prudent pathway towards acquiring RWIS data to meet the needs of the stakeholders. This strategic plan discusses how the needs of stakeholders align with the latest available methods for obtaining road weather information using an array of technologies that can satisfy user needs. Subsequently, the report provides MDOT guidance for future deployment phases to support the road weather program and prioritize which investments must occur at the state and regional level. The report is intended to augment the RWIS Strategic Assessment report from July 2014. The intent of the report is not to evaluate proposed ITS projects for RWIS-type projects, but rather to provide guidance in developing the scope of future RWIS projects to support the overall goals and practices of the department.

1.2 Vision & Goals

The vision for the MDOT RWIS program is to have a robust and reliable RWIS that provides users with valuable information about road and weather conditions around the entire state of Michigan using an array of existing and next generation technologies. The RWIS program will centralize all road weather and forecasting data from all available sources and share the data with all internal complementary applications to enhance the use of the information for end-users. The RWIS program will require statewide and regional based initiatives to ensure a robust system is deployed efficiently to maximize the tradeoffs between various technologies and complementary products (fixed, mobile, and crowd sourced assets). Key Goals for the RWIS program are:

- Determination of roadway conditions to support winter maintenance decisions, traffic operations and motorist advisories.
- Provision of enhanced weather forecasts to support efficient decision making.
- Support for reporting roadway performance to meet key Transportation Systems Management and Operations goals.

1.3 Use of the Strategic Plan

This strategic plan is designed to meet the needs of MDOT personnel in charge of road weather maintenance and/or traffic operations. It helps to identify what types of resources should be utilized to address specific needs in the respective areas of the state. It further allows regional users to make specific decisions about future RWIS investments that meet the overall goals of the statewide RWIS program. These decisions may include, but are not limited to:

Maintenance Users

- Which RWIS resources should be considered to enhance maintenance decision support?
- Which RWIS resources should be considered to provide the most optimal forecast based on the time domain (0-5 mins, 5 mins – 1 hr., 1hr – 6hrs, 6hrs – 24hrs)?
- Which RWIS resources should be considered to enhance treatment and monitoring of known trouble areas?
- Which RWIS resource will provide the ability to monitor the roadway?

Traffic Operations

- Which resources should be considered to provide near real-time notification to motorists about imminent weather conditions ahead of them?
- Which resources should be considered to provide near real-time notification to motorists about imminent weather conditions at specific locations?
- Which RWIS resources should be considered to provide the most optimal forecast based on the time domain (0-5 mins, 5 mins – 1 hr., 1hr – 6hrs, 6hrs – 24hrs)?
- Which resources should be considered to enhance traffic management during weather events?

ITS Program Office

- Which resources should be considered to address issues that are regionally significant for the purposes?
- Which resources should be considered to address statewide needs?
- Which system applications will support the future RWIS Data Use and Processing environment in the most cost effective manner?

1.4 EXISTING MDOT PROGRAM DESCRIPTION

MDOT's existing RWIS is comprised of a variety of field resources that acquire near-real time road weather information and systems that collect, store, process and disseminate the information for the end users. A detailed description of MDOT's RWIS system can be found in Appendix A. The appendix provides a brief overview of the resources and systems currently supporting the RWIS program in Michigan.

2 New Trends in RWIS Data Acquisition

This section provides an analysis of mobile data opportunities to support road weather management (RWM) functions in the State of Michigan. The analysis is based on market trends and examines connected vehicle (CV) sourced data and commercial weather services.

2.1 Connected Vehicle Sourced Data

There are emerging acquisition technologies in the CV environment that can provide end users with a denser, hyper-local resource for decision-making. These CV applications continue to emerge and serve as data collectors that anonymously transmit traffic, weather, and road condition information. This data can provide MDOT with the information necessary to assess operational and environmental conditions of roadways. Many new vehicle models are now capable of collecting a range of data elements that can augment data that is already sourced from fixed sensors to identify and implement the most beneficial roadway treatment or TSMO strategy. Data elements sourced from CVs can be categorized as "Observed Data Elements" (direct observations of atmospheric conditions), and "Input Data Elements" (Used in conjunction with observed data to determine roadway conditions).[1]

One telematics service provider that partners with automobile manufacturers began using onboard sensors in CVs to collect data elements to create real-time views of roadway conditions in 2017. Sensor data related to the speed, direction, vehicle location, hard braking, rain, windshield wiper usage, tire traction and fog light usage will be collected, processed, and combined with data from other sources (such as commercial weather service providers, other mobile devices, other equipped vehicles, and infrastructure components). The data will then be distributed to other vehicles subscribed to the same service. As this service evolves initially it will only be available on vehicles manufactured by three companies that are currently in partnership with the telematics service provider. It is important to note that today, 70 percent of global connected service sales come from premium vehicles. It is estimated that by 2022, that number is expected to fall to 50 percent as an increasingly number of lower end vehicles become equipped.[2]

2.2 Weather as a Service

Commercial weather service providers (CWSP) continue to emerge to provide "weather as a service" to government, private industry and consumers for a fee and as in-kind services based on memorandum of understanding between parties. In part these services are provided to users that want reliable, accurate and timely weather data delivered directly into vehicles to ensure the safest and most efficient trip possible. This data can also be used by MDOT to support operational decisions.

Several approaches are commercially available to deliver weather as a service. Some service providers specifically focus on providing detailed transportation specific information. These services ingest data from a range of sources allowing modeling and analysis of traffic data together which allows for "hyper-local forecasting." In turn vehicle operators, can be provided with map-based safety alerts related to a range of environmental factors, including:

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[1] *Vehicles as Mobile Weather Observation Systems.* Mahoney, Bill; Drobot, Sheldon; Pisano, Paul; McKeever, Ben; and O'Sullivan, Jim.

[2] http://www.strategyand.pwc.com/reports/connected-car-2016-study

- Precipitation - Current precipitation levels to help mitigate the risk of hydroplaning.
- Wind Speed – Extreme wind condition warnings to assist operators of high-profile and light vehicles.
- Icing - Current accumulations of freezing precipitation.
- Hail – Real-time view of hail storm threats.
- Lightning - Regional maps of lightning risk locations.
- Low Visibility - Real-time map-based views of locations where fog and other airborne elements such as dust and sand are present.

Commercial weather service providers are also available to provide analytics for hazardous weather detection and prediction, high-resolution point-specific forecasts, and content for mobile applications and interactive mapping services. These services typically ingest information from surface weather observation stations through the Meteorological Assimilation Data Ingest System (MADIS) and rely on a propriety predictive models internal to the organization, and numeric weather prediction models provided by the United States National Centers for Environmental Protection (NCEP).[3] CWSP provide updates of current weather observations and 24-hour forecasts at least hourly and updates to 10-day forecasts every 12 hours. Weather data provided via commercial weather services at a minimum generally includes:

- Time of observations.
- Observed air temperature.
- Apparent air temperature – (approximation of what the air temperature may feel like to an observer).
- Observed relative humidity.
- Derived dew point temperature,
- Observed wind speed and gusts.
- Observed wind direction.
- Observed weather conditions (clear, mostly clear, partly cloudy, mostly cloudy, cloudy, type of precipitation, and obscurations to visibility).
- Route information.

Observed and forecast data are provided to application developers and other consumers via an application program interface (API).

The increased availability of these services can help MDOT address the need to provide a range of weather related information to travelers, and their vehicles and computers.

Also of note is that some of the emerging CV-weather services have emerging capabilities to integrate with advance driver assistance systems (ADAS) and autonomous vehicle platforms to provide real-time and predictive machine-readable road weather conditions. However, the market penetration of these

[3] The United States National Centers for Environmental Prediction (NCEP) delivers national and global weather, water, climate and space weather guidance, forecasts, warnings and analyses to its Partners and External User Communities.

services will lag the in-vehicle provision of information as the autonomous vehicle industry continues to mature.

2.3 RWIS Resource Options

Technology advancements in vehicle-based information have allowed DOT's the ability to acquire information that was not previously available from other resources.[4] The FWHA guidelines for deploying Weather Responsive Traffic Management Strategies identify (3) newer pathways for acquiring road weather data to support the DOT's RWIS program. These include Intelligent Agency Fleets, CVs, and Connected Third-Party Fleet Services and Connected Travelers.

These three key pathways provide different types of data, but allow for the augmentation of traditional information collected from fixed resources along DOT roadway. Intelligent Agency Fleet and CVs are already part of MDOT's current RWIS program and can be leveraged to support RWIS user needs. It is anticipated that going forward these three mobile information resources coupled with the fixed ESS sources will create 4 Pathways for MDOT's RWIS Program.

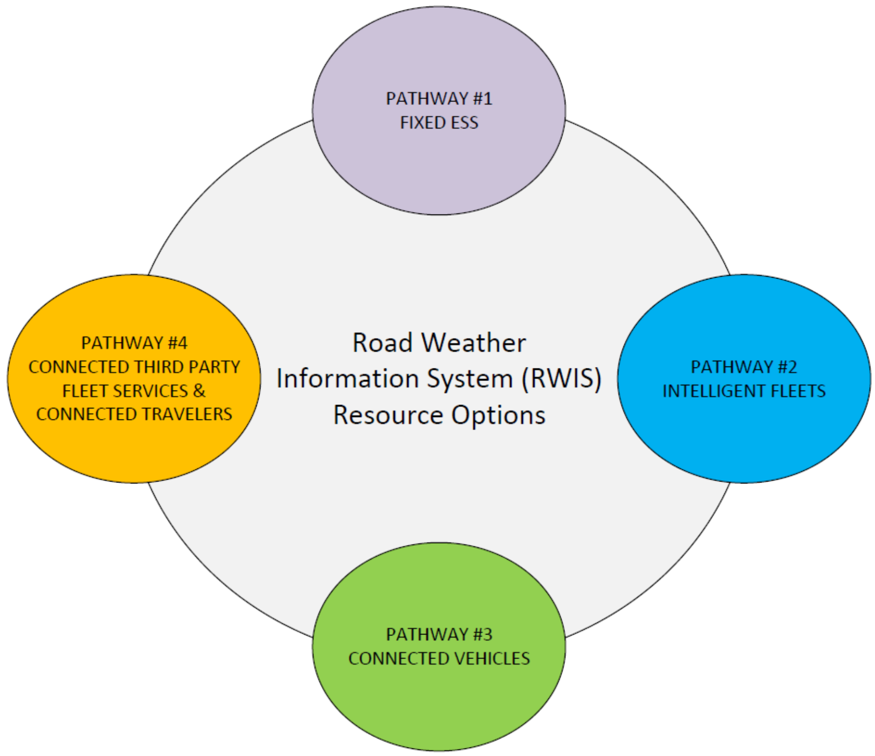

Figure 1: Road Weather Information System (RWIS) Resource Options

[4] United States Department of Transportation – Federal Highway Administration.
Guidelines for Deploying Connected Vehicle-Enabled Weather Responsive Traffic Management Strategies. Publication No: FHWA-JPO-17-478. November 2016.

3 Needs Assessment to Meet MDOT Vision

The end-users of road weather information are the primary drivers for the direction of the RWIS program. Each stakeholder in the MDOT RWIS program has distinct needs. MDOT's assessment of which needs are most critical should guide the decision regarding selection of the recommended pathway(s) that MDOT should support in the future. This section provides an overview of the primary stakeholder needs, resources that are available to support the needs, availability of critical road weather data, and identification of gaps that cannot be satisfied with newer technology resources.

3.1 Stakeholder Needs

3.1.1 Winter Maintenance

Winter maintenance staff is one of the primary RWIS stakeholders whose predominant requirement is accurate forecasts of pavement conditions and pavement temperatures to effectively respond to changing roadway conditions. Key maintenance user needs derived during the development of regional Concept of Operations workshops and statewide needs review:

- Improved visibility on conditions near the edge of their area of responsibility to help in allocating resources efficiently.
- Real-time RWIS reporting from the hosted web application.
- Clear camera images to support decision-making; Images must include clear night images.
- Forecasts to determine when and where a storm will take place.
- Information to determine if maintenance should treat the roadway, how they should treat, and whether the treatment was accurate.
- Better forecast and/or detection of lake effect snow bands, and snow squalls.
- Access to RWIS data on a smart phone or mobile application for in-field reporting to maintenance crews.
- Specialized road weather information at locations that may not require a full ESS site.
- Site-specific data such as surface conditions (or "grip" values) on bridges that tend to ice up and create problems for motorists or flood gauges in areas prone to flooding.

3.1.2 Traffic Management & Operational Needs

Traffic operations stakeholders in Michigan play an important role in the data acquisition and dissemination of road weather information. Road closures due to weather rarely occur in the State. Traffic operation requirements for road weather data acquisition and distribution include:

- Traveler information to be disseminated to motorists regarding recommendations about safe travel during inclement conditions. (e.g. don't use cruise control).
- Ability to collect road weather forecasts to be used by traffic operations to align with weather responsive management strategies.
- Frost depth data for non-freeway corridors to better manage road restrictions at the end of the winter season.
- Level of service on the roadway for meeting performance metrics.
- Traffic and Safety staff can utilize the technology to actively warn motorists of adverse road conditions at their immediate location to improve driver behavior.
- Pavement Management staff can utilize historical data to enhance pavement designs.

- Construction staff can utilize site specific forecasting for scheduling/planning road work (i.e. paving, striping).

3.2 Forecasting Needs

RWIS equipment and the associated support services form the basis of the MDOT road weather program. RWIS is unique in that reporting weather-related road conditions is its primary function. ESS sites for the RWIS program measure and report road temperature, road condition, and several metrics associated with the amount of deicing chemical in the snow, ice, and water on the road. In the assessment of road conditions, the original ESS configurations also incorporated sensors that measure atmospheric conditions. These atmospheric parameters also aid maintenance personnel in their understanding of weather conditions at the ESS site. The meteorological community found the measured weather conditions at RWIS sites helped fill voids in the meteorological network of observation sites that the weather community used to create forecasts and thereby helped improve the performance of local forecasts.

Another facet of the RWIS program was the development of pavement-specific forecasts that projected future road conditions, as well as future weather conditions. These pavement-specific forecasts of road conditions are derived directly from standard weather forecasts, whose performance level depends on the forecaster's abilities. The accuracy and reliability of the forecast can be drastically improved by requiring contracted entities to meet minimum performance requirements. Since most snow and ice control maintenance decisions deal with probable road conditions in the next three hours, these pavement-specific road condition forecasts are an essential tool in maintenance decision-making. Any improvement in the local weather forecast results in improvements in the road condition forecast. Thus, the RWIS program creates a synergy between the RWIS output and the information gained by the maintenance forces. Further, other stakeholders have found the availability of observed and forecasted road conditions to be real assets in assisting in their transportation or travel related decisions. The National Weather Service (NWS) has contributed to this advancement by moving towards winter weather advisories and travel condition warnings rather than simply projecting snow or ice totals.

3.2.1 Forecasting Time Requirements

There are several latencies in the generation of road weather forecasts that influence the time it takes to process actual road weather conditions and transform them into usable forecasts. The CV program was designed to transfer data almost instantaneously without incorporating the influence of projected changes in weather conditions or treatment activities. It assumes that the existing conditions will persist for the next five minutes or so. Road weather forecasts beyond one hour (tactical, strategic, and planning forecasts) depend upon a full forecast procedure. Imminent forecasts represent a bridge between persistence and classic forecasting. The following time line illustrates the time after an observation is made in the field when each step in the forecast process is complete. The times represent average times to completion. The key point of this time line is that the normal forecast process used by meteorologists takes 30 – 35 minutes to generate a weather forecast and 40 – 45 minutes to create a road condition forecast for the first hour. The numerical weather prediction process requires roughly another 60 minutes to generate a gridded forecast out to 24 hours. To circumvent this delay, meteorologists typically use the forecast from the previous hour and adjust the first hours of the new forecast based upon the data analyses 10 – 15 minutes before the current start time. The use of forecast guidance from the previous hour(s) is particularly a factor for imminent forecasts.

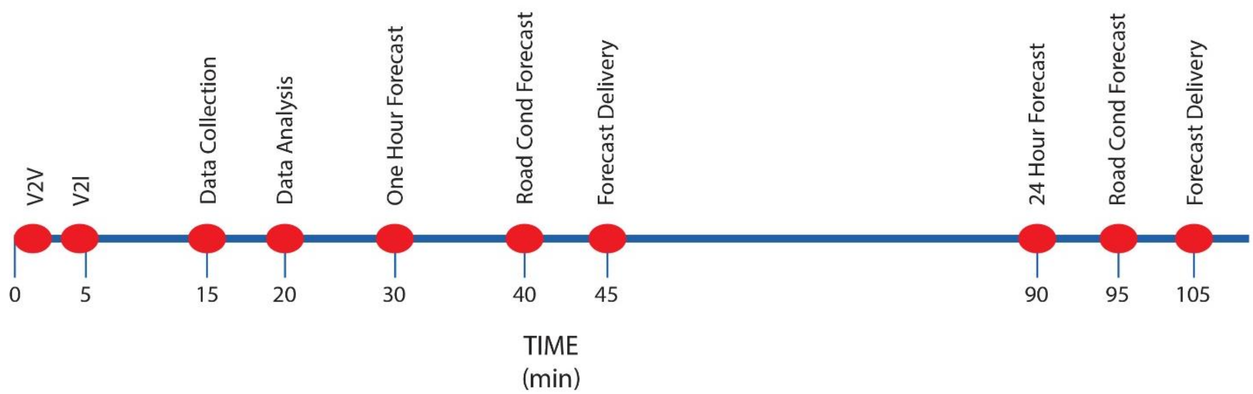

Figure 2: Forecasting

3.3 Forecast Types

Five different types of forecasts are available to provide conditions at differing intervals offering stakeholders information that can be used for a variety of purposes.

3.3.1 Persistence Forecasts

Connected Vehicles (CV)s serve as the sole source of road weather information in the time domain under 5 minutes. The communication and data processing activities for the other three road weather data sources delay the observed road weather information too long to support persistence forecasts. Figure 3 illustrates the vehicle-to-vehicle (V2V) delivery and the vehicle-to-infrastructure (V2I) data exchange service. The V2V exchange is a simple transfer of observed road weather conditions from a single vehicle to one or more vehicles almost instantaneously using wireless communications between the two vehicles.

For V2I exchange dedicated short range communications (DSRC) enabled devices collect transmissions from vehicles along the highway and transfer the data to an infrastructure roadside unit controller. The controller could be used to communicate locally or back to a centralized "head-end" such as a traffic operations center (TOC). The system then stores the observations for each collection point and then aggregates the observations from individual reports into a spatial representation of the CV data by parameter. A navigation interface on a user's vehicle will interact with the infrastructure controller to acquire guidance on road and weather conditions immediately ahead from the current GPS location. Alternatively, users may interact with the infrastructure controller to view conditions on any desired route or route segment.

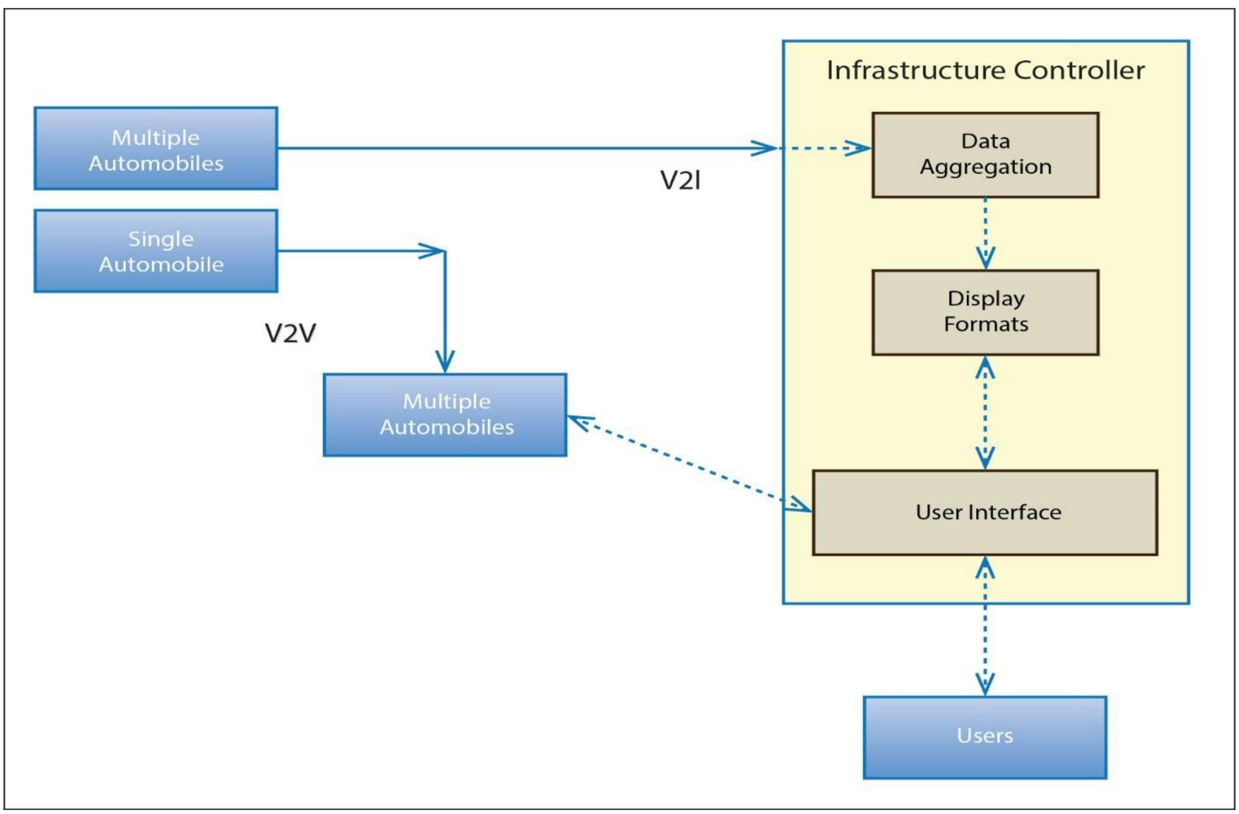

Figure 3: Persistence Time Domain

3.3.2 Imminent Forecasts

As illustrated in Figure 4 imminent forecasts are in large part an extension of the persistence forecasts. The construct is to modify the most current road weather observations based upon forecasted changes in the weather conditions influencing road conditions. Thus, the primary road weather resource remains the CV data, but observed road weather conditions are modified based upon transitions in both observed and forecasted weather conditions. The forecast steps include data aggregation of road weather conditions from CV sources supplemented by data from the other three road weather sources, generation of an initial analysis of the road conditions within the highway infrastructure, and modification of this initial state based upon the weather forecast. Since it is impossible to generate a weather forecast quickly enough from the initial set of observations, forecast data from the previous hour is used to create a projection of road conditions within the next hour. These modified road conditions are then formatted to meet end user requirements.

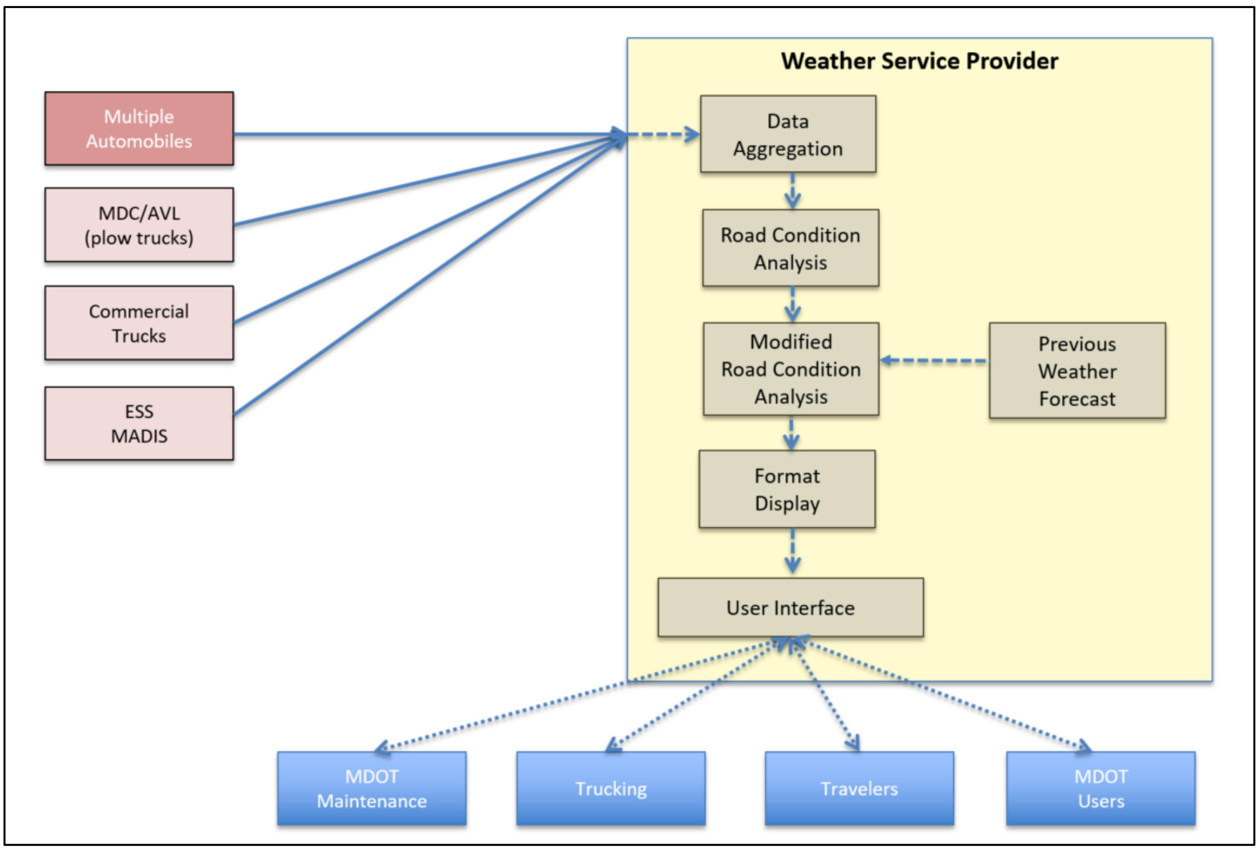

Figure 4: Imminent Time Domain

3.3.3 Tactical Forecasts

Tactical forecasts are one of the three remaining forecasts that use the classic weather forecasting technique to generate a base for a subsequent road condition forecast. In this forecasting scenario, all four road weather sources are used equally as input to the field analyses (digital representations of the interpolated data for the current state of each weather parameter) as illustrated in Figure 5. The field analyses become the initialization set for the generation of forecast values out to 6 or more hours.

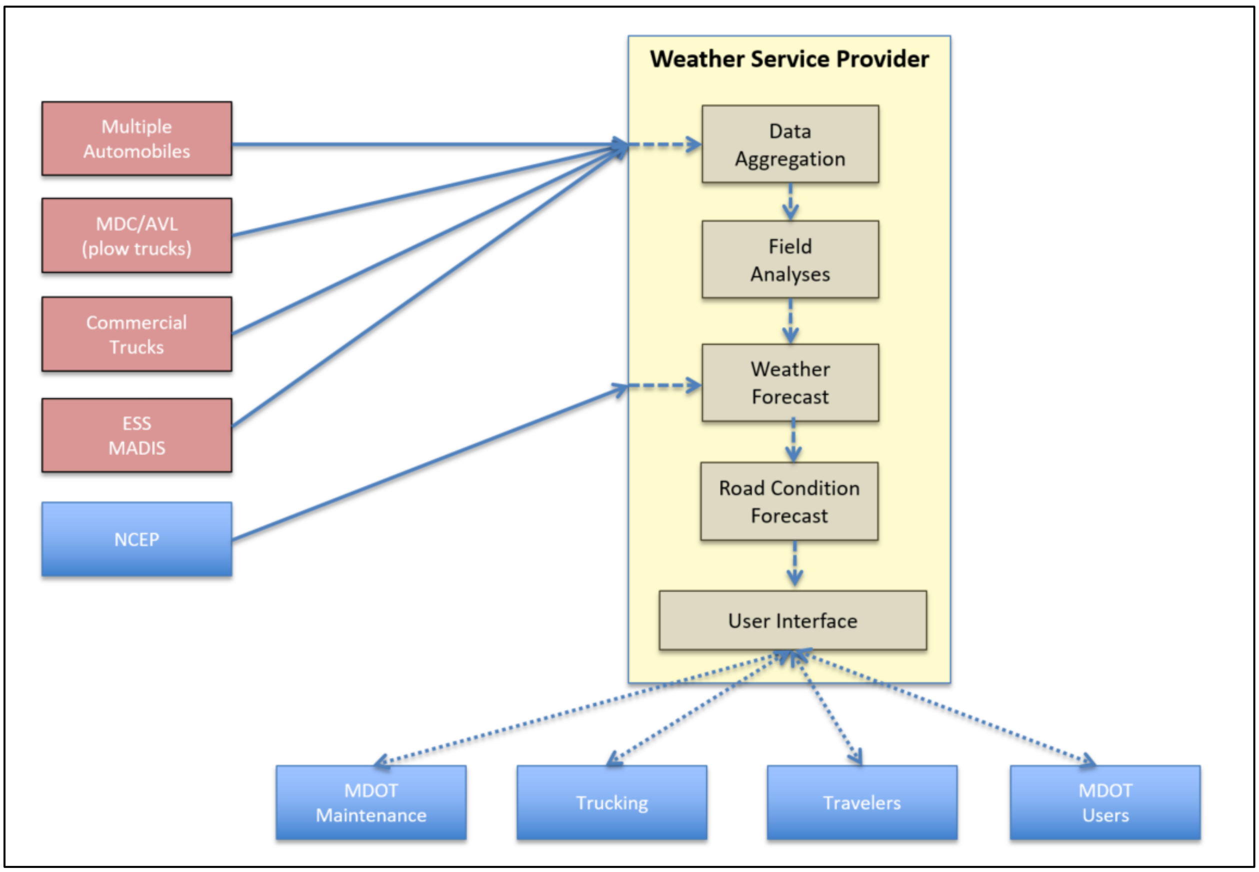

Figure 5: Tactical Time Domain

3.3.4 Strategic Forecasts

AS illustrated in Figure 6 strategic forecasts put their primary emphasis on MADIS and ESS data since this data is usually available more consistently and generally has a higher level of accuracy than the mobile data sources. Further, the accuracy of weather forecasts beyond about 12 hours is more influenced by the upper atmospheric data used as input than on the surface observations.

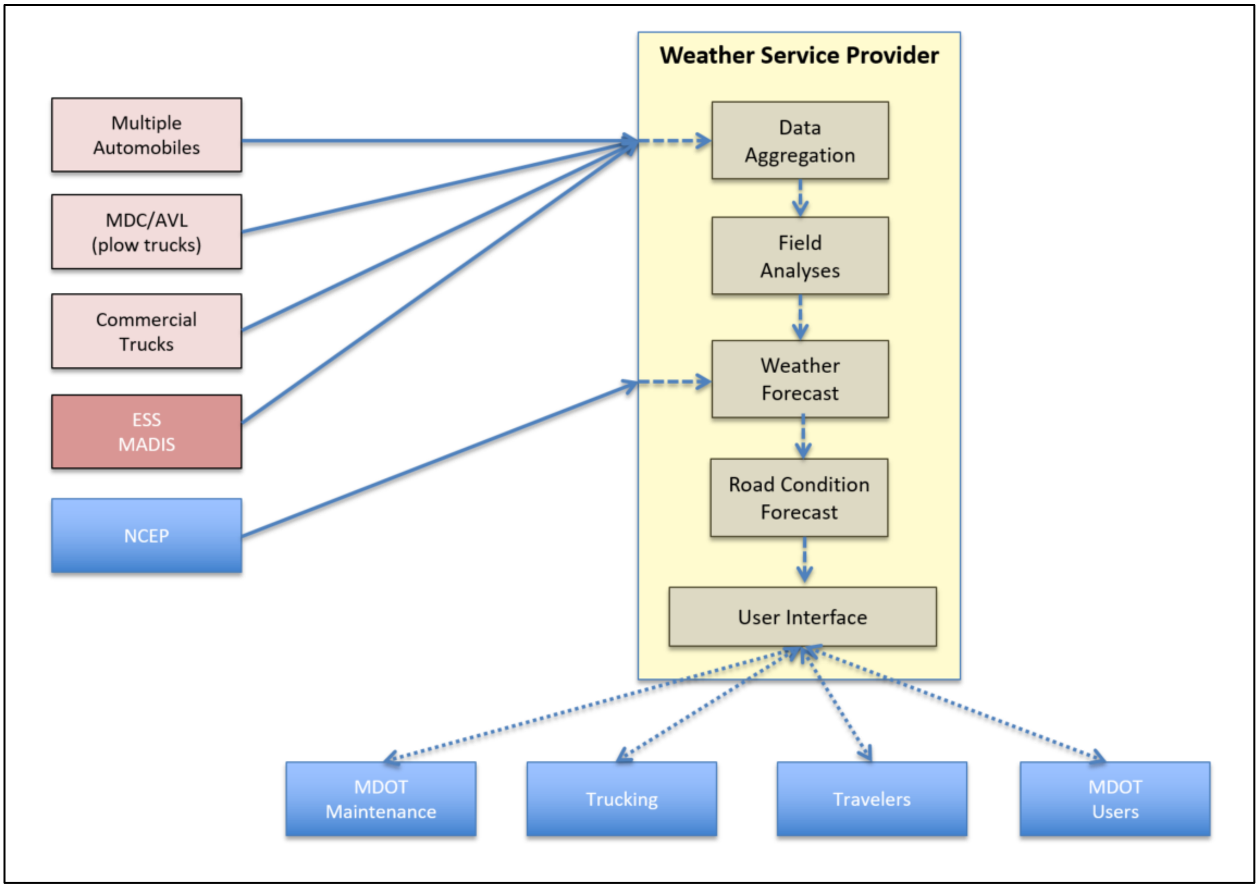

Figure 6: Strategic time Domain

3.3.5 Planning Forecasts

Planning forecasts can go out to 16 days. NCEP models require approximately 3 hours to generate forecasts out to 16 days. Since the interest in planning forecasts is typically 3 to 5 days or more, the initial road weather conditions do not need to be highly detailed since more degradation in the accuracy of the model is due to inaccuracies in the initial upper atmospheric measurements. Therefore, the processing flow is essentially the same as for strategic forecasts.

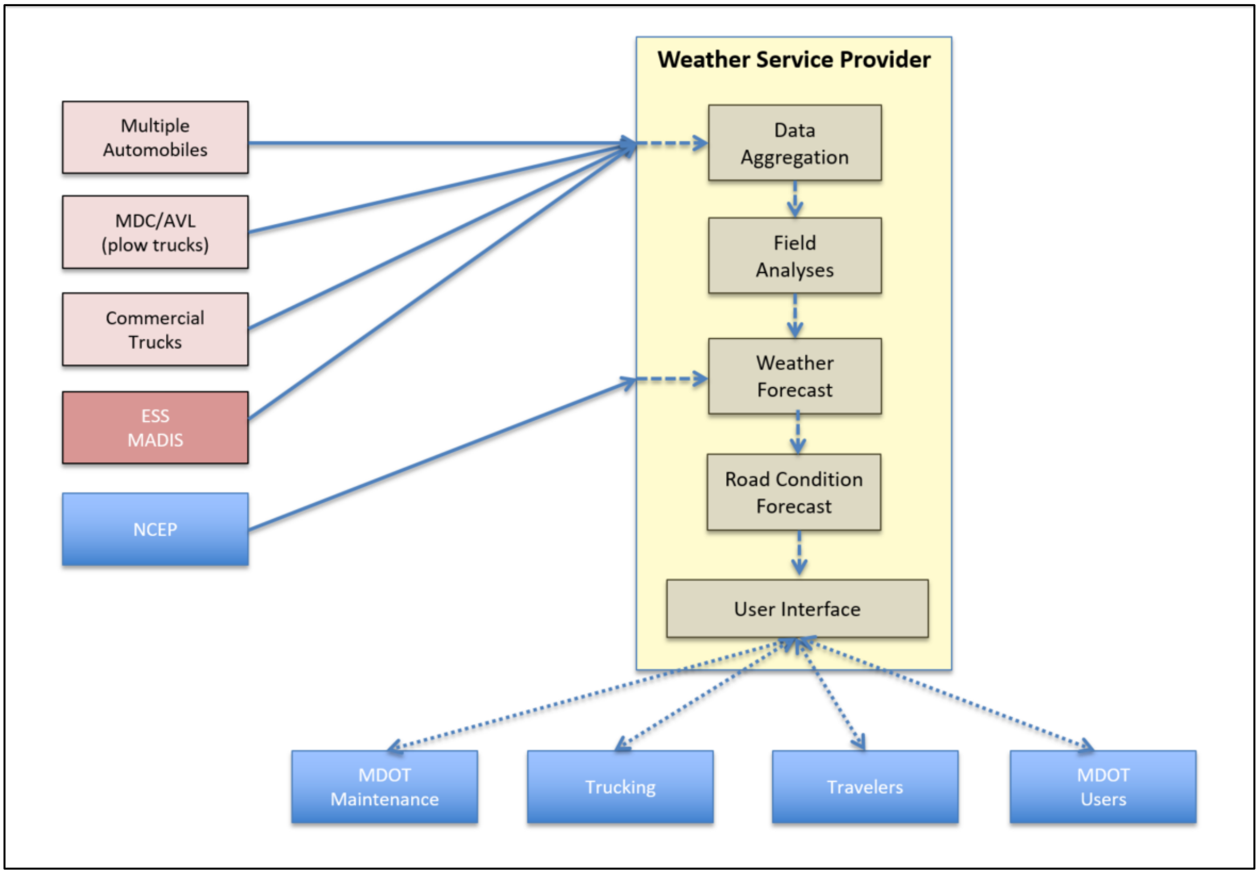

Figure 7: Planning Time Domain

Each of the five forecast types satisfies the unique needs of different road weather stakeholders. Table 1a and 1b presents the benefits and limitations of each type of forecast by DOT stakeholder and other stakeholder.

Table 1a: Benefits and Limitations of Forecast Types by DOT Stakeholder

<table>
<tr><th></th><th colspan="2">PERSISTENCE FORECAST
< 5 mins</th><th colspan="2">IMMINENT FORECAST
1 hour</th><th colspan="2">TACTICAL FORECAST
6-24 Hours</th><th colspan="2">STRATEGIC FORECAST
>24 Hours</th><th colspan="2">PLANNING FORECAST
1-16 days</th></tr>
<tr><th>STAKEHOLDER</th><th>MAJOR BENEFITS</th><th>LIMITATION</th><th>MAJOR BENEFITS</th><th>LIMITATION</th><th>MAJOR BENEFITS</th><th>LIMITATION</th><th>MAJOR BENEFITS</th><th>LIMITATION</th><th>MAJOR BENEFITS</th><th>LIMITATION</th></tr>
<tr><td>DOT Maintenance</td><td>Use CV road conditions to indicate an immediate safety or mobility concern</td><td rowspan="3">ESS & MDC data takes too long to be of use</td><td>Road conditions or immediate precipitation events that may require immediate attention</td><td>ESS & MDC data of marginal use due to time constraints in collection and integration</td><td>ESS, MDC/AVL, and CV data along with road weather forecasts derived from these sources provide the necessary guidance for the next 1 or 2 snow & ice control treatments</td><td>N/A</td><td>ESS and MDC/AVL data along with road weather forecasts derived from these sources provide the necessary guidance for scheduling shift changes and determining when to call in drivers</td><td>N/A</td><td>Preparation for anticipated storms and scheduling of staff and equipment to address these potential events</td><td rowspan="3">RWIS data from all sources has less influence than the processing factors of the numerical model that generates the forecast</td></tr>
<tr><td>Traffic Operations</td><td>Use CV road conditions to monitor areas of possible concern and issue traveler advisories</td><td>Use forecasts to assess areas of possible concern and issue traveler advisories</td><td rowspan="2">ESS & MDC data of marginal use due to time constraints in collection and integration</td><td>Use forecasts to assess areas of possible concern and issue or prepare to issue traveler advisories</td><td>N/A</td><td>TOCs and state police use forecasts to staff for winter events.</td><td>N/A</td><td>N/A</td></tr>
<tr><td>DOT Construction</td><td>N/A</td><td>N/A</td><td>Use 6-hour forecasts to make go/no go decisions on weather sensitive construction projects</td><td>N/A</td><td>Use 24-hour forecasts to plan options and staffing of weather sensitive construction projects</td><td>N/A</td><td>Use extended forecasts to structure plan to work around projected weather events</td></tr>
</table>

Table 2b: Benefits and Limitations of Forecast Types by Other Stakeholder

<table>
<tr><th></th><th colspan="2">PERSISTENCE FORECAST
< 5 mins</th><th colspan="2">IMMINENT FORECAST
1 hour</th><th colspan="2">TACTICAL FORECAST
6-24 Hours</th><th colspan="2">STRATEGIC FORECAST
>24 Hours</th><th colspan="2">PLANNING FORECAST
1-16 days</th></tr>
<tr><th>STAKEHOLDER</th><th>MAJOR BENEFITS</th><th>LIMITATION</th><th>MAJOR BENEFITS</th><th>LIMITATION</th><th>MAJOR BENEFITS</th><th>LIMITATION</th><th>MAJOR BENEFITS</th><th>LIMITATION</th><th>MAJOR BENEFITS</th><th>LIMITATION</th></tr>
<tr><td>Weather Service Provider</td><td>NWS will use road weather data parameters to enhance general weather forecast in this time domain, not road weather data.</td><td rowspan="4">ESS & MDC data takes too long to be of use</td><td>NWS will use road weather data parameters to enhance general weather forecast in this time domain, not road weather data.</td><td>NWS will need to modify existing data acquisition procedures to integrate CV data</td><td>NWS will use road weather data parameters to enhance general weather forecast in this time domain, not road weather data.</td><td>NWS and media put primary emphasis on 24-hour forecast and not on 6-hour period and do not integrate MDC/AVL data</td><td>NWS will use road weather data parameters to enhance general weather forecast in this time domain, not road weather data.</td><td>NWS and media do not address road conditions</td><td>NWS will use road weather data parameters to enhance general weather forecast in this time domain, not road weather data.</td><td rowspan="4">RWIS data from all sources has less influence than the processing factors of the numerical model that generates the forecast</td></tr>
<tr><td>Surface Transportation Weather Service Provider (STWSP)</td><td>Use CV road conditions to issue advisory warning message</td><td>Use CV road conditions and forecasts to issue advisory warning message</td><td rowspan="3">ESS & MDC data of marginal use due to time constraints in collection and integration</td><td>Either do use or will use all ESS, MDC/AVL, and CV data to support the road weather data and forecast needs of many of the other stakeholders in this list</td><td>N/A</td><td>Use ESS, MDC/AVL, and CV data to support the needs of many of the other stakeholders in this list</td><td>N/A</td><td>Use forecast output along with recent road weather conditions to project logistics planning to support operations during active storm events</td></tr>
<tr><td>Emergency Services</td><td>Immediate notification of impending slippery spot or zones of heavy precipitation</td><td>Use forecasts to determine any critical pathways that might be impacted by near term conditions</td><td>Use initial hours in 6-hour forecasts to determine any critical pathways that might be impacted by adverse weather-related conditions</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Travelers</td><td>Immediate notification of impending slippery spot or zones of heavy precipitation</td><td>Notification of impending slippery spots or zones of heavy precipitation along current and/or alternative routes</td><td>Use forecasts to update driving conditions and routing options</td><td>N/A</td><td>Use forecasts to determine specific route travel plans and anticipate any potential weather-related impact on these plans</td><td>N/A</td><td>Use forecasts to determine or adjust long distance route plans</td></tr>
</table>

4 Assessing Stakeholder Needs and Resource Availability

An analysis of stakeholder needs in comparison to road weather assets is a critical first step in determining how to best invest in RWIS resources in the future. The four primary resources for obtaining road weather information include fixed ESS sites, intelligent fleet vehicles (MDC/AVL), CV technologies, and connected third party fleet services. Each of these resources have unique sets of data acquisition capabilities that influence their value in satisfying stakeholder needs that typically require:

- Measurement of specific road weather parameters.
- Accurate readings of these parameters.
- Timely display of the currently observed parameters.
- Adequate number of observations to properly define the road weather condition.

Because each resource acquires different types of road weather data, one specific resource likely will not provide the type of information needed by each stakeholder. Therefore, moving forward, the MDOT RWIS program will require multiple data sets or services to satisfy the requirements of the Department and their stakeholders. MDOT's vision for the program will only be fully realized if the system adequately acquires data that satisfies the needs of each stakeholder group.

One way to evaluate the worth of an RWIS resource (pathway) is to first consider which resources serve as sources of specific RWIS data elements, and then look at which RWIS resource provides the necessary information to effectively meet stakeholder decision support requirements. Table 2 delineates the primary sources for each RWIS data parameter. Table 3 summarizes the primary resource that aids stakeholder decision support requirements. The tables indicate that the analyses are complicated by the fact that user needs change depending upon the valid time frame of data usage or stakeholder decision. Therefore, in Tables 2 and 3 the Data Needs and Decision Support Requirements are separated into five time spans. The diamonds in the Time Frame column tie the time span to the data need. As an example, the RWIS resource that provides road condition data that is less than 5 minutes old most effectively is quite different from the RWIS resources that best delivers road condition information that can be 60 minutes of age or more. Both tables contain ✪ icons to indicate that the RWIS resource is a primary source of the data need or decision support requirement for the specified time frame.

Table 3: Ability of RWIS Resources to Satisfy Stakeholder Needs

ABILITY OF RWIS RESOURCES TO SATISFY STAKEHOLDER NEEDS									
Data Needs	**Time Frame**					**Resource Availability**			
	Persistence Forecast 0 - 5 min	**Imminent Forecast 6 - 60 min**	**Tactical Forecast 1 - 6 hrs.**	**Strategic Forecast 6 - 24 hrs.**	**Planning Forecast > 24 hrs.**	**ESS**	**Fleet Vehicles (MDC)**	**Connected Vehicles**	**3rd Party MDC Data**
Forecast	◆							✪	
		◆						✪	
			◆			✪	✪		✪
				◆		✪	✪		✪
					◆	✪	✪		✪
Road Temperature	◆							✪	
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆		✪	✪	✪	✪
					◆	✪	✪	✪	✪
Road Condition	◆							✪	
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆		✪	✪	✪	✪
					◆	✪	✪	✪	✪
Liquid, Snow, Ice, Frost, & Compacted Snow Depths	◆							✪	
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆		✪	✪	✪	✪
					◆	✪	✪	✪	✪
Grip, Grip Loss	◆							✪	
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆		✪	✪	✪	✪
					◆	✪	✪	✪	✪
Subsurface Temperature & Freeze Depth	◆								
		◆				✪			
			◆			✪			
				◆		✪			
					◆	✪			
Air Temperature	◆							✪	
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆		✪	✪	✪	✪
					◆	✪	✪	✪	✪
Relative Humidity	◆							✪	
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆		✪	✪	✪	✪
					◆	✪	✪	✪	✪
Dew Point Temperature	◆							✪	
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆		✪	✪	✪	✪
					◆	✪	✪	✪	✪
Winds: Direction, Speed, & Gust	◆								
		◆				✪			
			◆			✪			
				◆		✪			
					◆	✪			
Precipitation Type	◆								
		◆				✪	✪		✪
			◆			✪	✪		✪
				◆		✪	✪		✪
					◆	✪	✪		✪
Precipitation Presence	◆						✪	✪	✪
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆		✪	✪	✪	✪
					◆	✪	✪	✪	✪
Precipitation Rate/Intensity	◆							✪	
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆		✪	✪	✪	✪
					◆	✪	✪	✪	✪
Barometric Pressure	◆								
		◆				✪			
			◆			✪			
				◆		✪			
					◆	✪			
Visibility	◆								
		◆				✪	✪		✪
			◆			✪	✪		✪
				◆		✪	✪		✪
					◆	✪	✪		✪
Camera Imagery	◆					✪	✪		✪
		◆				✪	✪		✪
			◆						
				◆					
					◆				

Table 4: Ability of RWIS Resources to Satisfy Stakeholder Decision Support Requirements

ABILITY OF RWIS RESOURCES TO MEET STAKEHOLDER DECISION SUPPORT NEEDS									
DECISION SUPPORT NEEDS	**Time Frame**					**Resource Availability**			
	Persistence Forecast 0 - 5 min	**Imminent Forecast 6 - 60 min**	**Tactical Forecast 1 - 6 hrs.**	**Strategic Forecast 6 - 24 hrs.**	**Planning Forecast > 24 hrs.**	**ESS**	**Fleet Vehicles (MDC)**	**Connec ted Vehicle s**	**3rd Party MDC Data**
Support Road Weather Forecast for Maintenance Planning	◆							✪	
		◆						✪	B/S
			◆			✪	✪		✪
				◆		✪	✪		✪
					◆	✪	✪		✪
Provide information to Maintenance about problematic locations	◆							✪	
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆					
					◆				
Provide road condition reports to the public	◆							✪	
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆					
					◆				
Enhance input to the maintenance decision support system (MDSS)	◆							✪	
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆					
					◆				
Provide visual assessment (camera stream or imagery) of road conditions	◆					✪	✪		
		◆				✪	✪		
			◆			✪	✪		
				◆					
					◆				
Enhance MDOT Weather Responsive Traffic Management Strategies; such as, provide information to Motorists/Traffic Operations about problematic locations	◆							✪	S
		◆				✪	✪	✪	✪
			◆			✪	✪	✪	✪
				◆					
					◆				
Provide vehicle locations of fleet and/or RWIS mobile source	◆							✪	
		◆					✪	✪	✪
			◆				✪	✪	✪
				◆					
					◆				
Provide treatment information (materials used for treated routes)	◆								
		◆					✪		
			◆				✪		
				◆			✪		
					◆		✪		

Note: The table includes the following acronyms in the 3rd Party MDC Data column that designate specific road weather parameters.

- B/S Blowing snow – events are entered by driver via an electronic interface
- S Slip

Key Notes

Key notes derived from the data presented in Table 2 and Table 3 are:

- CV and intelligent fleet data are the only resources that will provide data and support decisions in the 0- 5-minute time frame currently.
- CV data that will be as effective as ESS, intelligent fleet data, and 3rd party mobile data once a fully implemented CV program is in place (beyond the limits of this report) includes:
    - Road temperature.
    - Road condition.
    - Material depths.
    - Grip/grip loss.
    - Air temperature.
    - Relative humidity.
    - Precipitation presence.
    - Precipitation rate.
    - Barometric pressure.
- CVs cannot provide wind information, precipitation type, barometric pressure, or visibility or support decisions needing this information.
- ESS, intelligent fleet vehicles, and 3rd party fleet services are the primary resources to provide data and support end user tactical, strategic, and planning decisions.
- The primary resource to provide data and support user decisions begins to transition from CV to ESS and the mobile fleet sources during the 6 to 60-minute time frame. More emphasis on forecasting comes into play during this time-period. The data required for detailed forecasting is not available from connected vehicles, although the timeliness of the CV data still provides important information to the forecasts and decision-making in this time-period.
- The primary function of data acquisition and decision support in the 0 – 5-minute time frame is to support vehicle to vehicle alerts of adverse conditions and early alert of hot spots (e.g. to Transportation Operation Centers (TOC)).
- The primary function in the 6 to 60-minute time frame is to support imminent forecasts of critical road conditions and visibility issues that may impact safety and mobility.
- The primary function beyond 60 minutes is a focus on the tactical, strategic, and planning forecasts that enable current road weather support services.

The assessment detailed in Table 2 and Table 3 included reasons why each RWIS resource was classified as a primary resource or a lesser source of information. Key comments in the justification of primary RWIS resources in Table 2 and Table 3 include:

- Since the intent of the CV program is to transfer advisory messages from vehicle to vehicle almost instantaneously, it provides the only pathway to do this in the under 5-minute time frame.
- CV information becomes a critical unmatched source of traction information and insight into the local variations in precipitation patterns.
- Waiting for or investing in the development of the capabilities of the CV Program seems to be the most viable alternative to support persistence forecast requirements.

- Imminent forecasts (0 to 60 minutes from observation time) will derive most of their benefit from a dense CV observation network over the highway infrastructure. This data set will provide a mechanism to generate short term (< 60 minute) forecasts of rapidly changing precipitation events, the advent/cessation of precipitation, and detailed projections of road conditions highlighting locations where there may be safety concerns.
- The primary benefactors of information and forecasts in the 0 – 60-minute time frame will be travelers, although MDOT maintenance, traffic operations, emergency services, and other agencies supporting immediate travel needs will find value in the use of imminent forecasts.
- ESS and fleet-derived data provide a higher value than does CV data in the support of tactical, strategic, and planning forecasts, primarily because these RWIS resources have more accuracy, a more complete complement of observed parameters, and a regular reporting schedule.
- The suite of weather data from full ESS configurations is helpful in filling voids in the meteorological data set needed to initialize the tactical forecast model runs.
- The integration of mobile data sources offers the potential to greatly increase the observation network. An important consideration in assessing whether to add additional ESS equipment or move to mobile sensors to collect road condition information is that mobile sources can create a denser network of road weather information for a lesser cost. However, the creation of multiple road condition observations in space and time makes it difficult to integrate these observations into the existing analysis and forecasting procedures.
- Since the performance of planning forecasts has greater dependence on the initialization of the upper atmosphere parameters and the functionality of the processing procedures, the type of RWIS data used for input to the forecast has only limited impact on the planning forecast. Therefore, the decision regarding whether to add fixed or mobile data sources will have minor impact on the value of planning forecasts to support stakeholder decisions.

5 Investment Strategies

There are multiple data acquisition strategies to support MDOT's RWIS program. As MDOT considers how to prioritize these strategies, the regional stakeholder needs and use of the weather information will ultimately drive which "mix" of data acquisition will optimally support the stakeholders. Within the state, stakeholders may value information that support maintenance decision making over information to support traffic operations and traveler information. While traveler information appears to be key theme across the state, additional significance may be placed where:

- Traffic flows are higher such as in urban centers of Detroit, Lansing, Grand Rapids, Saginaw, and Flint
- The availability of alternate routes
- The number of weather-related crashes and incidents are more prevalent
- The density of connected vehicles does not provide sufficient data to support weather decisions

To address these varying degrees of conditions, it is likely there will be four key need areas that will drive the future of the RWIS program.

Maintenance Decision Support (Within 1 hour)	**Maintenance Decision Support (<24 Hours) & Limited Traffic Operations**	**Balanced Maintenance Decision Support /Traffic Operations Needs**	**Traffic Safety and Operations**

MDOT Regions should consider revisiting their Concept of Operations to identify with which group their region most adequately aligns. This will help guide which types of RWIS resources can be utilized to adequately address needs. It is possible that each region identifies a need for both maintenance and traffic operations; however, there may be higher priorities in the short term that allow for developing a staged deployment strategy in the state. The region should consider where on the spectrum the priorities fall to select the appropriate short term RWIS plan. Regional users should also consider what tools and resources are currently available within the existing MDOT program in their respective areas to identify where gaps remain. The section below discusses the strategies that are best suited to meet each of these focus areas.

Maintenance Decision Support (within 1 Hour)

MDOT may focus on increasing fleet data and/or 3rd party input to support maintenance decision support. This will enhance the data between available fixed weather stations for the short term. MDOT should not seek out snow plows only, but rather other fleet type vehicles within Michigan that MDOT could leverage as a mobile resource such as Contract County vehicles, MDOT courtesy patrol, state vehicles (TSC) maintenance vehicles and/or Michigan State Police. MDOT may want to consider establishing a data collection network (either internally or under a third-party contract) to collect and aggregate mobile observations in Michigan.

Table 5: RWIS Resource Correlation - Maintenance Decision Support (within 1 hour)

Key Need Area	Stakeholder Need	Time	Spatial	Data Parameters
Maintenance Decision Support (within 1 Hour)	• Road weather forecast for next 5 minutes • Current conditions • Maintenance problem areas – current • Traveler problem areas – current • Road condition reports – current • Support MDSS • Enhance visual assessment of road conditions • Enhance traffic management strategies • MDOT vehicle locations	• Persistent • Imminent	• Point • Route Segment • Garage / Multiple Segments • Region • State	• Road Conditions from Mobile Sources • Road Condition from Connected Vehicles • Grip or Traction information from Connected Vehicles

Maintenance Decision Support (< 24 hours) & Limited Traffic Operations

MDOT should consider a number of fixed ESS within the region equally spaced to support general road condition forecasting. This will enhance maintenance decision support planning for upcoming storms. Other resources could provide supplemental data, but long term forecasts will be enhanced by fixed ESS. The fixed ESS will provide additional data points to MDOT traffic operation centers to enhance the weather traveler information program. RWIS research indicates a base ESS network with a grid spacing of 60 km (36 mi) provides data that fulfills this level of forecasting.

Table 6: Maintenance Decision Support (< 24 hours) &Limited Traffic Operations

Key Need Area	Stakeholder Need	Time	Spatial	Data Parameters
Maintenance Decision Support (< 24 hours) &Limited Traffic Operations	• Rd weather forecast beyond 1 hour • Maintenance problem areas – future • Traveler problem areas – future • Enhance traffic management strategies	• Tactical • Strategic • Planning	• Point • Route segment	• Fixed Road Locations • Treatment Information • Road Conditions from Mobile Sources • Road Condition from Connected Vehicles • Grip or Traction information from Connected Vehicles

Balanced Maintenance/Traffic Operations

MDOT should consider deploying a small number of fixed ESS to satisfy long term forecasts to support maintenance decision support. Additionally, MDOT should consider using the *Guidelines for Deploying Connected Vehicle-Enabled Weather Responsive Traffic Management Strategies* [5] to determine which traffic management strategies could be used. It is likely that a mix of intelligent fleet and/or 3rd party data will be needed to assist traffic operations respond to incidents. The key strategy is to enhance the data ingest to DuAP for the MDOT WxTINFO program.

Table 7: Balanced Maintenance/Traffic Operations

Key Need Area	Stakeholder Need	Time	Spatial	Data Parameters
Balanced Maintenance/ Traffic Operations	• Road weather forecast for next 5 mins • Road weather forecast for next hour • Road weather forecast beyond 1 hour • Current conditions • Maintenance problem areas - current • Maintenance problem areas - future • Traveler problem areas - current • Traveler problem areas - future • Road condition reports - current	• Persistence • Imminent • Tactical • Strategic • Planning	• Point • Route Segment • Garage / Multiple Segments • Region • State	• Treatment Information • Camera • Road Conditions from Mobile Sources • Road Condition from Connected Vehicles • Grip or Traction information from Connected Vehicles • GPS & Data from the Vehicle Electronics Controller

[5] United States Department of Transportation – Federal Highway Administration.
Guidelines for Deploying Connected Vehicle-Enabled Weather Responsive Traffic Management Strategies. Publication No: FHWA-JPO-17-478. November 2016.

	• Support MDSS • Enhance visual assessment of road conditions • Enhance traffic management strategies • Travel planning • MDOT vehicle locations			

<u>Traffic Safety and Operations</u>

MDOT should consider using the *Guidelines for Deploying Connected Vehicle-Enabled Weather Responsive Traffic Management Strategies* [6] to determine which traffic management strategies could be used. It is likely that a mix of intelligent fleet and/or 3rd party data will be needed to assist traffic operations staff respond to incidents. The key strategy is to enhance the data ingest to DuAP for the MDOT WxTINFO program.

Table 8: Traffic Operations Focus

Key Need Area	Stakeholder Need	Time	Spatial	Data Parameters
Traffic Safety and Operations	• Road weather forecast beyond 1 hour • Current conditions • Maintenance problem areas - current • Maintenance problem areas - future • Traveler problem areas - current • Traveler problem areas - future • Road condition reports - current • Support MDSS • Enhance visual	• Persistence • Imminent • Tactical • Strategic	• Point • Route Segment • Garage / Multiple Segments • Region • State	• Camera • Road Conditions from Mobile Sources • Road Condition from Connected Vehicles • Grip or Traction information from Connected Vehicles • GPS & Data from the Vehicle Electronics Controller

[6] United States Department of Transportation – Federal Highway Administration.
Guidelines for Deploying Connected Vehicle-Enabled Weather Responsive Traffic Management Strategies. Publication No: FHWA-JPO-17-478. November 2016.

Key Need Area	Stakeholder Need	Time	Spatial	Data Parameters
	assessment of road conditions • Enhance traffic management strategies • Travel planning • MDOT vehicle locations • Evaluation of material & vehicle use			

Procurement Considerations for Third Party Data

The third-party fleet services program is a private-sector venture that exists to collect road weather data from commercial trucks to support their operations. This data is similar to the data from the DOT's intelligent fleet program and offers a mechanism to augment the mobile data being collected by MDOT.

MDOT may seek out regional data from a third party where it is critically needed instead of acquiring third party data for the entire state. For example, could service providers only provide information for the tri-county Metro Detroit region to support traffic operations decision making rather than providing data for the entire state? This could be a more cost effective approach if it can be geographically bound. Even though the entire state would benefit if third party data was acquired at the statewide level, priorities might not support that level of investment.

Procurement Considerations for Intelligent Fleet

Analysis indicates that the intelligent fleet pathway offers valuable data to meet the general road weather stakeholder needs. Intelligent fleets provide a variety of strategic and tactical decision-making for state DOT maintenance and traffic operations. Data from fleets is appealing because the agencies control the fleets, and data collected from them can serve multiple purposes for forecasting, traffic management, winter maintenance operations, and asset management[7]

MDOT may seek mobile packages that enhance road condition forecast and near-real time information. Aftermarket sensor suites are readily available to provide air temp, RH, dew point, grip, pavement condition, pavement temperature and are as accurate as fixed sensors (if they are not used with snow plows). This strategy will require amending current support contracts if MDOT does not currently own and maintain the fleet vehicles. Amendment of these contracts may be done at the statewide level or done regionally. MDOT may consider identifying where vehicles travel prior to selecting the type of fleet in which to invest. A pilot on a few different types of vehicles may help identify which resource will be provide an abundance of data. MDOT may consider prioritizing their own vehicles in the short term.

Procurement Considerations for Fixed ESS

Table 2 suggests that MDOT may gain the most from expanding its fixed-base ESS network to cover the remainder of the state at a maximum spacing/minimum density necessary to meet the focus areas required by the stakeholders. The ESS component of the RWIS program focuses on the measurement of road conditions and associated weather conditions affecting the road conditions. The fixed ESS sites provide continual observations of road conditions, weather conditions, and the temperatures at depths beneath the pavement. The measured parameters and CCTV imagery are instrumental to the MDOT maintenance decision process. However, MDOT maintenance gains as much or more benefit from the road condition and weather forecasts derived from the inclusion of ESS data in the RWIS forecast products. ESS weather data fills voids in the NWS observation network and thereby improves local forecasts generated by all weather service providers. Forecasting benefits from a continual source of reliable observations from a network of fixed observations. This is not provided by mobile data sources; therefore, ESS becomes an invaluable resource to support the road weather forecast requirement.

[7] FHWA - Guidelines for Deploying Connected Vehicle-Enabled Weather Responsive Traffic Management Strategies

An optimal spacing requirement for an ESS network is dependent upon the projected use of the individual sites within the network. To support the forecast requirement, the greatest benefit appears to result from a grid network of 60km (36mi). Since the NWS already has a network of observation sites, the location of ESS sites needs to be adjusted to permit inclusion of these sites in the grid design. This grid spacing also provides an appropriate spacing for a network to record representative road condition variables. Often an agency decides to place an ESS at a site that has unique environmental characteristics or is accident-prone. Additional sites may be necessary to provide more representative values for MDOT users in adjacent areas. Prior to the introduction of mobile sensing platforms, the recommendation was for a denser network in urban areas (30 – 40km (18 – 24mi)) to provide a network of sites to observe road conditions. For future MDOT planning the 60km network spacing should be appropriate and selection of new ESS sites should be adjusted to integrate existing NWS sites. To obtain the full value of the ESS sites for forecasting purposes, they need to include a full set of atmospheric sensors as well as road condition sensors.

Benefits would be derived from the deployment of additional sites should additional or construction-specific funding become available.

Procurement Considerations for Connected Vehicles

The CV Program offers an extensive expansion to the road weather data acquisition capabilities and may substantially transform road weather analysis techniques. However, this program is not likely to mature to the point where it becomes a viable road weather resource in the immediate future. Therefore, our recommendation is for MDOT to monitor the progress of this program and continue research and development efforts in the establishment of the program. MDOT should leverage the guidelines for Deploying Connected Vehicle Enabled Weather Responsive Traffic Management Strategies and the MDOT statewide CV Strategic Plan to ensure all future road weather CV initiatives are aligned with MDOT's strategic plan and the latest FHWA guidance. An alternative approach is to initiate the design and development of a system to collect information from CVs and other mobile platforms.

APPENDIX A - MDOT RWIS Program Description

MDOT's existing RWIS are comprised of a variety of field resources that acquire near-real time road weather information and systems that collect, store, process and disseminate the information for the end users. This section provides a brief overview of the resources and systems currently supporting the RWIS program in Michigan. The graphic below illustrates the existing data exchange environment in which MDOT currently utilizes to support the road weather program.

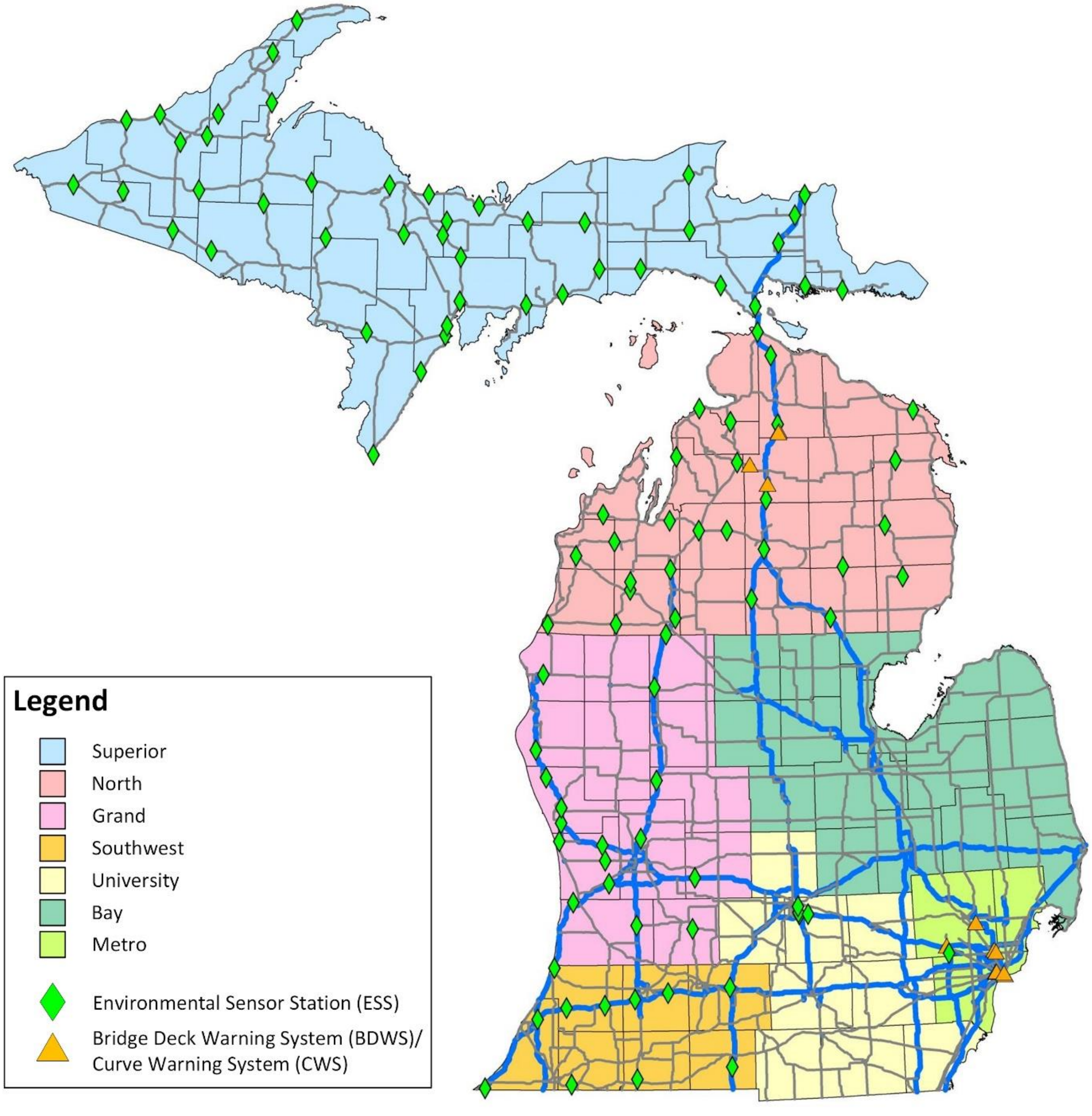

Figure 1: Relationship of Resources and Systems

Road Weather Data Resources

Fixed Environmental Sensor Stations

MDOT has invested in a total of 110 existing fixed ESS assets since 2007 across the state of Michigan. In addition, MDOT has 9 Active Curve and/or Bridge Deck Warning locations that include an array of fixed ESS equipment. The ESS sites shown above in the Grand Region are not yet constructed, except for the five that are now located in the Grand Region due to the Regional Prosperity Initiative (RPI) boundary changes in 2015. All of the planned locations are slated to be online by the end of 2018. Deployment areas were focused on locations where road weather challenges presented the largest maintenance and operational deficiency to date. MDOT's ESS program can consist of all or some of the following types of sensors:

- Visibility Sensor
- Wind Sensor
- Subsurface Temp Sensor or Temp Profile
- Air Temp/Relative Humidity
- Precipitation Sensor
- Closed Circuit Television (CCTV) Camera
- Barometric Pressure Sensor
- Pavement Temperature/Condition Sensor
- Microwave Vehicle Detection Systems

Mobile Data Collection (MDC) and Connected Vehicle Systems

Mobile Data Collection (MDC) and Automatic Vehicle Location (AVL) are key capabilities of the mobile road weather data acquisition program. Traditionally, most MDC units typically record air temperature, pavement temperature, material application rates (solid and liquid), and plow position by using externally mounted sensors on the vehicle. The MDC data are coupled with the GPS location and time from the AVL component.

MDOT's MDC/AVL Deployment includes outfitting snowplows with cameras, GPS/AVL, a link to the spreader controller for monitoring chemical usage, plow status, air temperature, humidity, dew point, and pavement temperature. Not all vehicles are equipped with the same technology. The current plan is to ensure 310 state-owned snowplows have a camera and can collect dew point/humidity more accurately.

MDOT currently supports USDOT/FHWA connected vehicle research projects, specifically the Integrated Mobile Observation (IMO) program, to assess how data from vehicles can enhance and support current data needs. These projects/programs also change the way a DOT does business.

MDOT, in partnership with various public and private partners, including the University of Michigan, announced in 2014 plans to deploy a large-scale deployment of CV technologies in Southeast Michigan along freeway corridors (as well as intersecting and parallel arterials). One key goal is the ability to report road weather information using Vehicle-to-Infrastructure (V2I) techniques. MDOT continues to leverage their Data Use and Processing (DUAP) platform and the Vehicle based Information Data Acquisition System (VIDAS) key repositories for collecting and processing the CV data for these applications. These platforms enable MDOT to provide valuable data to a variety of systems that ultimately benefit the end customer. To support the application development of RWIS, MDOT is in the process of deploying 71 number of DSRC units and 15 ESS stations along I-94.

FHWA Wx-TINFO

MDOT received a FHWA grant to use the IMO data to post motorist advisory warnings (MAW) to MDOT dynamic messages signs, the MI Drive web site, and smartphones. MDOT performed the research on this IMO project in coordination with UMTRI, ATMS software vendor Parsons Transportation Group (PTG), Data Use Analysis and Processing (DUAP) project consulting partner Mixon-Hill, the Department of Technology Management and Budget (DTMB), and the National Center for Atmospheric Research (NCAR). The system collected near real-time environmental/weather and traffic-related data from both fixed environmental and mobile sensors, processed the information into advisories, alerts, or traveler information and disseminated the traveler information in near-time for pre- trip applications.

RWIS Data Collection, Processing, Forecasting, and Use

Michigan's ESS collect a variety of data that may include, but are not limited to: pavement temperature (in-pavement and non-invasive), pavement conditions, atmospheric parameters, frost/ice/snow/liquid depths, traffic counts, camera imagery, and visibility. Transportation agencies use the data from these sensors, additional weather information from non-RWIS weather stations, and forecasts to make decisions on deploying maintenance crews and determining appropriate pavement treatments. These actions are critically important to public safety, the state's economy, and the environment. The following is a brief description of each of those system components currently used by MDOT.

- Central Management System - The RWIS Central Management System (CMS) is primary resource tool to support winter maintenance staff. The CMS polls fixed ESS data from the field and allows the user to view near real-time weather conditions at each of the stations. Data from MDOT fixed ESS stations, as well as data from the National Weather Service and the Federal Aviation Administration are available within the CMS. The CMS also hosts MDOT ESS camera feeds and curve/bridge deck warning points.
- Maintenance Decision Support System - The Maintenance Decision Support System (MDSS) is a forecast and decision support tool. MDSS provides weather and road condition forecasts and real-time treatment recommendations specific to winter road maintenance routes (e.g., treatment locations, types, times, and rates), tailored for winter road maintenance decision makers.
- Advanced Transportation Management System (ATMS) – MDOT's ATMS is a centralized system that integrates data from a number of MDOT's traditional ITS field devices (cameras, traffic sensors, and Connected Vehicle sources) through a singular interface. The ATMS is a valuable tool to provide accurate and useful messaging to motorists. The ATMS also integrates weather data from the RWIS CMS. TOCs can directly access ESS data, which then can be used to post winter weather related messages to motorists via DMS. Additionally, other programs such as WxTINFO are providing weather information to ATMS and Mi Drive via DUAP for the purpose of communicating weather advisories to end users of these services.
- Data Use Analysis and Processing (DUAP) - The MDOT DUAP program provides a platform and system that supports performance management by enhancing agency-wide usage of CV data, mobile data, and fixed data to increase data sharing, availability, and awareness across the agency. DUAP provides MDOT decision makers with more robust, near-time data from CVs, mobile platforms, and other internal MDOT systems to support decision making in support of agency objectives at reduced costs and with increased operational efficiency. The MDOT DUAP system provides users with background weather information that can be used to validate weather alerts generated for the Wx-TINFO functionality. DUAP is capable of[1]:
    - Consolidating weather information from a variety of sources to obtain a more detailed view of the current conditions
    - Locating weather events requiring alerts to be sent to the traveling public
    - Sending events to ATMS for propagation to affected DMSs and the Mi Drive website
    - Updating DMSs based on weather event changes

[1] (MDOT Weather Responsive Traveler Information (Wx-TINFO) System Implementation Project, 2016)

- Providing quality checking and quality assurance functionality for validating data including, but not limited to, spatial and step comparisons
- Viewing weather data and events historically

APPENDIX B - RWIS USER NEEDS BACKGROUND

The RWIS program was originally designed to solely support airport runway and DOT maintenance operations during winter weather situations. Pavement sensors were the focal point of RWIS and their objective was to determine the presence of snow, ice, liquid, and deicing chemicals on pavement surfaces to estimate the road condition. The need for observed data within the maintenance community was quickly augmented by the addition of techniques to forecast pavement conditions and pavement temperatures. When these parameters were coupled with forecasted weather conditions, maintenance personnel had an effective tool to evaluate when and where maintenance actions would likely be necessary. This tool allows the DOT's to estimate the most effective treatment activity to deal with the anticipated road conditions and ultimately save both time and money.

RWIS has provided the maintenance community with the ability to observe measured remote road and weather conditions; however, the ability to see actual conditions can provide a much better assessment of the weather conditions. Maintenance Staff in the past have overwhelmingly expressed a need to be able to access camera imagery from fixed ESS sites to support their response decisions. The ability to visually verify conditions often provides clarification of what the measured parameters indicate. Additionally, maintenance personnel have indicated that the ability to obtain weather and road condition information on mobile devices provides them greater flexibility in making ongoing adjustments in their maintenance decisions.

Maintenance stakeholders also expressed a growing need for an effective method to determine performance metrics regarding their maintenance activities. This requires both a determination of the state of a weather event and the level of service of the roadway. Using fixed or mobile resources coupled with other weather resources offer a mechanism to define the state of an event either through direct observation from a single ESS site or through an assessment of the trend of an event from data from multiple observation resources. One approach for level of service is the use of pavement sensors to determine the state of the road surface and correlate this with a degree of mobility. This approach has not proven as effective as measuring vehicle speeds and determining when roadways permit drivers to return to normal driving speeds.

Forecast Tables and Background Information

This section looks at the relative value of each RWIS parameter in satisfying decision support needs of the predominant stakeholders having an interest in the RWIS program. Most of the needs are road weather forecast related. However, since most users receive their forecasts along with presentations of road weather data, the analysis considers the decisions impacted by the raw RWIS data as well. The RWIS program was initially based upon observations from fixed ESS sites, but in the past 25 years instrumentation that collects several of the RWIS variables has been installed on mobile vehicles. Therefore, RWIS now includes data from fixed ESS sites, MDC/AVL data on DOT vehicles, and instrumentation on commercial and privately owned vehicles under the CV Program. This value analysis includes data from these three sources; however, the correlation is not a simple analysis because user needs change dependent upon the timeframe in which the decision must be made. The Introduction listed five different forecast time domains ranging from near real-time decisions out to planning decisions. This section reviews the value of each RWIS parameter in meeting the needs of the primary stakeholders for each of these five forecast time frames. The five correlations are shown in Tables 2 through 6. The numbers presented in the tables represent a measure of the value attributed to each RWIS parameter in meeting the respective stakeholder. The value rating scale is based upon a Likert scale ranging from 1 for no value to 9 for very high value. To allow the user to see general value trends value scores in specific ranges are color coded as follows:

Likert Score Range	Value Category	Color
7 - 9	High	Green
4 - 6	Mid-Level	Yellow
3 – 5	Low	Red
1 – 2	Unimportant	Blank with no number

The value of the parameter in meeting the stakeholder need assumes that the RWIS parameter is completely representative of the conditions around the ESS site or mobile vehicle. Many sites do not provide totally representative measurements of conditions in the area. For example, wind measurements along roadways cut through a forest may not represent wind information that would be captured by an open area such as an airfield cut into the same forest. Using this “completely representative” assumption Tables 2 – 6 provide an assessment of values for each of the forecast periods.

Table 2. Value of RWIS parameters used for a Persistence Forecast to support the specified stakeholder needs.

		VALUE OF RWIS PARAMETERS IN SUPPORT OF PERSISTENCE FORECASTS																		
		ESS																		
		ROADWAY						ATMOSPHERICS												
STAKEHOLDER GROUP	NEED	RD TEMP	RD COND INV	RD COND IR	GRIP	SUBSFC TEMP ONE	SUBSFC TEMP COL	AIR TEMP	DEW PT	RH	WIND DIR	WIND SPEED	WIND GUST	PRECIPITATION TYPE	PRECIPITATION RATE	PRES WX	VIS	BAR	CAM	TRAF
DOT Maintenance	Road conditions	6	4	6	6	3	3												5	5
	Weather conditions							6	6	6	6	6	6	6	6	6	6	4	4	
	Snow/ice response	6	4	6	6			6	6	6	6	6	6	6	6	6	6	4	5	5
	Construction go/no go	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	5	5
	Field work go/no go	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	3
Weather Service Provider	Generate wx fcst							6	6	6	6	6	6	6	6	6	6	4	4	
	Display wx conditions							5	5	5	5	5	5	5	5	5	5	3		
	Issue warnings	4	4	4	5			6	6	6	6	6	6	6	6	6	6		4	
Sfc Transportation Weather Service Provider	Generate wx fcst							6	6	6	6	6	6	6	6	6	6	4	4	
	Generate road wx fcst	6	6	6	6	5	5	6	6	6	6	6	6	6	6	6	6	4	6	
	Display wx conditions							5	5	5	5	5	5	5	5	5	5	4	5	
	Display road conditions	6	4	6	6	3	3													
Traffic Operations	Road conditions by rte seg	7	5	7	7	3	3												5	5
	Weather conditions by rte seg							6	6	6	6	6	6	6	6	6	6	4	4	5
	Advisory messages	5	5	7	7												6		5	7
DOT Construction	Road conditions for ops																		4	
	Weather conditions for ops							6	6	6	6	6	6	6	6	6	6	4	4	
Emergency Services	Road conditions for ops	5	4	5	5	3	3												5	
	Weather conditions for ops							6	6	6	6	6	6	6	6	6	6	4	4	
	Impending traffic delays	5	4	5	5														6	
Commercial Vehicles and Travelers	Road conditions by rte seg	6	5	6	6	3	3												5	
	Weather conditions by rte seg							6	6	6	6	6	6	6	6	6	6	4	4	5
	Potential delays	5	4	6	6														6	
	Travel times																			

		MDC/AVL												CONNECTED VEHICLE						
		ROADWAY					ATMOSPHERICS							ROADWAY			ATMOSPHERICS			
STAKEHOLDER GROUP	NEED	RD TEMP	RD COND MSR	RD COND OB	GRIP	GRIP LOSS	AIR TEMP	DEW PT	RH	PRECIPITATION Y/N	PRECIPITATION TYPE	PRECIPITATION RATE	PRES WX	RD TEMP	RD COND	GRIP	AIR TEMP	PRECIPITATION Y/N	PRECIPITATION TYPE	PRECIPITATION RATE
DOT Maintenance	Road conditions	6	6	5	7	9								8	8	8				
	Weather conditions						6	6	6	6	6	6	6				8	9	9	9
	Snow/ice response	6	6	6	7	9	6	6	6	6	6	6	6	8	8	8	8	9	9	9
	Construction go/no go	5	5	5	6	5	6	6	6	6	6	6	6	5	5	6	6	8	8	8
	Field work go/no go	4	4	4	4	4	6	6	6	6	6	6	6	4	4	4	6	8	8	8
Weather Service Provider	Generate wx fcst						6	6	6	6	6	6	6				8	9	9	9
	Display wx conditions						5	5	5	5	5	5	5				5	5	5	5
	Issue warnings	4	4	4	5	5	6	6	6	6	6	6	6	4	4	6	6	7	7	7
Sfc Transportation Weather Service Provider	Generate wx fcst						6	6	6	6	6	6	6				8	9	9	9
	Generate road wx fcst	6	6	6	6	6	6	6	6	6	6	6	6	8	8	8	8	9	9	9
	Display wx conditions						5	5	5	5	5	5	5				8	9	9	9
	Display road conditions	6	6	6	6	6								8	8	8				
Traffic Operations	Road conditions by rte seg	7	7	7	7	8								8	8	8				
	Weather conditions by rte seg						6	6	6	6	6	6	6				8	9	9	9
	Advisory messages	5	7	7	7	8								6	8	8				
DOT Construction	Road conditions for ops																			
	Weather conditions for ops						6	6	6	6	6	6	6				7	8	8	8
Emergency Services	Road conditions for ops	6	6	6	7	8								8	8	8				
	Weather conditions for ops						6	6	6	6	6	6	6				7	8	8	8
	Impending traffic delays	5	5	5	6	7								6	8	8				
Commercial Vehicles and Travelers	Road conditions by rte seg	6	6	6	7	8								7	8	8				
	Weather conditions by rte seg						6	6	6	6	6	6	6				8	9	9	9
	Potential delays	5	5	5	6	7								5	8	8				
	Travel times																			

Table 3. Value of RWIS parameters used for an Imminent Forecast to support the specified stakeholder needs.

STAKEHOLDER GROUP	NEED	VALUE OF RWIS PARAMETERS IN SUPPORT OF IMMINENT FORECASTS																																			
		ESS																			MDC/AVL												CONNECTED VEHICLE						
		ROADWAY						ATMOSPHERICS													ROADWAY					ATMOSPHERICS							ROADWAY			ATMOSPHERICS			
		RD TEMP	RD COND		GRIP	SUBSFC TEMP		AIR TEMP	DEW PT	RH	WIND			PRECIPITATION		PRES WX	VIS	BAR	CAM	TRAF	RD TEMP	RD COND		GRIP	GRIP LOSS	AIR TEMP	DEW PT	RH	PRECIPITATION			PRES WX	RD TEMP	RD COND	GRIP	AIR TEMP	PRECIPITATION		
			INV	IR		ONE	COL				DIR	SPEED	GUST	TYPE	RATE							MSR	OB						Y/N	TYPE	RATE						Y/N	TYPE	RATE
DOT Maintenance	Road conditions	7	5	7	7	3	3												5	5	7	7	6	7	8								8	8	8				
	Weather conditions							7	7	7	7	7	7	7	7	7	7	4	5							7	7	7	7	7	7	7				8	9	9	9
	Snow/ice response	7	5	7	7			7	7	7	7	7	7	7	7	7	7	4	6	6	7	7	6	7	9	7	7	7	7	7	7	7	8	8	8	8	9	9	9
	Construction go/no go	6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	4	6	5	6	6	6	6	6	6	6	6	6	6	6	6	5	5	6	6	8	8	8
	Field work go/no go	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	6	6	6	6	6	6	6	6	6	6	6	6	6	6	4	4	4	6	8	8	8
Weather Service Provider	Generate wx fcst							7	7	7	7	7	7	7	7	7	7	5	5							7	7	7	7	7	7	7				8	9	9	9
	Display wx conditions							7	7	7	7	7	7	7	7	7	7	3								5	5	5	5	5	5	5				5	5	5	5
	Issue warnings	4	4	4	5			6	6	6	6	6	6	6	6	6	6		4		4	4	4	5	5	6	6	6	6	6	6	6	4	4	6	6	7	7	7
Sfc Transportation Weather Service Provider	Generate wx fcst							7	7	7	7	7	7	7	7	7	7	4	5							7	7	7	7	7	7	7				8	9	9	9
	Generate road wx fcst	7	6	7	7	6	6	7	7	7	7	7	7	7	7	7	7	4	6		7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9	9
	Display wx conditions							7	7	7	7	7	7	7	7	7	7	4	6							7	7	7	7	7	7	7				8	9	9	9
	Display road conditions	7	5	7	7	3	3														7	7	7	7	7								8	8	8				
Traffic Operations	Road conditions by rte seg	7	5	7	7	3	3												6	6	7	7	7	7	8								8	8	8				
	Weather conditions by rte seg							7	7	7	7	7	7	7	7	7	7	4	5	5						7	7	7	7	7	7	7				8	9	9	9
	Advisory messages	5	5	7	7												7		5	7	5	7	7	7	8								6	8	8				
DOT Construction	Road conditions for ops																		5																				
	Weather conditions for ops							7	7	7	7	7	7	7	7	7	7	4	4							7	7	7	7	7	7	7				7	8	8	8
Emergency Services	Road conditions for ops	6	5	6	6	3	3												5		7	7	7	7	8								8	8	8				
	Weather conditions for ops							7	7	7	7	7	7	7	7	7	7	4	4							7	7	7	7	7	7	7				7	8	8	8
	Impending traffic delays	6	5	6	6														6		5	6	6	6	7								6	8	8				
Commercial Vehicles and Travelers	Road conditions by rte seg	7	6	7	7	3	3												6		7	7	7	7	8								7	8	8				
	Weather conditions by rte seg							7	7	7	7	7	7	7	7	7	7	4	4	5						7	7	7	7	7	7	7				8	9	9	9
	Potential delays	6	5	7	7														7		7	7	7	8	8								5	8	8				
	Travel times	4	4	4	4	3	3	4	4	4	4	4	4	4	4	4	4	4			4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 4. Value of RWIS parameters used for a Tactical Forecast to support the specified stakeholder needs.

STAKEHOLDER GROUP	NEED	VALUE OF RWIS PARAMETERS IN SUPPORT OF TACTICAL FORECASTS																																			
		ESS																			MDC/AVL												CONNECTED VEHICLE						
		ROADWAY						ATMOSPHERICS													ROADWAY					ATMOSPHERICS							ROADWAY			ATMOSPHERICS			
		RD TEMP	RD COND INV	IR	GRIP	SUBSFC TEMP ONE	COL	AIR TEMP	DEW PT	RH	WIND DIR	SPEED	GUST	PRECIPITATION TYPE	RATE	PRES WX	VIS	BAR	CAM	TRAF	RD TEMP	RD COND MSR	OB	GRIP	GRIP LOSS	AIR TEMP	DEW PT	RH	PRECIPITATION Y/N	TYPE	RATE	PRES WX	RD TEMP	RD COND	GRIP	AIR TEMP	PRECIPITATION Y/N	TYPE	RATE
DOT Maintenance	Road conditions	8	7	8	8	6	6												7	5	8	8	7	8	9								8	8	8				
	Weather conditions							8	8	8	8	8	8	8	8	8	8	4	6							8	8	8	9	9	9	8				8	9	9	9
	Snow/ice response	8	7	8	8	6	6	8	8	8	8	8	8	8	8	8	8	4	8	6	8	8	7	8	9	8	8	8	8	8	8	8	8	8	8	8	9	9	9
	Construction go/no go	7	6	7	7	5	5	7	7	7	7	7	7	7	7	7	7	4	7	5	7	7	7	6	6	7	7	7	7	7	7	7	6	6	6	6	8	8	8
	Field work go/no go	7	6	7	7	5	5	7	7	7	7	7	7	7	7	7	7	4	7	6	6	7	6	6	6	7	7	7	7	7	7	7	4	4	4	6	8	8	8
Weather Service Provider	Generate wx fcst							7	7	7	7	7	7	7	7	7	7	5	5							8	8	8	8	8	8	8				8	8	8	8
	Display wx conditions							7	7	7	7	7	7	7	7	7	7	3								5	5	5	5	5	5	5				5	5	5	5
	Issue warnings	4	4	4	6			7	7	7	7	7	7	7	7	7	7		4		4	4	4	7	7	7	7	7	7	7	7	7	4	4	7	6	7	7	7
Sfc Transportation Weather Service Provider	Generate wx fcst							8	8	8	8	8	8	8	8	8	8	4	7							8	8	8	8	8	8	8				8	9	9	9
	Generate road wx fcst	8	7	8	8	7	7	8	8	8	8	8	8	8	8	8	8	4	7		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	9	9	9
	Display wx conditions							8	8	8	8	8	8	8	8	8	8	4	7							8	8	8	8	8	8	8				7	7	7	7
	Display road conditions	8	7	8	8	3	3														8	8	8	8	8								7	7	7				
Traffic Operations	Road conditions by rte seg	8	7	8	8	3	3												7	6	8	8	8	8	8								8	8	8				
	Weather conditions by rte seg							8	8	8	8	8	8	8	8	8	8	4	7	6						8	8	8	8	8	8	8				8	9	9	9
	Advisory messages	5	5	8	8														5	7	5	7	7	8	8								6	8	8				
DOT Construction	Road conditions for ops	8	7	8	8	3	3												5		8	8	8	4	4								8	8	6				
	Weather conditions for ops							8	8	8	8	8	8	8	8	8	8	4	4							8	8	8	8	8	8	8				7	8	8	8
Emergency Services	Road conditions for ops	8	7	8	8	3	3												5		8	8	8	8	8								8	8	8				
	Weather conditions for ops							8	8	8	8	8	8	8	8	8	8	4	4							8	8	8	8	8	8	8				7	8	8	8
	Impending traffic delays	7	5	7	8														6		5	7	7	7	7								6	8	8				
Commercial Vehicles and Travelers	Road conditions by rte seg	8	7	8	8	3	3												6		8	8	8	8	9								7	8	8				
	Weather conditions by rte seg							8	8	8	8	8	8	8	8	8	8	4	7	5						7	7	7	7	7	7	7				8	9	9	9
	Potential delays	6	5	7	7														7		7	7	7	8	8								5	8	8				
	Travel times	4	4	4	4	3	3	4	4	4	4	4	4	4	4	4	4	4			4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 5. Value of RWIS parameters used for a Strategic Forecast to support the specified stakeholder needs.

STAKEHOLDER GROUP	NEED	ESS ROADWAY RD TEMP	ESS ROADWAY RD COND INV	ESS ROADWAY RD COND IR	ESS ROADWAY GRIP	ESS ROADWAY SUBSFC TEMP ONE	ESS ROADWAY SUBSFC TEMP COL	ESS ATMOSPHERICS AIR TEMP	ESS ATMOSPHERICS DEW PT	ESS ATMOSPHERICS RH	ESS ATMOSPHERICS WIND DIR	ESS ATMOSPHERICS WIND SPEED	ESS ATMOSPHERICS GUST	ESS ATMOSPHERICS PRECIPITATION TYPE	ESS ATMOSPHERICS PRECIPITATION RATE	ESS ATMOSPHERICS PRES WX	ESS ATMOSPHERICS VIS	ESS ATMOSPHERICS BAR	CAM	TRAF	MDC/AVL ROADWAY RD TEMP	MDC/AVL ROADWAY RD COND MSR	MDC/AVL ROADWAY RD COND OB	MDC/AVL ROADWAY GRIP	MDC/AVL ROADWAY GRIP LOSS	MDC/AVL ATMOSPHERICS AIR TEMP	MDC/AVL ATMOSPHERICS DEW PT	MDC/AVL ATMOSPHERICS RH	MDC/AVL ATMOSPHERICS PRECIPITATION Y/N	MDC/AVL ATMOSPHERICS PRECIPITATION TYPE	MDC/AVL ATMOSPHERICS PRECIPITATION RATE	MDC/AVL ATMOSPHERICS PRES WX	CONNECTED VEHICLE ROADWAY RD TEMP	CONNECTED VEHICLE ROADWAY RD COND	CONNECTED VEHICLE ROADWAY GRIP	CONNECTED VEHICLE ATMOSPHERICS AIR TEMP	CONNECTED VEHICLE ATMOSPHERICS PRECIPITATION Y/N	CONNECTED VEHICLE ATMOSPHERICS PRECIPITATION TYPE	CONNECTED VEHICLE ATMOSPHERICS PRECIPITATION RATE
DOT Maintenance	Road conditions	9	8	9	9	8	8												7	5	9	9	8	9	9								7	7	7				
	Weather conditions							9	9	9	9	9	9	9	9	9	9	4	8							9	9	9	9	9	9	9				7	8	8	8
	Snow/ice response	9	8	9	9	8	8	9	9	9	9	9	9	9	9	9	9	4	8	6	9	9	8	9	9	9	9	9	9	9	9	9	7	7	7	7	8	8	8
	Construction go/no go	8	7	8	8	5	5	8	8	8	8	8	8	8	8	8	8	4	7	5	8	8	8	8	8	8	8	8	8	8	8	8	6	6	6	6	8	8	8
	Field work go/no go	8	7	8	8	5	5	8	8	8	8	8	8	8	8	8	8	4	7	6	8	8	8	8	8	8	8	8	8	8	8	8	5	5	5	5	8	8	8
Weather Service Provider	Generate wx fcst							8	8	8	8	8	8	8	8	8	8	5	7							8	8	8	8	8	8	8				8	8	8	8
	Display wx conditions							7	7	7	7	7	7	7	7	7	7	3								5	5	5	5	5	5	5				5	5	5	5
	Issue warnings	4	4	4	6			7	7	7	7	7	7	7	7	7	7		4		4	4	4	8	8	7	7	7	7	7	7	7	4	4	8	6	7	7	7
Sfc Transportation Weather Service Provider	Generate wx fcst							9	9	9	9	9	9	9	9	9	9	4	8							9	9	9	9	9	9	9				8	8	8	8
	Generate road wx fcst	9	8	9	9	8	8	9	9	9	9	9	9	9	9	9	9	4	8		9	9	9	9	9	9	9	9	9	9	9	9	8	8	8	8	8	8	8
	Display wx conditions							9	9	9	9	9	9	9	9	9	9	4	8							9	9	9	9	9	9	9				7	7	7	7
	Display road conditions	9	8	9	9	5	5														9	9	9	9	9								7	7	7				
Traffic Operations	Road conditions by rte seg	8	7	8	8	8	8												7	6	8	8	8	8	8								8	8	8				
	Weather conditions by rte seg							9	9	9	9	9	9	9	9	9	9	4	7	6						9	9	9	9	9	9	9				8	8	8	8
	Advisory messages	5	5	8	8														5	7	5	7	7	8	8								6	8	8				
DOT Construction	Road conditions for ops	8	7	8	8	8	8												5		8	8	8	4	4								8	8	6				
	Weather conditions for ops							9	9	9	9	9	9	9	9	9	9	4	4							9	9	9	9	9	9	9				7	8	8	8
Emergency Services	Road conditions for ops	8	7	9		8	8												5		8	8	8	9	9								8	8	9				
	Weather conditions for ops							9	9	9	9	9	9	9	9	9	9	4	4							9	9	9	9	9	9	9				7	8	8	8
	Impending traffic delays	7	5	7	8														6		5	7	7	7	7								6	8	8				
Commercial Vehicles and Travelers	Road conditions by rte seg	9	8	9	9	8	8												6		8	9	9	9	9								8	9	9				
	Weather conditions by rte seg							9	9	9	9	9	9	9	9	9	9	4	7	5						9	9	9	9	9	9	9				7	8	8	8
	Potential delays	7	7	8	8														8		7	8	8	8	8								7	8	8				
	Travel times	8	8	8	8	3	3	8	8	8	8	8	8	8	8	8	8	4			8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7	7

VALUE OF RWIS PARAMETERS IN SUPPORT OF STRATEGIC FORECASTS

Table 6. Value of RWIS parameters used for a Planning Forecast to support the specified stakeholder needs.

STAKEHOLDER GROUP	NEED	VALUE OF RWIS PARAMETERS IN SUPPORT OF PLANNING FORECASTS																																					
		ESS																			MDC/AVL												CONNECTED VEHICLE						
		ROADWAY						ATMOSPHERICS													ROADWAY					ATMOSPHERICS							ROADWAY			ATMOSPHERICS			
		RD TEMP	RD COND INV	RD COND IR	GRIP	SUBSFC TEMP ONE	SUBSFC TEMP COL	AIR TEMP	DEW PT	RH	WIND DIR	WIND SPEED	GUST	PRECIPITATION TYPE	PRECIPITATION RATE	PRES WX	VIS	BAR	CAM	TRAF	RD TEMP	RD COND MSR	RD COND OB	GRIP	GRIP LOSS	AIR TEMP	DEW PT	RH	PRECIPITATION Y/N	PRECIPITATION TYPE	PRECIPITATION RATE	PRES WX	RD TEMP	RD COND	GRIP	AIR TEMP	PRECIPITATION Y/N	PRECIPITATION TYPE	PRECIPITATION RATE
DOT Maintenance	Road conditions	7	7	7	7	7	7												4	4	7	7	7	7	7								6	6	6				
	Weather conditions							7	7	7	7	7	7	7	7	7	7	4	4							7	7	7	7	7	7	7				6	6	6	6
	Snow/ice response	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	4	4	4	7	7	7	7	7	7	7	7	7	7	7	7	6	6	6	6	6	6	6
	Construction go/no go	6	6	6	6	5	5	6	6	6	6	6	6	6	6	6	6	4	4	4	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
	Field work go/no go	6	6	6	6	5	5	6	6	6	6	6	6	6	6	6	6	4	4	4	6	6	6	6	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
Weather Service Provider	Generate wx fcst							7	7	7	7	7	7	7	7	7	7	5	7							7	7	7	7	7	7	7				5	5	5	5
	Display wx conditions							4	4	4	4	4	4	4	4	4	4	3								4	4	4	4	4	4	4				4	4	4	4
	Issue warnings	4	4	4	4			4	4	4	4	4	4	4	4	4	4		4		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Sfc Transportation Weather Service Provider	Generate wx fcst							8	8	8	8	8	8	8	8	8	8	4	4							8	8	8	8	8	8	8				6	6	6	6
	Generate road wx fcst	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	4	4		8	8	8	8	8	8	8	8	8	8	8	8	6	6	6	6	6	6	6
	Display wx conditions							5	5	5	5	5	5	5	5	5	5	4	4							5	5	5	5	5	5	5				4	4	4	4
	Display road conditions	5	5	5	5	5	5														5	5	5	5	5								5	5	5				
Traffic Operations	Road conditions by rte seg	7	7	7	7	7	7												4	4	7	7	7	7	7								6	6	6				
	Weather conditions by rte seg							7	7	7	7	7	7	7	7	7	7	4	4	4						7	7	7	7	7	7	7				6	6	6	6
	Advisory messages	4	4	4	4														4	4	4	4	4	4	4								4	4	4				
DOT Construction	Road conditions for ops	7	7	7	7	7	7												4	4	7	7	7	7	7								6	6	6				
	Weather conditions for ops							7	7	7	7	7	7	7	7	7	7	4	4	4						7	7	7	7	7	7	7				6	6	6	6
Emergency Services	Road conditions for ops	7	7	7	7	7	7												4	4	7	7	7	7	7								6	6	6				
	Weather conditions for ops							7	7	7	7	7	7	7	7	7	7	4	4	4						7	7	7	7	7	7	7				6	6	6	6
	Impending traffic delays	4	4	4	4														4		4	4	4	4	4								4	4	4				
Commercial Vehicles and Travelers	Road conditions by rte seg	8	7	8	8	8	8												4		8	8	8	8	8								6	6	6				
	Weather conditions by rte seg							8	8	8	8	8	8	8	8	8	8	4	4	4						8	8	8	8	8	8	8				7	7	7	7
	Potential delays	7	7	8	8														4		7	8	8	8	8								7	7	7				
	Travel times	8	8	8	8	3	3	8	8	8	8	8	8	8	8	8	8	4			8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7	7

APPENDIX C - TSMO Background Data

Idaho

Idaho's RWIS network includes non-invasive pavement friction (or "grip") sensors. They use this data to determine when a safe grip factor is achieved.

They also use a storm severity index to better measure from storm to storm. Idaho's Storm Severity Index uses three storm parameters to determine storm severity. Those parameters are maximum wind speed, maximum water equivalent layer, and surface temperature.

Storm Severity Index = WS (Max) + WEL (Max) + 300/ST (Min)

Where the following units are used:

- WS = Wind Speed (mph)
- WEL = Water Equivalent Layer (millimeters)
- ST = Surface Temperature (degrees F)

Lower values indicate lighter storm events. The range is 10- 80 for typical storm events. Severe cold and high winds could result in an index as high as high as 500

The winter performance index is used to measure the effectiveness of roadway treatment to the specific severity of the storm

Winter Performance Measure Index = Ice Up Time (hours) / Storm Severity Index

- Ice up time is the duration of the event when the grip is below 0.60 for more than ½ hour.

The goal is to have a Winter Performance Index of 0.50 or less.

This approach requires grip sensors at RWIS stations. It might be worth investigating to determine if CV data for dynamic traction control and wheel monitoring for AWD and ABS be used in place of the grip sensors. This information is currently considered proprietary by the automotive companies for passenger cars. A different standard (J1939) is used for heavy duty vehicle and this information may be more accessible for those vehicles. Also, fleet owners (like MDOT) may be able to pay for CAN bus data for even their passenger vehicles.

Ohio

Ohio DOT uses a performance evaluation protocol known as SNIPE (Snow 'N Ice Performance Evaluator). SNIPE measures the time for speeds to return to normal levels after a winter storm. RWIS data is used to determine when an event starts and stops. SNIPE also needs speed sensors to determine when speeds return to normal.

A weather event is considered to begin when 40% of a county's RWIS stations report snow or freezing rain, the air or pavement temperature is below 34 degrees, and traffic speeds drop by 10 mph on 15% of the priority routes in a county.

A weather event ends when 60% of County's RWIS stations report "none" or rain for precipitation, wind speed is less than 15 mph, and snow does not begin within 2 hours. Recovery is said to occur when speeds are within 10 mph expected speeds. Their goal is to recover speeds in 2 hours or less.

(Iowa also uses a time to return to "normal" speed as a performance measure.)

CV data may be able to be used in the SNIPE system to determine speeds if enough vehicles are instrumented. It is also possible that the air temperature from CVs would be useable in the SNIPE approach.

APPENDIX D – Growth of Information

The increased market penetration of CVs provides an opportunity to significantly increase the volume and accuracy of data that can be used to support RWM functions over the next five years. It is estimated that by 2020 most new vehicles produced globally will be equipped with data connectivity technologies that enables data to flow to, and from the vehicle. This will be enabled either through built-in equipment, or through the tethering of mobile devices. The number of CVs is expected to reach 61 million by 2020.[8,9] The increased market penetration of CVs not only enables a significant growth in the volume of data that can be collected, but it also broadens that types of data that can be collected as auto manufacturers will evolve in terms the types and numbers of vehicle sensors that will collect the data. In-car telematics that leverage connectivity, either via Wi-Fi or dedicated short-range communications (DSRC), will continue to provide real-time safety, convenience, entertainment and communications services to the driver. This means that CVs are becoming hubs that generate, process, send and receive vast amounts of data that help to drive a range of functions, including RWM.[10,11] This provides an ideal opportunity to provide fully-customized, highly precise, and time relevant forecasts and weather warnings based on the user needs.

The increasing ability to collect CV sourced data enables a range of new business-to-business, business-to-consumer, and business-to-government services. For example, according to an Accenture study, data sourced from CVs will be used to develop value added consumer services such as vehicle diagnostics, driving dashboards, and concierge services.[12,13] To facilitate the delivery of these services to consumers, commercial entities, and government agencies will likely require auto manufacturers to foster partnerships with a range services providers, including application developers, IT security companies, enterprise companies with established cloud-based infrastructures and data analysis experience, and as it relates to RWN functions, with "weather as a service companies".[14] The increasing emergence of these types of services will help to meet the need of MDOT personnel in the North and Superior Regions

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[8] Gartner, Inc. is an information technology research and advisory company that delivers the technology-related insight to clients across a range of industries.

[9] http://www.gartner.com/newsroom/id/3460018

[10] Baker & McKenzie. *Global Information Technology & Communications 2015 – Connected Cars*.

[11] DSRC (Dedicated Short Range Communications) is a two-way short- to- medium-range wireless communications capability that permits very high data transmission critical in communications-based active safety applications. In Report and Order FCC-03-324, the Federal Communications Commission (FCC) allocated 75 MHz of spectrum in the 5.9 GHz band for use by Intelligent Transportations Systems (ITS) vehicle safety and mobility applications. http://www.its.dot.gov/factsheets/dsrc_factsheet.htm

[12] https://www.accenture.com/t20160519T222110__w__/us-en/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Dualpub_4/Accenture-Mobility-Connected-Vehicle.pdf

[13] Accenture PLC is a global professional services company which provides strategy, consulting, digital, technology and operations services.

[14] http://www.forbes.com/sites/vmware/2017/01/26/7-keys-to-the-connected-car/#7b7d9874ee99

to access to RWIS data on a smart phone or mobile application rather than being limited to access to the information through a web interface.[15]

[15] Michigan Department of Transportation. R*oadway Weather Information System – Deployment Strategy Memorandum.* March 2014.

APPENDIX E - Transportation Systems Management & Operations (TSM&O), Road Weather Management & Performance Measures

As part of MDOT efforts in further developing their Transportation Systems Management and Operations (TSMO) program, seven strategic areas of focus were identified. The RWIS program goals align well with 6 of the 7 focus areas.

Integrate Operations Across All Business Areas

RWIS provides the basis for improving winter roadway operations. Providing road weather data and information through connected vehicle technologies incorporates road weather data collection with a variety of other MDOT applications.

Integrate the Operations of Intelligent Transportation Systems (ITS) and Signals

Road weather information can be used to help operate traffic signals more effectively during winter weather conditions. Weather and road condition data can be used to determine beneficial changes to signal timing parameters to respond to winter weather situations. Timing parameters that could be changed based on conditions include gap, minimum and maximum green times, and clearance interval (all red). For coordinated systems, winter weather could slow traffic more than normal and specific coordinated signal timing plans could be implemented to reflect those slower traffic conditions.

Adapt Processes, Products, and Training to Advances in Technology

RWIS data is important for efficient winter maintenance operations. It is also important as part of MDOT's traveler information system so travelers can make informed decisions about when, where, and even whether to travel. Connected vehicle and mobile data can supplement data from fixed environmental sensor stations. By using these new sources of data, MDOT would adapt their winter maintenance data acquisition to these new technologies.

Enhance Communications and Outreach to External and Internal Stakeholders

RWIS activities to date have included extensive stakeholder outreach. Because gathering and using road weather data involves multiple disciplines and multiple organizations, communication and outreach to stakeholders would be a natural aspect of the RWIS program into the future.

Prioritize Resources to Meet Critical Emerging Needs

One of the most critical aspects of the RWIS program is to enhance winter maintenance personnel's ability to prioritize the use of their resources. RWIS data provides the basis for prioritizing and allocating winter operations resources.

Drive Progress with Meaningful Performance Measures

RWIS data from ESS sites and MDC/AVL sources can provide information that can be used for measuring performance of winter operations; thus, the success of the RWIS program may be assessed using archived RWIS information in several different ways to meet specific performance evaluations The evaluations range from assessing the level of performance during one maintenance activity to summarizing average performance levels over multiple winter seasons

Agencies across the country have been searching for improved winter operations performance measures. Two primary approaches are discussed below: time to recover friction on the roadway (“grip”) or time to recover “normal” speed. Each are measured after a winter weather event has ended. Two examples are presented below.

Idaho’s RWIS network includes non-invasive pavement friction (or “grip”) sensors. They use this data to determine when a safe grip factor is achieved.

They also use a storm severity index to better measure from storm to storm. Idaho’s Storm Severity Index uses three storm parameters to determine storm severity. Those parameters are maximum wind speed, maximum water equivalent layer, and surface temperature. Lower values indicate lighter storm events. The winter performance index is used to measure the effectiveness of roadway treatment to the specific severity of the storm. There are several references for Idaho’s approach, including:

- https://ops.fhwa.dot.gov/publications/fhwahop12046/rwm10_idaho1.htm
- ftp://dayweather.com/.../Idaho+Transportation+Dept+-+Bob+K..pptx

This approach requires grip sensors at RWIS stations. However, in the future, measure of pavement friction, the road coefficient of friction may be available. This is identified as a data element in the Basic Safety Message (BSM), Part 2. BSM Part 2 data elements are considered optional. Currently, there are no immediate plans to implement BSM Part 2, but it would be worth considering for future data to help in treatment decisions as well as for performance measurement purposes.

Ohio DOT uses a performance evaluation protocol known as SNIPE (Snow ‘N Ice Performance Evaluator). SNIPE measures the time for speeds to return to normal levels after a winter storm. RWIS data is used to determine when an event starts and stops. SNIPE also needs speed sensors to determine when speeds return to normal. Their goal is to recover speeds in 2 hours or less.

Connected vehicle data may be able to be used in the SNIPE system to determine speeds if enough vehicles are instrumented. It is also possible that the air temperature from connected vehicles would be useable in the SNIPE approach.

The concept of returning pavement friction to a less slick condition could also be useful, especially if connected vehicle data could be used to determine friction. Storm severity would be needed for this performance measure as well. Both the Idaho method of more directly measuring pavement slickness or the Ohio method of inferring pavement slickness from traffic speeds may be worth considering for a performance measure for winter operations. Identifying winter operations performance measures is an important aspect for the MDOT TSM&O program.

APPENDIX F – Advantages and Disadvantages of Different RWIS Pathways

Statewide Network of ESS Locations

Specifications

- Gridded network of fixed road weather data acquisition sites.
- Grid spacing of roughly 60 km (36mi), which would be accomplished by adding 5-10 new ESS sites in each of Bay, Metro, and University Regions.
- Acquire representative road weather conditions 30 – 40 km (18 – 24 miles) from the site.
- Acquire conditions at a limited number of locations that have adverse weather and/or road conditions that affect travel and/or maintenance.
- Road weather sensors measure representative values of:
  - Road temperature
  - Air temperature
  - Road condition
  - Dew point temperature
  - Subsurface temp profile
  - Relative humidity
  - Wind direction
  - Wind speed
  - Wind gust
  - Precipitation type
  - Precipitation intensity/rate
  - Visibility
- Optional road weather sensor measurements may include:
  - Grip/friction
  - Barometric pressure
- The site should include a multi-image camera to view road conditions and general weather conditions.

Primary Beneficiaries

- MDOT direct and contract highway maintenance personnel via:
  - Road weather forecasts and MDSS.
  - ESS road conditions and weather information.
  - Camera imagery.
- Weather service providers who use observations to improve weather and road condition forecasts and MDSS recommendations.
- Transportation services (traffic operations, state police, EMS).
- Travelers.

Advantages

- Data is available continually 7 X 24.
- Sites provide representative road weather data that meets NWS data quality standards.
- Sites provide representative road weather data that supports the forecasting process.
- Sites provide subsurface temperature not available via other RWIS services.
- Alert systems can trigger instantaneous alerts when observed ESS conditions reach preset criteria.
- Data can be used to support performance measures, especially as it's paired with MDSS.

Disadvantages

- Higher initial cost than other RWIS options.
- Only provides information at fixed locations.
- Average age of ESS observations is 15 minutes old when seen by user when viewed in MDSS.

Rationale

ESS sites provide a consistent set of observations continually whether MDOT vehicles are on the road or not. The instrumentation at the ESS sites provide accurate and reliable information regarding the state of the atmosphere and road conditions that can be used to support numerical weather predictions and road conditions. This numerical prediction technique allows models to extrapolate the conditions from the fixed sites to any location within MDOT's highway network and forms the basis for road and weather forecasts for specific MDOT routes.

Expand the MDOT Intelligent Fleet Network

Specifications

- A network of vehicles (either MDOT owned or vehicles contracted to maintain or monitor roads within the MDOT highway network) instrumented to collect road weather and maintenance information in near real time.
- At a minimum snow plows, should measure and report instantaneous values or average values over short travel distances of:
  - GPS location.
  - Air temperature.
  - Date/time.
  - Treatment application rate.
  - Vehicle speed.
- Optimally snow plows should report these additional parameters:
  - Road temperature.
  - Relative humidity.
  - Road condition.
  - Dew point temperature.
  - Grip.
  - Presence of precipitation.
  - CAN bus engine parameters.
  - Wiper operation
  - Headlamp switch position.
  - Observed precipitation type.
  - Observed precipitation rate.
  - Observed visibility.
  - Observed road condition.
  - Observed snow depth.
- Snow plows may also have a dash-mounted camera viewing road weather conditions
- Supervisor vehicles should carry instrumentation to measure and an interface to report all of the parameters listed in the two subsections above
- Data should be transmitted to a central site at a frequency of 10 minutes or less

Primary Beneficiaries

- MDOT maintenance personnel:
  - Through MDC website providing access to current and historical vehicle-reported data and onboard camera imagery
  - From MDSS road condition forecasts that integrate MDC road weather and treatment information from vehicle reports
  - Using summaries of treatment actions collected by MDC
  - By comparing MDSS recommendations versus actual material usage

- Weather service providers who use observations to improve weather and road condition forecasts and MDSS recommendations
- Traffic operations and EMS by knowing location and treatment activity of maintenance fleet
- Travelers and media through knowledge of the location of snowplows and their treatment activity

Advantages

- Lower initial cost than ESS.
- Detailed treatment rates via spreader controller:
  - To support MDSS
  - To log data for maintenance management
- Specific location of snow plows:
  - For maintenance planning.
  - To advise media and travelers.
- Trace of road conditions along vehicle route.
- Additional road weather data for current analyses of road weather parameters in support of forecasting:
  - Road condition.
  - Road temperature.
  - Air temperature.
  - Estimate of precipitation rates.
  - Driver observations of precipitation type, precipitation rate, visibility.

Disadvantages

- Data is only available when vehicles are on the roadway and data transmissions may be limited to times when the vehicle is involved in active maintenance practices
- Weather conditions around a snow plow during snow and ice control operations makes it difficult to accurately and reliably measure road weather conditions:
  - Road conditions – sensor gets caked with snow & slush.
  - Relative humidity and dew point are impacted by cloud of snow created by plow.
  - Precipitation intensity/rate is impacted by motion of vehicle and cloud of snow created by plow.
- Average age of MDC observations is 10 - 15 minutes old when seen by user and age tends to be variable due to poorer communications from some segments of highway.
- Standard techniques for integrating data from mobile sources into the existing fixed-base observation network have not been established.
- Ability to integrate with contract agencies is difficult at best. Complications are due to the actual contract along with outfitting of some vs. all vehicles, vehicle use off-trunk line.

Rationale:

Mobile data collection from MDOT vehicles provides two significant benefits to the road weather program, including a more detailed assessment of road conditions along a section of roadway, and an active record of the application of deicing materials. The collection of condition information along the roadway permits an assessment of variability of road conditions often associated with differential effects of cross winds and sheltering. This profile of road conditions supports winter maintenance responses and provides travelers with an indication of sections of roadway that are safety concerns. The collection of treatment actions creates a log of the spatial disbursement of materials and provides a mechanism to track the use of materials by event, shift, or for a route for a season.

Road weather data collected by active MDC units provides a continual report of a growing set of parameters. However, to date the integration of road weather data into the analyses that support weather and road condition forecasting has been limited. There are three dominant causes:

1. Measurement devices that report values that do not meet acceptable specifications for accuracy and reliability
2. The lack of a standard procedure to integrate mobile measurements into the standard analysis scheme used by weather service providers
3. The environment around snow plows performing winter maintenance varies from the ambient conditions along the highway

Measured data collected from supervisor's trucks tends to be more representative of actual road weather conditions. And reported observations of precipitation, visibility, snow cover, and road conditions are beneficial in the analysis routines, though the reporting interval is irregular and intermittent. Thus, it would be advisable to consider assets that do not have a negative impact to sensing of near real-time weather conditions.

Recent advances in RWIS instrumentation for vehicles offers the potential to eliminate data deficiencies identified above over time. The continual measurement of road temperatures and road conditions can now be done with IR sensors. The latest suite of MDC sensors now includes a sensor to record relative humidity and air temperature and generate dew point temperature. Recently, auto manufacturers began integrating a sensor to monitor precipitation on the windshield to adjust wiper frequency. This technique holds promise as a continuous monitor of precipitation intensity. However, techniques will be needed to reduce the effects of road spray and plow-induced snow. Sensor manufacturers are testing techniques to measure wind conditions and subtract the influence of vehicle speed. It is likely that there will be MDC road weather packages available in a couple of years that can provide road weather data that meets performance specifications, however, the cost of this package will also increase substantially.

Integrate Existing Commercial Mobile Data

Specifications

- A network of commercial vehicles instrumented to collect road weather and CAN bus information critical to the safety, operation, and management of trucking fleets.
- Weather Telematics is currently the only third party mobile data provider approved by the NWS.
- The system has a sensing component located 3 to 4 meters above the road surface that acquires and transmits these weather parameters:
  - Air temperature.
  - Relative humidity.
  - Dew point temperature.
  - Presence of precipitation.

- Light intensity.
  - Barometric pressure.
  - Ozone concentration.
- The system has a sensing element located on the underbody of the truck approximately one meter above the road surface that acquires and transmits the road temperature.
- The system acquires and transmits these truck-related parameters:
  - Time.
  - GPS location parameters.
  - Vehicle speed.
  - Journey time.
  - Weather-related vehicle diagnostics.
  - Anti-lock brake information.
  - Wheel slip.
- The processing controller can integrate other devices such as an in-cab camera.
- The data from the mobile source is provided to the NWS and is available to weather service providers under contract.
- High density data is available along most Interstates and heavily trafficked state and federal highways; more sporadic data is available along low volume delivery routes.

Primary Beneficiaries

- Trucking firms that have their fleets instrumented.
- Weather service providers who integrate these observations into their analysis to improve weather and road condition forecasts.
- Any stakeholder that needs high resolution weather and/or pavement temperature information.

Advantages

- No expenditure needed for instrumentation since the data are collected by commercial vehicles.
- Detailed weather and road temperature information especially along major trucking routes.
- A continuous stream of mobile data on a 7 X 24 basis on the major trucking routes.
- The use of a quality checking system that is approved by the NWS.

Disadvantages

- No road condition data, although Weather Telematics uses a proprietary algorithm to estimate the potential for black ice
- Current sensors cannot determine conditions that cause reduction in friction, such as compacted snow, refreeze, frost, hydroplaning
- Average age of the 3rd party observations is not currently known but estimated at around 10 minutes
- Suite of observed data is only partially useful as background information in the support of road weather forecasting

Rationale:

Mobile data collection from commercial vehicles provides a data source that has characteristics like that of the MDC and CV programs. The commercial data comes from vehicles owned by trucking firms that are instrumented with a uniform set of instrumentation. This configuration is similar to the MDC setup and the atmospheric and CAN bus data are essentially the same. The two significant differences are:

- MDC vehicles collect road condition states and treatment application data and the commercial vehicles do not
- DOTs own the MDC assets whereas the trucking companies own the assets installed on the commercial vehicles

The data set of the commercial vehicle program is basically the same as the data planned for the CV Program except for some CAN bus parameters that the trucking firms desire for fleet management. In addition, it is anticipated that the data collection, integration, and dissemination of composite displays within the vehicle to infrastructure (V2I) component of the CV Program will occur in roughly the same time frame as that of the commercial vehicle program. Thus, the only significant difference between the commercial and CV programs is ownership of the on-vehicle instrumentation.

It is anticipated that the only cost to MDOT for access to the commercial data would be a service fee for use of the data collected by the commercial vehicle vendor. Currently, MDOT users have access to MDC data via the MDC data collection vendor and their weather service provider. The most probable approach to the acquisition of the commercial data would be to integrate the commercial vehicle data with the MDC data on MDSS (weather service provider's site). Then depending upon contractual agreements regarding access to the commercial vehicle data, it might be advantageous to make the raw commercial vehicle data directly available to MDOT personnel.

Since the commercial vehicle information has the same basic format as the projected CV data set, there is a strong argument to integrate this program into the RWIS strategy to gain experience with the data and data acquisition programs as a precursor to the implementation of the CV program in Michigan.

Support the Expansion and Integration of Data from the Connected Vehicle Program

Specifications

- A network of privately-owned vehicles (POV) instrumented to collect road weather and CAN bus information critical to the safety and mobility of the all vehicles operating on MDOT's highway infrastructure.
- Owners of POV will be the owners of the instrumentation that will provide road weather data.
- It is likely that most of the instrumentation will be integrated into new vehicles by the manufacturers and these devices will need to meet government standards.
- It is reasonable to expect that after-market vendors may also provide the road weather instrumentation.
- The CV Program is developing to provide V2V communications and V2I communications.
- V2I data transfer will occur in a time frame similar to MDC and the commercial vehicle programs.
- V2V data transfer will occur nearly instantaneously using short range communications techniques.
- The CV Program is in the transition stage from research to an operational deployment.
- The system has sensors located on or within the body of the vehicle that will acquire and transmit these road weather parameters:
  - Air temperature.
  - Relative humidity.
  - Dew point temperature.
  - Presence of precipitation
  - Light intensity.
  - Barometric pressure

- Road temperature.
- Road condition
- ABS status.
- Traction status
- Other CAN bus parameters.

- In addition, the vehicle controller must acquire and transmit:
  - Time
  - GPS location
  - Vehicle speed

- And the processing controller may be able to integrate other devices such as a dash cam.
- Data acquisition will occur at fixed points along a highway segment by sampling observations from multiple vehicles and statistically averaging the values over a defined period of time.
- This sampling technique will provide a dense network of observations that will easily integrate into the existing current road weather analysis scheme.

Primary Beneficiaries

- Travelers are provided near-real time data for weather alerts directly in their vehicle.
- Weather service providers who integrate these observations into their analysis to improve weather and road condition forecasts.
- Any stakeholder that needs high resolution weather and/or pavement temperature information.

Advantages

- No expenditure needed for instrumentation
- Detailed weather and road temperature information especially along highways with moderate to high AADT
- A continuous stream of mobile data on a 7 X 24 basis
- Nearly instantaneous exchange of road weather parameters critical to the safety of surrounding or approaching vehicles

Disadvantages

- No method to assure quality data from all instrumented vehicles.
- The need for the development of a technique to assess data quality and eliminate observations that are obviously errant.

Rationale

The framework for the deployment of the CV Program is relatively well established; however, the details in assuring that the program performs per the program planning will occur in evolving stages. It is anticipated that market forces and developments in communications will impact how the CV deployment occurs. In addition, it is likely that advances in instrumentation design will modify and/or improve the road weather data set that becomes part of the CV package.

The biggest challenge of the CV Program will be the implementation of techniques to assure data quality. New POVs will be delivered with the necessary instrumentation to meet CV specifications for the manufacturing year. But once the vehicle is purchased users have no incentive to keep the CV instrumentation performing within specification guidelines. Thus, it will become the responsibility of the data acquisition system to quality check each observation prior to accepting the observation and integrating it into data analyses or advisory messages in the V2V program.

MDOT could receive the CV data, through the basic safety message #2 (BSM2) and process it internally, including performing the quality checks. An alternative is for MDOT to purchase the CV data stream from a third-party aggregator who would perform the quality checks. MDOT as a statewide effort to provide an additional means of safety messaging, is deploying RSU infrastructure at signalized intersections to provide Signal Phase and Timing (SPAT) data to vehicles capable of receiving the information for intersection related safety applications.

Due to data quality concerns, the value of the CV program will require the deployment of an undefined number of instrumented vehicles. The generation of data with an acceptable level of quality will require a statistical averaging algorithm requiring observations from a minimum number of vehicles in a specified amount of time. The vehicle sample size and time-period are not well defined yet. It is likely that the CV program will achieve the necessary data quality requirements first in urban areas and then require the deployment of a significantly larger number of vehicles to permit use of the data from rural locations. The deployment rate of CVs is purely an estimate at this time as is an estimate of the number of vehicles it will take to acquire an adequate sample of observations per unit time; however, it is likely that it may take 3 to 5 years before CV data becomes a viable data source. However, once the necessary vehicle density is achieved, the data acquired from this network of observations will significantly improve the analyses of transportation-critical parameters such as precipitation patterns, road conditions, and areas where traction issues are likely to impact safety.

In summary, the existing approach to emphasize the support of MDOT maintenance forces through access to road weather observations and forecasting tools will benefit particularly from the deployment of additional ESS sites distributed as evenly as possible throughout the state of Michigan. ESS sites located in areas void of existing observation weather facilities will provide the most value to the general forecasting performance. The benefit of additional ESS sites is particularly important for tactical, strategic, and planning forecasts.

However, where stakeholder's needs focus more on short term guidance or exclusively on near-term road conditions or weather-related events that adversely impact road conditions, the implementation of a fleet of vehicles instrumented with mobile data collection units becomes more advantageous. This implies that persistence and imminent road weather forecasts would benefit more from an expansion of a MDOT CV network.

In addition, the evolution of the nascent CV Program for individually owned vehicles will eventually supplement the data from the MDOT intelligent vehicle program and may reduce the need to deploy and maintain devices on some portion of the MDOT maintenance fleet.

APPENDIX G – System Capability Assessment

MDOT's RWIS program is no longer a simple system approach but a "system of systems" solution that encompasses a broad spectrum of capabilities that have their own unique development and support requirements. MDOT has had active involvement in all the transportation support programs, but each system evolved independently of the others and was typically managed by different divisions within MDOT. One of the key steps MDOT has taken to support data use for alternate applications such as enhancing traveler information, is the integration of road weather related advisories from DUAP. This is a huge step towards an efficient exchange of information needed to serve the variety of current DOT operational requirements and lays the foundation for future programs and the development of a cohesive exchange of data that can be shared to more effectively solve transportation issues for all stakeholders.

MDOT recognizes that maintaining and operating multiple systems to perform a variety of functions can be costly and complex, especially when there are overlapping features between systems. To help assess the capabilities of the key data systems that support RWIS, the table below was developed to provide a side-by-side comparison of key requirements. Key requirements for the system capability are listed below and used as the criteria.

RWIS Systems Capabilities	**MDSS**	**ATMS**	**DUAP**	**CMS**
Assess current road and weather conditions using observations	YES	YES – through DUAP	YES	YES
Data ingest from:				
National Weather Service (NWS)	YES	TBD	YES	YES
Automated Weather Observing System (AWOS)	YES	TBD	YES	YES
Automated Surface Observing System (ASOS)	YES	TBD	YES	YES
MDOT ESS	YES	YES	YES	YES
Data feed to MADIS	YES		YES	YES
Data feed to Mi Drive	TBD	YES	YES	YES
WxTINFO Capable	NO	YES – through DUAP	YES	NO
Provide time- and location-specific weather forecasts along transportation routes	YES	TBD	TBD	YES, but not currently required
Predict how road conditions would change due to forecasted weather and the application of several candidate road maintenance treatments	YES	NO	TBD	**NO**
Notify state agencies of approaching conditions	YES	??	TBD	**NO**
suggest optimal maintenance treatments that can be achieved with resources available to the transportation agencies	YES	NO	TBD	**NO**
Evaluate predictions reliability & maintenance treatment effectiveness for roads & weather conditions to improve decision support	YES	NO	TBD	**NO**
Data Storage Location	Centralized – On Consultant's Hardware	Centralized TMC / TOC Server	Centralized - On Consultant's Hardware	Centralized – On Consultant's Hardware
System Availability	24/7/365	24/7/365	24/7/365	24/7/365
Simultaneous Users	YES – how many?	YES – how many?	YES – how many?	90
Ability to exchange data with other systems / servers	?? YES, MDOT **ATMS** MDOT **DUAP** DOT **TMC / TOC** 3rd party MSP	YES, MDOT **DUAP** **CMS** DOT **TMC / TOC** 3rd party MSP	YES, MDOT IMOs & Snow plows DOT **TMC / TOC** 3rd party MSP RITIS	YES, MDOT **ATMS** **MDSS** (ITERIS) DOT **TMC / TOC** 3rd party MSP NTCIP MIB
Data Archiving for 12 months?	TBD	TBD	YES	YES - All data including CCTV video Archived monthly for 12 months
Access to system from web-based login	YES	NO?	YES	YES
NTCIP Data Collection Capabilities	YES	YES	YES	All Data - Up to 150 ESS stations
Camera image Collection	Yes – through DUAP & ATMS	YES	YES	YES
Ability to ingest traffic data	TBD	YES	YES	YES

Conclusions & Recommendations:

The support systems for MDOT's RWIS program are driven by three core functions:

- Data Use Analysis and Processing – The ability to ingest weather data from a variety of sources including fixed, mobile, connected vehicle and 3rd parties, the ability to display graphically historical information, the ability to analyze and process the data in to a format that can be used for decision making and or/performance monitoring
- Maintenance Decision Support – The ability to ingest weather data from a variety of sources to provide maintenance staff a tactical, strategic, or planning weather forecast, the ability to provide recommendations for treatment, and assist track usage of materials for maintaining the roadway.
- Weather Responsive Traffic Management –The ability to ingest weather data from a centralized platform to allow for weather responsive management, the ability to provide recommended weather messaging to the traffic operations

Each of these core functions provide MDOT stakeholders different degrees of information and allow the end users to utilize the information based on their respective responsibilities. It is recommended that MDOT maintain systems that support these three core functions. The table shown above identifies where there are key overlaps between the systems that support the RWIS program. Many of the unique features that are required for each core function can be developed by one or more platforms. However, this development would be considered a custom solution and that is often not the preferred platform to support the functions. For example, it is possible that MDOT's DUAP system provide MDSS capability, however, the sophistication of the MDSS platform may not be readily found even if developed by MDOT's DUAP partner. Thus, it is recommended to maintain systems that provide core functions at the level of sophistication that MDOT has grown accustom to.

The Central Management System is the only platform that is not providing the level of sophistication necessary to support MDOT's core functions described above. The CMS platform does provide users a graphical user interface to support view of near real-time and historical weather information (including camera imagery). However, this exact information can be made available to users from MDOT's DUAP system essentially negating the value of the CMS. MDOT's DUAP provides a degree of sophistication of processing weather related information and forecasts to provide motorist advisory warnings. This type of processing is not typically found in a CMS product on the market. It should be noted that the CMS platform is contracted within MDOT in conjunction with the equipment maintenance contract. While there are some advantages to this, MDOT may consider separating equipment maintenance from the head-end integration/hosting platform similar to the remainder of the ITS program where the ATMS platform is separated from the contracting of the ITS field maintenance.