MDOT
Michigan Department of Transportation

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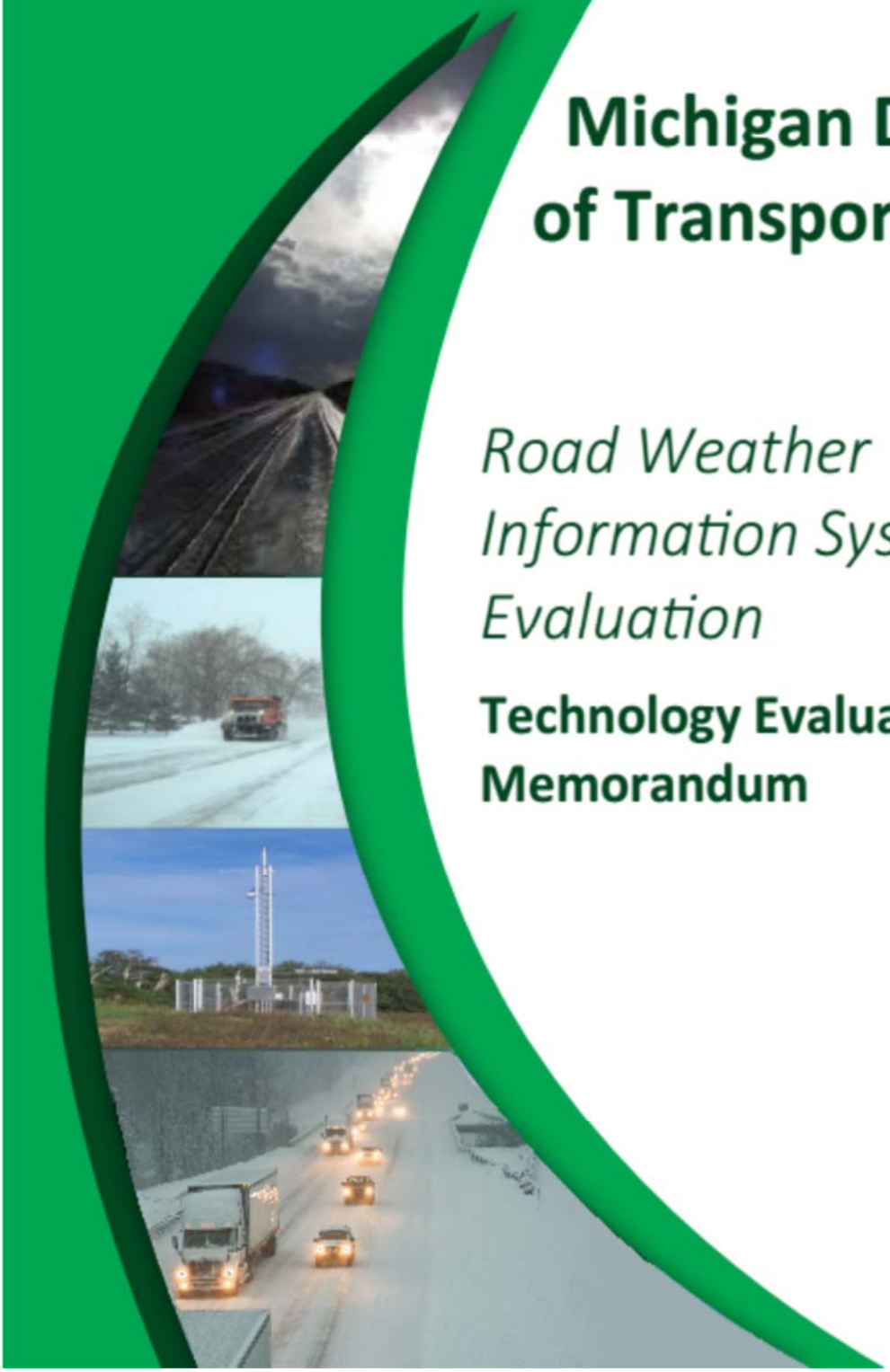

Michigan Department of Transportation

Road Weather Information System (RWIS) Evaluation

Technology Evaluation Memorandum

December 2013

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1.0 PROJECT OVERVIEW

The Michigan Department of Transportation (MDOT) has embarked on a statewide evaluation aimed at evaluating the statewide road weather program. The purpose of this project is to take a comprehensive statewide look at existing and planned deployments of weather resources, summarize best practices from around North America, and evaluate new technologies or trends that may enhance the RWIS program. As a result of these tasks, a "stepped" deployment plan will be developed that identifies short term and long term initiatives MDOT should focus their resources on to maximize benefit from their Road Weather Information System (RWIS) program.

1.1 Technology Evaluation

This technology evaluation document is intended to identify existing and emerging technologies that could potentially be used as components of a comprehensive RWIS program for the Michigan DOT. The RWIS program is intended to meet the needs of MDOT staff and other potential users of the system as identified in the existing system evaluation conducted in Task 3.0. The requirements derived from MDOT users in Task 3.0 provides a basis for evaluating how the RWIS programs within other states and provinces can serve as a guide for the ongoing road weather support program in Michigan. The technologies evaluated in this document were identified as having the potential to meet MDOT needs in the best practices effort in Task 2. The best practices review included a literature review, web searches, and interviews with staff from 20 states and provinces that have program elements or program needs similar to those in Michigan.

The technology evaluation matches technologies identified with system needs. It includes an assessment of how well the identified technologies will meet MDOT's RWIS needs. It is almost certain the best path forward for MDOT will include implementing a variety of different technologies and integrating them within the existing RWIS program. This evaluation was developed with this in mind.

Section 2 of this document covers weather sensors and Environmental Sensor Station (ESS) instrumentation. Section 3 discusses next generation RWIS technologies. Section 4 describes new applications and techniques in the RWIS arena that are relevant to MDOT's needs. Section 5 provides the assessment of these technologies, primarily in the form of a matrix. Finally, Section 6 provides a discussion of next steps in the project.

2.0 ESTABLISHED WEATHER RESOURCES

MDOT's RWIS program will likely continue to include fixed environmental sensor stations. There are a number of technological advances in sensors, as well as some alternative ways to get the same information that these sensors provide. This section will present advances in technologies and new sensors that may make the MDOT program more efficient or that will provide more accuracy in the data collected.

2.1 Environmental Sensor Station

A RWIS ESS site is a configuration of sensors, data processors, and communications interfaces designed to collect atmospheric, pavement, traffic, soil, environmental, and/or hydrological information within a DOT right of way. ESS units are typically permanent structures, although the base configuration may be placed on a mobile platform and moved to a designated location to address specific temporary requirements. Historically most ESS configurations to support winter maintenance were designed with a specific suite of sensors (vis-à-vis, standard ESS), but the set of sensors may vary depending upon the unique needs of the agency "owning' the ESS site. Where the full complement of instrumentation is not needed, DOTs can deploy a 'partial ESS'. Additionally, standard ESS sites may contain optional sensors to monitor conditions unique to a specific site or expand the capability of the standard site to capture a broader spectrum of road weather information. ESS sites operate continually and provide a steady stream of information critical to support the DOT decision processes for maintenance, traffic, or environmental requirements.

2.1.1 Standard ESS Instrumentation

The set of instruments found on a classic ESS configuration to support winter maintenance activities may consist of all or some the following:

- Air Temperature/Relative Humidity Sensor – provides air temperature and relative humidity from which the dew point temperature is derived by the processing unit,
- Wind Sensor – measures horizontal wind speed, wind direction, and gusts,
- Precipitation Sensor (ESS sites contain one of the following sensor types)
    - Y/N – measures the presence or absence of precipitation,
    - Weather identifier – measures the precipitation type (rain, drizzle, snow, sleet, freezing rain, hail), quantity, and intensity using optical and/or radar technologies,
    - Weather identifier and visibility – measures precipitation type, intensity, and quantity plus visibility,
    - Rain gauge – measures the quantity of precipitation
- Surface Sensor (ESS sites contain one or more of the surface sensor types)
    - Passive in-pavement sensor – provides a reading of pavement temperature, surface conditions, and estimates of chemical concentration,
    - Active in-pavement sensor – provides freeze point temperature, surface condition, and estimates of chemical concentration,
    - Non-intrusive pavement sensor – measures pavement temperature, surface condition, composition of the snow, ice, and liquid components and their depth, and infers grip index,
    - Thermistor – measures pavement temperature
- Subsurface Sensor – measures temperatures below the pavement; may measure temperature at one or multiple depths,
- Processing unit – routinely polls RWIS sensors, converts sensor output to digital values, and communicates the data to a central server

2.1.2 Optional Instrumentation for Standard ESS

Agencies may opt to include several additional sensors to meet specific needs or interests within the DOT. These may include:

- Barometric Pressure Sensor – provides the atmospheric pressure at the site measured as station pressure; the device is also known in aviation as an altimeter.,
- Visibility Sensor - measures atmospheric visibility by determining the amount of light scattered within an optical sample volume by lithometeors (e.g., smoke, dust, haze) or hydrometeors (fog, rain, snow) in the air,
- Solar Radiation Sensor – measures the flux of incoming solar radiation,
- Net Radiometer – measures the upward and downward flux of radiation in the infrared spectrum,
- Snow Depth Sensor – measures the depth of snow using sonic energy,
- IP Surveillance System (CCTV) – used to visually monitor the site, road condition, and traffic
    - Fixed image cameras,
    - Pan, tilt, zoom (PTZ) cameras
- Traffic Monitoring Devices
    - In-pavement sensors – provides traffic speed and traffic volume per configured lane,
    - Microwave vehicle detection system (MVDS) – radar-based system provides an accurate reading of traffic speed, vehicle type (cars or trucks), and traffic volumes per configured lane

2.1.3 Partial ESS Instrumentation

In certain situations an agency has a specific requirement to monitor one or two conditions and the investment in the full complement of instrumentation within the Standard ESS Instrumentation package is not necessary or desirable. These partial configurations that employ a subset of the standard ESS and an RWIS processing unit are designated "partial ESS" designs. Partial systems may contain any selection of standard or optional sensors in a configuration different from the standard package. Typical partial instrument package types in use include:

- Pavement condition monitoring sites that use surrogate atmospheric observations from other ESS sites
- Visibility monitoring locations
- Camera installations
- Hydrologic monitors for stream depth and flooding
- A processing unit to transmit data to a central server in NTCIP format.

2.1.4 Mobile ESS Sites

Several DOTs have found it useful to design and build ESS configurations that are not permanently installed at a specific field site. Classic, stationary ESS installations usually use 10 to 30 foot towers to support the instrumentation with the tower affixed to a concrete pedestal. In addition, these classic installations used in-pavement pavement sensors, which required buried cables from their installation position to the ESS processing unit. The mobile ESS configurations were designed in two separate formats:

- ESS configuration containing atmospheric sensors, possibly a camera, and the processing unit mounted on mobile platform that could be physically moved to a site; these processor could be connected to a wireless in-pavement sensor, cabled sensor, or a non-intrusive unit installed nearby,
- ESS configuration of desired sensors placed upon a post or structure that could be easily removed and installed elsewhere; augured poles are commonly used and the instruments and design permits quick installation of the individual sensors on the pole or support structure

2.1.5 Mobile Data Collection

Vehicle location tracking had its roots in the 1970s with the implementation of Long Range Navigation (LORAN) technology. Public use of Global Positioning Service (GPS) technology in the 1990s augmented the development of Automatic Vehicle Location (AVL) equipment and services. During the period from 2003 to 2005 vendors developed data processing units for DOT vehicles that integrated AVL capabilities with Mobile Data Collection (MDC) units containing logic to collect and transmit road weather data from the vehicle. Subsequently, many transportation agencies in the U.S have installed MDC/AVL devices on vehicles within their fleet vehicles to monitor such parameters as location, vehicle performance characteristics, maintenance and/or treatment actions, and observed conditions. Fleet vehicles can include snowplows, courtesy patrol, maintenance trucks, and pool vehicles that are used by DOT personnel. Specific configurations of mobile monitoring devices have been implemented to collect information from these mobile devices to supplement RWIS programs. This established weather resource is constantly going through changes as new technology enhances the capabilities of the mobile data collection platform. Within the last few years, MDC applications have become more reliable and a more prominent support tool for a number of agencies, but remain an evolving technology. Therefore a more thorough discussion of MDC/AVL is covered in the Next Generation Technology section 3.3.

2.2 Characteristics of Standard ESS Sensors

This section provides an overview of Standard RWIS ESS sensors that are available today and notable changes in technology or detection/collection methods.

Traditional ESS sites include several key categories for obtaining weather information. These include atmospheric sensors, pavement sensors and sub-surface sensors. With the advancements in technology, these sensors have evolved and provided a vast array of information that is useful to the end user. The section below describes the various types of data that is available with each category of instrumentation and products that are currently available in market to support this function.

2.2.1 Atmospheric Sensors

Atmospheric instruments at an ESS site typically include an air temperature/relative humidity sensor, a wind speed sensor, and a precipitation sensor. Some states have opted to include a barometric pressure sensor, a visibility sensor, a snow depth sensor, and occasionally radiation flux sensors. In special situations agencies have included water depth sensors and sensors to capture gaseous concentrations such as carbon monoxide.

2.2.1.1 Wind Sensors

Early in the development of RWIS all of the wind sensors were propeller-type sensors. This type of sensor performed well as long as the bearings were replaced at least once a year or more in high wind locations. They also had a tendency to ice up during freezing rain situations. Once ultrasonic sensors became price competitive, they began to replace the propeller anemometers. The advantage of the ultrasonic sensors is no moving parts and resistance to icing when heated. Servicing costs are considerably less as well. Ultrasonic sensors are currently in place in Michigan and are being deployed as part of all new installations. Wind sensors are typically mounted at the top of the support structure. The original RWIS siting guidelines specified a height of 30 feet to meet World Meteorological Organization (WMO) specifications developed to support the aviation industry and weather community. These guidelines have become more relaxed, partially because most ESS sites in DOT right-of-ways do not provide the necessary site requirements for an unobstructed wind flow field also mandated by the WMO specifications. Some agencies are moving to all-in-one sensor systems where all of the standard ESS sensors are packaged in a single unit which is typically mounted on a structure more commonly around 10 feet in height. These combined packages are less expensive than procuring the individual sensors independently and include an integrated ultrasonic sensor. Other than these changes there does not appear to be a major shift in the way the industry determines wind speed/direction that would provide a more accurate and reliable output.

2.2.1.2 Air Temperature and Relative Humidity

Air temperature and relative humidity sensors are used in combination to determine the ambient air temperature and the amount of moisture in the atmosphere. The key parameter derived from an air temperature/RH sensor is the dew point temperature, which when used with pavement temperature is a critical factor in determining the potential for frost and dew at an ESS location. The sensor itself is composed of a shielded thermistor to measure air temperature and a moisture sensitive material to measure relative humidity. Devices to measure dew point temperature directly are very expensive and have never been used in ESS configurations. Human hair was used to measure relative humidity in early installations, but these have been almost totally replaced by sensors that use capacitance sensors. Capacitance sensors are less expensive, more compact, and function with minimal maintenance. The one limitation of capacitance solutions over hair is their slight degradation in humidity measurement accuracy at high humidity values (90 – 100%). The air temperature/RH probes are installed inside a radiation shield that protects the measuring devices from solar radiation and precipitation. Still moisture can condense on the protective cover of the moisture probe inside the radiation shield, thus a technique is used to heat the moisture probes to eliminate the moisture and thus any errant readings. Air temperature/RH sensors are normally mounted on the ESS tower or pole at eye level.

Air temperature sensors have become a common sensing device on newer personal vehicles and many DOT fleet vehicles. The growing interest in the Connected Vehicle program and DOT mobile data collection applications have created considerable interest in the accuracy and reliability of temperature probes in a mobile environment. Air temperature measurements on DOT fleet vehicles are commonly done with an externally mounted sensor attached to the mirror bracket assembly. The sensor is reasonably protected from the harsh environment that commonly surrounds maintenance vehicles and provides a relatively accurate air temperature reading. Air temperature sensors integrated into personal vehicles are mounted on the backside of the front bumper or forward edge of the engine compartment. The air temperature sensors are prone to heat from the body or engine when the vehicle is standing still or moving slowly. Currently there is no standard specification for air temperature sensors and there is no specification for testing the temperature sensing devices or servicing the units. Research organizations, such as the National Center for Atmospheric Research (NCAR), recognize this accuracy limitation and have proposed using multiple inputs over a period of time and averaging the air temperature values. Nevertheless, vehicle mounted air temperature sensors appear to be a major trend in the way air temperature data will be collected in mobile applications.

Within the last year a mobile road condition package that incorporates separate relative humidity and air temperature sensors along with their mobile road condition monitoring sensor. The output from these devices allows the mobile road condition system to provide air temperature, relative humidity, and dew point temperature as continuous values along a highway. It is highly likely that other vendors in the industry will introduce similar solutions and that relative humidity and dew point temperatures will become a common output from DOT mobile platforms. If the automotive industry finds value in capturing pavement temperature as a safety resource for drivers, it is probable that they would also integrate an RH sensor to support a frost warning/advisory system to alert drivers of possible frost conditions.

2.2.1.3 Precipitation

Precipitation sensors are one of the most valuable sensors needed for an ESS. In the original RWIS configuration all that was needed was a sensor that sensed the presence or absence of precipitation to support the pavement condition algorithm. This is why there are so many Y/N sensors in existing configurations. The need for better precipitation information led to the integration of a present weather identifier and visibility sensor. These optical 'present weather' sensors output the type of precipitation, its rate/intensity, accumulation and visibility (depending on sensor). The sensors performed well if their lenses were kept clean. However, winter highway environments become infused with salt spray as traffic moves through the slush and residual layer of deiced water. Therefore, the lenses of the weather

Figure 2-1: Doppler Radar Precipitation Sensor

identification sensors need to be cleaned regularly. Recently, a radar based present weather sensor was introduced into the market that is not affected by the salt spray environment.

Typically, precipitation sensors are mounted on the tower or pole above the location of the air temperature/RH sensor on a horizontal strut a couple of feet away from the tower to limit wind turbulence at the sensor's position. If a propeller-type wind sensor is mounted on the top of the support structure, the doppler sensor also has to be mounted at this height or higher to avoid interference with the radar signal. Both the optical and radar-based sensors provide accurate estimates of the precipitation type and intensity during normal precipitation events if serviced on a regular basis. Both sensors exhibit a tendency to overestimate the amount of precipitation when wind speeds are in excess of 30 mph due to turbulence that impacts the rate of fall of snow or water droplets.

2.2.2 Pavement Sensors

The road weather community uses pavements sensors to provide the pavement temperature, the road condition, and the amount of chemical in the surface layer at given location. A number of different sensor solutions have been developed to obtain pavement information.

2.2.2.1 Passive Pavement Temperature & Condition

Passive pavement condition sensors are considered invasive sensors since they are physically installed in the highway pavement. This requires a saw cut in the pavement for the sensor and the cable that carries the sensor output from the sensor to the ESS controller. The sensors are placed in the cut made in the pavement, leveled, and permanently secured in position with epoxy. They are typically implanted into the pavement on the outside edge of the wheel track closest to the shoulder. For the driving lane this is the right wheel track and for the passing lane it is the left wheel track. The sensors are designated as passive sensors because their measurement technique does not change the chemical or thermal conditions of the layer of snow, ice, water, and chemical they are measuring. These sensors output pavement temperature, pavement condition status (dry, wet, trace moisture, etc), the chemical concentration, and factors derived from surface condition and chemical concentration. The chemical concentration is measured using the conductivity of ions in the aqueous component of the surface layer. Since different chemicals have different rates of conductivity for different concentrations of the chemical, the type of chemical normally used must be set for each sensor. If a different type of chemical is used in treatment of the road, the chemical concentration values are no longer correct. The passive pavement condition sensors have been the most commonly used way to collect pavement data.

2.2.2.2 Active Pavement Temperature & Condition

Active pavement sensors heat and cool the mixture of snow, ice, water, and chemical back and forth through the freeze point of the mixture. There is a thermal energy jump or reduction during the initiation of thawing or start of freezing that an active sensor picks up. The temperature at which the heat energy change occurs is the freeze point temperature. The freeze point temperature is measured accurately regardless of the type of chemical used as the antifreeze agent. The sensors are considered active because they are changing the composition of the layer of snow, ice, water, and chemical they are measuring. Because active sensors heat and cool the surface of the sensor, they cannot measure the pavement temperature. Therefore, active sensors are coupled with a passive sensor, which measures the pavement temperature. The only parameter measured by an active sensor is the freeze point temperature, but when this freeze point is coupled with the pavement temperature, the ESS controller can use the combined input from the two sensors to provide a good estimate of the chemical characteristics of the surface layer (percentage of ice and chemical concentration) and the surface condition. Active sensors are installed in the pavement using techniques similar to passive sensors. Active sensors are used along with passive sensors on fixed automated spray technology (FAST) systems to trigger hydraulic delivery of a chemical antifreeze agent when the pavement temperature and freeze point temperature indicate imminent freezing of the layer.

Passive and active sensors were introduced in the 1980s. Pavement sensor manufacturers have made minor adjustments in sensor features since their initial introduction, but there haven't been substantive advancements in technology since the sensors were first introduced.

2.2.2.3 Non-Invasive Pavement Temperature & Condition

Non-invasive sensors use infrared optics to determine pavement temperature and the amount of snow, ice, and water on top of the pavement. The water molecule absorbs IR energy differently when it occurs as water, ice, or snow. The non-intrusive sensor uses this feature to measure the amount of energy in specific wavelengths and uses the energy levels in these wavelength bands to determine the depth of snow, ice, and water in the surface layer. The non-intrusive sensors also measure the amount radiation in the full IR spectrum to determine the temperature of the top surface of the pavement or the top of the layer of snow, ice, and water on the pavement. Based upon the proportion of snow, ice, and water plus the surface temperature, the sensor provides an assessment of the surface condition and level of grip a motorist would experience driving on the surface. The higher the grip value, the more traction a vehicle will get during wet or icy conditions. Some vendors have also used the depth information to estimate the ice percentage in water and the freeze point of the water.

Figure 2-2: Non-Invasive Pavement Sensor

Non-invasive sensors need to "view" the pavement from an oblique angle that may vary from about 30° to 85° from horizontal and must be no more that 45 feet from the desired measurement area. For many ESS sites the existing or proposed location of the ESS support structure will not allow a non-intrusive sensor to be positioned on the ESS tower or pole. The sensor may need its own support structure or may be placed on existing structures such as DMS, signs, or poles used for other DOT requirements. The sensor is coupled to a controller separate from the ESS controller, which needs its own source of power. The data from the pavement condition controller can easily be transferred to the ESS control and become part of the normal NTCIP data transmission from the ESS site. Or the sensor can function as an independent partial ESS site. The image to the right of this section shows a non-intrusive pavement condition sensor on the left strut and a present weather sensor on the right strut, each with its own controller at the base of the support structure.

Non-intrusive sensors are cost comparable to invasive sensors over a 10-year window. The initial investment is higher than invasive sensors, but non-invasive sensors have lower maintenance requirements. Invasive sensors if not affected by human actions (road construction, cable cuts due to trenching, plow damage), can last more than 10 years, however due to frequent roadway maintenance, sensors implanted in the roadway typically have a lifetime less than 10 years.

The technology for non-invasive sensors was recently converted for use on a mobile platform. This device is being used as part of several on-going research efforts for data collection from vehicles. The output from the mobile non-intrusive sensor includes the time, GPS location, and pavement condition. When coupled with a pavement temperature sensor and an air temperature/RH sensor, a road condition sensing package reports time, location, pavement condition, pavement temperature, air temperature, and dew point temperature as a continuous stream of discrete observations. The mobile sensor systems have performed well when attached to light-duty vehicles, but struggle in the harsh environment that surrounds snowplows during plowing operations. MDOT may consider using non-invasive technology on existing or proposed ITS infrastructure to enhance pavement temperature and condition coverage in urban settings where data is not readily available.

2.3 Established Weather Resources Summary

Table 2-1 summarizes new technologies and applications that can provide improvements to established weather resources. These technologies and applications can be used to meet some of MDOT's needs that were identified during the evaluation of the existing system.

Table 2-1: Summary of Potential Improvements to Established Weather Resources

Technology or Application Advancement	Relevance to MDOT RWIS Program	Function	Available on MDOT's System
Vehicle mounted air temperature Sensors	Identified need for improving mobile observations.	Mobile air temperature data points	Yes – data is being collected as part of the statewide AVL contract.
Highly accurate precipitation sensor	Identified need for start/end to precipitation event for performance monitoring	Accurate precipitation using doppler technology	Yes – available at limited locations in Superior Region.
Non-Invasive Pavement Sensors	Identified need for determining grip values	Non-invasive sensor provides road temperature, condition and grip value	Yes – limited deployment in Superior, Metro and North regions.
Partial ESS	Identified need to target high focus areas	Ability to deploy limited number of sensors with a RPU	Yes – limited deployment in Superior and Metro regions.
Mobile ESS	Identified need to set up temporary observation sites	Ability to move ESS units to specific locations for temporary requirements	No
Mobile Data Acquisition	Identified need to enhance mobile observations from DOT vehicles	Ability to obtain weather data and AVL information from mobile data points	Yes – data to be available as part of the AVL contract.

In general, the new technologies presented in this section are known in MDOT and are in use in some areas within Michigan. For example, the Metro Region has implemented non-invasive sensors. The next step for MDOT is to determine where these new technologies should be implemented, under what conditions, and how to migrate to these technologies.

3.0 RECENTLY INTRODUCED AND EVOLVING NEXT GENERATION RWIS TECHNOLOGIES

This section describes next generation technologies that have the potential to transform the traditional way of collecting and using weather data and presents how they may meet identified needs of MDOT RWIS program users and/or why MDOT should follow their development for future consideration.

3.1 Connected Vehicle

Connected vehicle is a suite of technologies and applications that use wireless communication standards to provide connectivity that can deliver transformational safety, mobility, and environmental improvements in surface transportation. The US DOT and private and public corporations have researched connected vehicles to determine its potential benefits and costs of deployment. Connected Vehicle technology involves the ability to share basic information about vehicles such as position, speed, and direction of travel with infrastructure or other vehicles. This technology involves two methods of communication; Vehicle to Vehicle Communication (V2V) and Vehicle to Infrastructure Communication (V2I). V2V involves the ability to wirelessly communicate safety information with surrounding vehicles about forward crash warnings, intersection collision avoidance, stopped traffic/traffic queuing, and inclement weather conditions. Warnings related to weather condition, can be derived from values in the vehicle including wiper status, wiper rate, sun data, rain data, air temperature, air pressure, precipitation situation, tire friction, traction control enable/disable, position, and speed. Gathering road and weather data from vehicles is typically generated by the data that is provided from the vehicle.

V2I applications allow agencies and weather support partners to obtain vehicle information to be used in tracking of historical information, processing and collecting data at a head-end server, and performance reporting. In addition, vehicle data could be used to supplement a plethora of weather applications including displaying live road condition data where existing fixed/mobile stations are not available. Each vehicle represents a piece of information that could be used for real-time monitoring of weather and roadway conditions.

The decision regarding a national deployment of connected vehicle technologies remains years away. While the National Highway Traffic Safety Association (NHTSA) intends to make a decision regarding moving forward with rulemaking in 2014, the rulemaking process can take several years, with the ultimate outcome and rules yet uncertain. Given the need for interoperability of systems and broad market penetration for it to be effective, at the time that regulation is put into effect, there must be a coordinated, strategic deployment plan for connected vehicle technology, both in-vehicle and roadside. At this time, standards and requirements should be finalized for back-end applications such as MDOT's central weather reporting tool to be able to process weather data from vehicles as it comes available.

3.1.1 Integrated Mobile Observation

MDOT has been actively involved with the United States DOT (USDOT) and the Federal Highway Administration (FHWA) Connected Vehicle program initiatives since 2005. MDOT currently supports several USDOT/ FHWA Connected Vehicle projects and has initiated several Connected Vehicle research projects that look at how data from vehicles can enhance and support Michigan's current data needs, but also potentially change the way a DOT does business. In partnership with MDOT's Connected Vehicle research program, the USDOT/FHWA Road Weather Management Program (RWMP) proposed funding MDOT's Integrated Mobile Observation (IMO) 2.0 project using MDOT fleet vehicles.

As a result, MDOT has partnered with the University of Michigan Transportation Research Institute (UMTRI) and the USDOT/ FHWA RWMP to develop and deploy sensor technology on MDOT fleet vehicles that collect near real-time vehicle data to support winter weather maintenance decision support systems and other Connected Vehicle initiatives. For the IMO 2.0 project, MDOT is using 60 MDOT fleet vehicles for the 15 month long project starting in January 2013. The target vehicles for this project manage the I-94 corridor during the winter months. These vehicles will be instrumented with location based smart phone technology that will provide a Bluetooth connection to a surface monitoring device and a small module that plugs into the diagnostic port to collect data from the vehicle Controller

Area Network (CAN) bus. Data sets being collected from the vehicle include; camera image of road conditions, location, time, direction, accelerometer (x,y,z), road surface and air temperature, humidity, dew point, ABS, traction control, wheel speed, and wind shield wiper status.

Not all data sets are captured on all vehicles. For example, of the 60 vehicles, 20 are winter maintenance snowplow trucks that will collect smart phone location-based technology and road surface conditions but not CAN bus data. Cellular communication via the smart phone sends the data once every five minutes to six potential servers for post processing purposes. The six servers include: IMO 2.0 MDOT/UMTRI, National Center for Atmospheric Research (NCAR), Maintenance Decision Support System (MDSS) – Meridian, NAVTEQ, RITA- Adkins, and MDOT Data Use Analysis and Processing (DUAP) project. The main focus will be directed toward applications developed and used from the data to enhance and support those data sets currently collected by NCAR, MDSS and DUAP.

MDOT is currently piloting the MDSS software (MDOT pool-funded project with 16 other states) in four maintenance garages along the I-94 corridor in the Southwest Region. MDSS collects data from MDOT's Road Weather Information System and CCTV cameras, FAA's Automated Weather Observation System, the National Weather Service, etc. to supplement operators' decisions for roadway management and treatment during a winter weather event. IMO 2.0 will provide near real time information about current roadway atmospheric conditions, thereby bridging the data gap that exists between static weather stations feeding MDSS. The goal of MDSS and IMO 2.0 working together is to provide for a more effective and efficient treatment system, so operators can realize true winter maintenance operational savings that add value to the entire organization.

3.1.2 Weather Response Traffic Management

As a result of the vehicle data collection from the IMO project, 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, smartphones and support the 2014 ITS World Congress demonstrations in Detroit. This is in response to an FHWA Weather Responsive Traveler Information System (WxTINFO) implementation project/opportunity. MDOT will coordinate the work with UMTRI, Advanced Traffic Management System (ATMS) software vendor Delcan, MDOT's 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 WxTINFO project will be a two-year project starting in November 2013 and overlapping with the current IMO project deliverables.

The FHWA/MDOT WxTINFO system will be designed to function as a statewide weather data collection and messaging system. Traveler information/advisory message locations will be dependent on the primary locations of the data sources feeding the system from both fixed Road Weather Information System (RWIS) and mobile platforms. The primary location of the mobile observations for purposes of this project will be along the I-94 corridor where a majority of the IMO instrumented vehicles will be operating MDOT's Vehicle-based Information and Data Acquisition System (VIDAS) project will also have a select number of vehicles (10-15) collecting mobile observations throughout the entire state, covering all seven MDOT regions, including a percentage of vehicles in locations with RWIS/Environmental Sensor Stations (ESS). The primary geographic location for ESS observations will be in the MDOT northern Lower Peninsula and Upper Peninsula. ESS will provide a baseline or control of weather related data to compare to the IMO and/or VIDAS mobile data collection platforms. The comparisons will help provide quality control between different data collection systems.

The system will collect environmental/weather and traffic related data from both fixed environmental and mobile sensors, process this information into advisories, alerts, or traveler information and disseminate the traveler information for pre-trip applications. Applications will be used by MDOT's traveler information Mi Drive Web site (www.michigan.gov/drive), en-route traveler information utilizing roadside dynamic message signs (DMS), a smart phone application, and the 2014 ITS World Congress demonstrations. Fixed and mobile data will be processed by the MDOT DUAP project in cooperation with the NCAR Vehicle Data Translator (VDT). These programs will work

together to provide data quality checks and logic/algorithms for determining the correct messaging decision based on the data received (see Figure 3-1: FHWA/MDOT IMO & WxTINFO System ArchitectureFigure 3-1 below, FHWA/MDOT IMO & WxTINFO System Architecture).

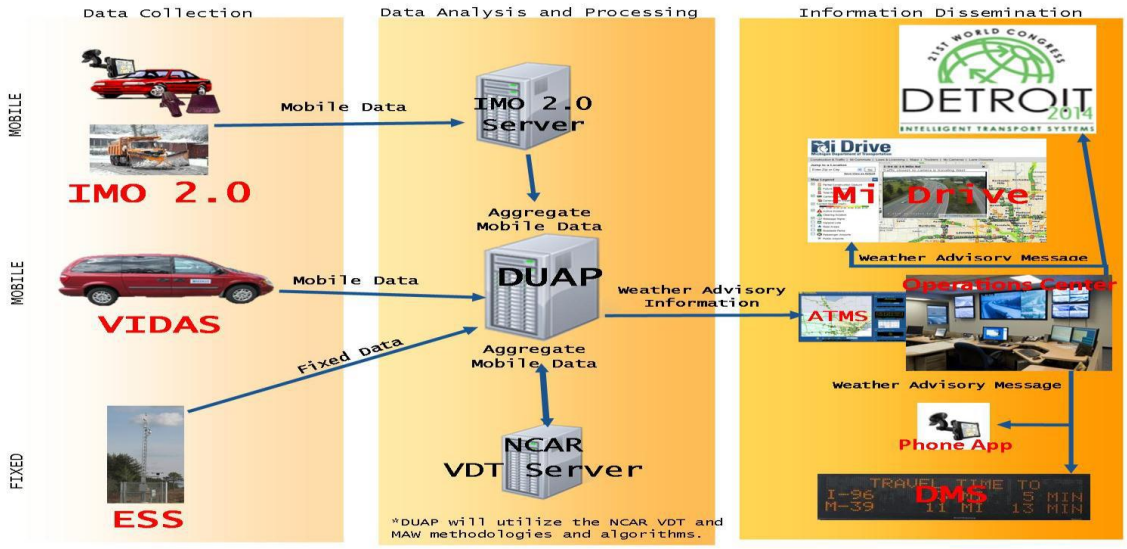

Figure 3-1: FHWA/MDOT IMO & WxTINFO System Architecture

System Benefits and Applications

The system will utilize data collected from fixed and mobile infrastructure to provide targeted or pinpoint road weather advisories and alerts to travelers, pre-trip and en route. The goal of this project is to move from disparate systems, to implementation of a fully integrated WxTINFO system from concept to implementation using fixed and mobile data. The following are benefits that can be achieved:

- **Traveling Public Benefits:**
  The WxTINFO project will demonstrate how providing motorists with more timely/valuable information allows them to make safer decisions both pre-trip and en route in relation to traveling the road network in inclement weather conditions.
- **Operations Benefits:**
  MDOT operations are critical in providing motorists with valuable information during winter weather events. MDOT Transportation Operations Centers (TOCs) can become overwhelmed with incidents that occur during winter weather events. Having the ability to utilize a WxTINFO system to advise TOCs of necessary weather-related advisory or alert locations would increase real-time knowledge of roadway conditions, thereby increasing motorist safety.
- **Maintenance Benefits:**
  MDOT maintenance activities are critical in providing motorists with safe driving conditions during winter weather events. MDOT maintenance staff manages multiple maintenance activities (plowing, salting, etc.) during winter weather events. Having the ability to utilize a WxTINFO system to potentially advise maintenance staff of necessary winter maintenance locations, including real-time unsafe pavement/roadway conditions, would enhance response times and improve the use of maintenance resources.

Additional potential applications that can be developed from the IMO and WxTINFO mobile data include:

- Targeted individual messages to DMS and the Mi Drive Web site

- Provide performance measure/management
- Enhance the Maintenance Decision Support System
- Provide remote imaging and physical monitoring of environment (camera photos)
- Provide visibility monitoring (e.g., snow squalls, localized lake effect white outs, fog, etc.)
- Give slippery surface notification (ABS lockup and differential wheel speed)
- Pin point icy road conditions (driver and maintenance staff)
- Give early notification to first responders, hospitals, work place, schools, etc.
- Provide regional and cross jurisdictional alerts
- Provide in-vehicle alerts
- Provide vehicle diagnostics (miles, hours, routine maintenance, etc.)

3.1.3 Connected Vehicle Research

In late 2012, the FHWA funded a study to determine whether existing on-board vehicle sensors can be used to predict changing road friction. This study was to also demonstrate integration with Connected Vehicles and assess weather data available from the vehicle network. Virginia Tech is currently conducting the study, monitoring rotational rates of tires for driven vehicle, reviewing distance travel, weather variables, and determining rotational differentials over time. Based on these elements, they are looking to predict relative friction values of the tires. Several other features from the vehicles are being obtained as part of the study including: accelerator, brake pedal activation, anti-lock brakes, gear position, steering wheel angle, speed, seat belt information, and air bag deployment.

The study is not complete, however the following benefits or outcomes are expected:

- Potential information to reduce motor vehicle injuries and lost lives
- Decreased property damage
- Better application for winter maintenance resources
- Increased mobility and awareness
- Decreased adverse environmental impact.

Obtaining such data will ultimately allow agencies to understand when and where friction of the vehicles are reduced and be able to deploy resources more effectively. Conversely, this ability will allow active warnings to the motorist in the vehicle and in travel information outlets about adverse conditions in real-time without the significant investment of roadway sensors.

3.2 Virtual RWIS

The cost to deploy, operate, and maintain instrumentation to collect weather and/or road weather information limits the ability to capture local irregularities in many of the data fields needed to support weather and maintenance support requirements. The spatial distribution of existing National Weather Service (NWS), Federal Aviation Administration (FAA), RWIS, and other observation networks is inadequate to provide the needed level of detail in data fields such as:

- Precipitation
- Radiation energy fluxes (solar and infrared bands)
- Pavement temperature
- Road condition and chemical concentrations
- Sub-pavement temperature and moisture content

During rapidly changing or highly variable weather conditions any of the road weather parameters discussed in section 2 may have local variability not resolved by the existing observational networks. One of the key difficulties in the road weather support of DOT maintenance activities, and particularly snow and ice control, is that many of the DOT maintenance response issues deal with localized variations in critical parameters (snowfall amounts, differential icing due to slight changes in pavement temperature, local frost conditions). In addition to these issues, DOTs have advisory and control responsibilities for local wind conditions, blowing snow, flooding).

The meteorological community, weather support providers, and RWIS vendors have recognized the implication of the density of the observational data set and have attempted to project weather conditions from the established observation sites to interstitial locations not served by one of the weather or road weather sites. The techniques to extrapolate weather conditions from known locations to "virtual" observation sites include:

- Interpolation
- Climatological extrapolation
- Two-dimensional field analyses where observed values are mathematically transformed to a grid representation and then extracted back out for a specific geographic point
- Three dimensional field analyses where the vertical influence of the atmosphere is incorporated into the grid representation and then subsequently used to determine the data parameters at a specific point

Even within these broad categorical approaches there exist diverse approaches to facilitate a best estimate of the road weather parameters at a given, un-instrumented point.

Virtual RWIS (vRWIS) requirements use similar extrapolation techniques as presented above but also need to deal with pavement temperature and road condition variables. One technique that uses a form of climatological extrapolation to determine pavement temperature is the thermal mapping program. The approach is to physically map road temperatures under specific types of weather conditions and use the temperature profile developed along a roadway as a mechanism to adjust a known pavement temperature to any point along that roadway for the thermal changes derived from the previous thermal mapping passes for the weather category that best fits the existing weather conditions. This technique works well for potential frost or liquid to ice conditions but has lesser value for current conditions where snow and ice exist on the pavement.

The most prevalent approach is to use either a two- or three-dimensional field analysis technique to extrapolate the weather conditions at a specific "virtual RWIS" site and use the output from this analysis technique as input into a pavement condition model. There are two current approaches to modeling pavement conditions:

- Thermal energy balance models
- Thermal and mass balance models

The combined thermal and mass balance models incorporate computations for the latent heat exchanges associated with the conversion of the water molecule from one state to another. The amount of heat exchanged during this transition in state is quite significant in the thermal energy balance of the water, snow, and ice layer. The thermal energy balance models without the mass balance modules make assumptions to parameterize the heat exchange but have limited ability to deal with amount of mass converted from one form to another. The addition of the mass computations is particularly important when a specified mass of some anti-icing or de-icing chemical is added to the layer and the phase relationship of ice and water need to be reestablished as a function of the freeze point depression of the chemical.

The current pooled fund study (PFS) MDSS is an example of a vRWIS. At the end of each weather observation report time at the top of the hour, the surface observations are combined with upper air data in a local analysis and prediction system (LAPS), an analysis scheme developed by the National Oceanic and Atmospheric Administration (NOAA). Subsequently the PFS MDSS program extracts all the necessary weather parameters from LAPS for a central point for every road segment supported in the PFS MDSS program (~1500 currently). These values represent the atmospheric conditions for a vRWIS at that site for the top-of-the-hour observation time. MDSS then creates a forecast of conditions out to 24 hours and at each subsequent 10-minute interval uses the forecasted weather information as input of the observed conditions at that time. Once LAPS updates this process of providing a best estimate weather analysis resource is started for the next hour. The best estimate weather conditions for each point is then run through a thermal and mass balance pavement forecast/analysis model to provide a pavement temperature, road condition, and analysis of the mass of water, snow, compacted snow, and ice on the pavement. Thus at every 10-minute interval the PFS MDSS provides a complete vRWIS analysis for each MDSS route and system users can view the conditions at the analysis time.

MDOT'S weather service provider, may provide a similar technique to support the weather forecast service for all designated locations where MDOT requests a pavement forecast. It would be possible for the service provider to

display a vRWIS presentation similar to the existing observed RWIS conditions for each forecast site where no ESS actually exists.

The potential to create a better representation of road weather conditions continues to improve as new processing techniques are developed and the ability to analyze weather conditions gets better. Enhancements in weather analysis techniques and pavement modeling will improve the accuracy of the existing technologies and improve the ability to refine local variations in the critical weather parameter fields that impact road condition analyses and prediction. Undoubtedly the greatest benefit will accrue from an improved analysis and prediction of precipitation at finer resolutions.

In addition to the established approaches, individuals in academia are exploring additional techniques to create vRWIS output and use this to support new techniques to project road weather conditions. Tingting Wu at the University of Illinois has developed a technique to input hourly data from the NWS public weather observation sources to create a climatic history of the weather conditions. The technique is similar to that used by the PFS MDSS and by MDOT's weather service provider's analysis and forecast programs. The vRWIS program developed by Mr. Wu has three unique features not emphasized by the PFS MDSS and the service provider's applications: a focus on display of data for vRWIS sites using Google earth mapping functions; spatial representation of the translation of specific weather or pavement-related conditions, and the presentation of sub-pavement temperature and moisture conditions. The research demonstrates the value of using state of the art visual presentation techniques to present spatial information in a layered format that users can interpret easily. The sub-pavement information in this research appears to be the output from the EICM model, developed in part by the University of Illinois. This model was used to support Use Case 2 in the *Clarus* Regional Demonstration project for the FHWA. The model is a powerful tool for simulation of the thermal and moisture profile under an impermeable pavement layer. This model and similar models will be the subject of a study recently initiated by the Aurora PFS consortium. Although the PFS MDSS or statewide weather service provider programs currently utilized by MDOT could provide this service, this type of research yields the innovative approaches to data presentation that come out of the academic environment and continue to improve DOT support services.

3.3 Mobile Data Collection

MDC and Automatic Vehicle Location (AVL) are key capabilities of the mobile road weather data acquisition program. Currently most MDC/AVL units typically record air temperature, pavement temperature, material application rates (solid and liquid), and plow position without user intervention. Many MDC/AVL units can include an in-cab display that permits entry of lane of operation, road conditions, type and rate of material being applied, and various weather conditions. The unit may also interface to an in-vehicle camera and capture images at a routine interval. This information is collected at short intervals and communicated wirelessly to a central processing site. Current work is underway to read parameters from the CAN bus and add these to the MDC/AVL data set. Of particular interest are CAN bus parameters such as wiper status, position of light switch, speed, ABS parameters, and wheel traction.

The MDC/AVL providers install the controller units on DOT vehicles or train a DOT representative to perform this function. The installation normally includes a small computer with an in-cab display monitor. In certain deployments, the computer was programmed to create a screen display on the monitor that allows DOT drivers to select the input options the DOT has selected to support MDSS and/or their resource monitoring programs. However, more recently, the in-cab monitor is used only as a display of information and drivers no longer have to input data to support MDSS. The system is automated to ensure that drivers are not required to be distracted with entering data into the in-cab monitor. The use of cellular communications in vehicles enables data aggregation to a central server. Cellular communications can often be challenging in rural settings where coverage is not as robust as urban environments. DOT management and operations use the data to measure performance of fleet vehicles and roadway treatment plans. Another benefit of a MDC/AVL platform includes providing feedback to the driver about current and forecasted weather conditions and how much material is required to treat that segment of the roadway.

Recently sensor manufacturers introduced an array of sensors that can be outfitted on light-duty vehicles, trucks, and snowplows to obtain real-time road condition and atmospheric data. The package includes a non-invasive road condition sensor, pavement temperature sensor, an air temperature/RH sensor, and a controller to capture and communicate the data. The controller interrogates the sensors at a specified time interval and stores the air temperature, dew point temperature, surface condition state, depth of the liquid, ice, and snow components, and an estimate of the grip index or coefficient of friction.

MDOT is currently in the deployment stage of a statewide MDC/AVL contract, which includes outfitting 270 snowplows with MDC/AVL units and 2500 fleet vehicles in Michigan with AVL. The MDC/AVL units on the snowplows will obtain the following parameters:

- GPS – provides the latitude and longitude of a vehicle.
- Spreader controller and associated sensors – devices measure and convert application rates of treatment materials (solids and liquids)
- Pavement temperature sensor – measures pavement temperature using infrared radiation techniques
- Plow position sensor – measures the position of the various plows attached to a vehicle
- Camera, in-vehicle dash-mounted – provides images of the roadway
- In cab display automatic input for treatment applications, lane position, road conditions, and weather parameters
- Processing unit – ingests input from any of the devices installed in the vehicle that are connected to the processor, composes data exchange packets, and communicates the data to a central collection location

The data will be processed by MDOT's vendor and will be used to visually track all of the trucks and vehicles on a GIS based mapping tool. Additionally, the system will automatically output treatment reports from the snow plows. The atmospheric data from the snow plows will be sent to MDOT's MDSS vendor.

3.3.1 Enhanced MDSS

An enhanced MDSS is defined as the integration of data from mobile sources into the federal prototype MDSS with the potential to provide enhanced MDSS recommendations. All mobile sources would be part of the enhanced data set but the primary emphasis of the Enhanced MDSS program is the inclusion of Connected Vehicle information. For clarity, the original prototype MDSS solution developed in 2001 used observed weather conditions from NWS, FAA, RWIS, and other stationary observation points along with numerical forecast guidance to generate recommendations for specific segments of highway or defined maintenance routes. The federal prototype continues to use this data set to support its MDSS guidance.

The states involved in the development of the PFS MDSS recognized the necessity to supplement these stationary data sources with data from the winter maintenance vehicles. This was necessary to effectively assess the amount of deicing chemical being applied to the snow, ice, and water layer on the roadway and whether plowing was in use. As indicated in section 2.1.5, MDC/AVL solutions were developed in the 2003 – 2005 time frame to provide this treatment information. The units provided the treatment information plus road condition information, some weather observations, and camera imagery. The fourteen states actively involved in the PFS MDSS have MDC/AVL units on at least a portion of their fleet and have demonstrated the ability to integrate the MDC/AVL information into the existing MDSS recommendation guidance logic.

Much of the research focusing on the Enhanced MDSS program within the FHWA addresses the mechanism to collect information and distribute information from mobile sources. The IMO projects discussed in section 3.1.1 represent FHWA-funded projects to demonstrate the ability to consolidate data from MDC/AVL sources and transfer the data to a central repository to support any application that can use the information. Prior to the cessation of the *Clarus* Initiative, the *Clarus* development team had programmed the *Clarus* System to routinely collect and store MDC/AVL data from the IMO state participants. The effort to create a clearinghouse for all ESS data addressed by the *Clarus* Initiative has laid the foundation for a broader initiative called the Weather Data Environment (WxDE)

initiative. Its objective is to leverage the success of *Clarus* into a weather-oriented extension of the Research Data Environment (RDE) being developed in the Connected Vehicle Real-Time Data Capture and Management (DCM) Program. The WxDE database would include ESS, MDC/AVL, Connected Vehicle, commercial vehicle, and other pertinent weather data and serve as a resource for all MDSS applications.

The PFS MDSS will already integrate data from the MDC/AVL units currently being deployed. Once the data formats and data exchange protocols for Connected Vehicle data are formalized and a data exchange infrastructure is in place, the PFS MDSS will incorporate this data set into MDSS processing. MDOT will benefit from this modification to MDSS as the volume of commercial and private sector participants increases.

3.3.2 Improved RWIS and Mobile Data Services

A new option in obtaining streaming video from remote locations where power and communications creates significant video monitoring challenge, involves the use of a mobile/leased platform. This includes remote camera installations with live video broadcasting from even the most off-the-grid locations. This option conserves energy for video streaming by utilizing the latest advancements in Internet and satellite connectivity, coupled with solar power, to provide ongoing live video streaming from locations that don't have electricity or hard-wire communications. The installation typically includes a fixed or leased infrastructure (pole), device and electrical equipment. Potential users should be aware of an initial investment for the equipment and recurring fee for the data hosting and servicing. The monthly service fee would increase with the number of sensors that are required on the pole/trailer
This solution includes the camera placed on a vendor-supplied structure (typically, poles) or on trailers and therefore offer temporary and permanent data collection solutions as required by the client. This platform allows for expandability to include environmental sensors and nonintrusive pavement monitoring sensors on the same structure. Data from the site may be transferred to the agency in one of two ways. MDOT could have their weather service provider collect the data directly from ESS processing unit or have the vendor collect the data on a cloud server and then have the weather service provider access the data from the cloud via the web. Video can be easily integrated with various Advance Traveler Information Systems (ATMS) platforms.

Generally, video can be transmitted over various cellular data networks such 1X Data speeds (3G), Evolution Data Only (EVDO), HSPA+ or LTE. The cellular service at a given location will vary depending on the optimal coverage. Vendors that support this mobile video and ESS platform will work with ESS equipment vendors to establish the necessary instrument data exchange formats and outfit the instrumentation on the proposed camera pole. When a camera or ESS is needed at a location of with limited grid power, the system can be engineered using solar or wind based generation to ensure 24/7 operations; however, commercial power can be used as the power source when it is readily available or where the use of solar might not be possible or not be a good choice.

The use of this platform for the RWIS market has been to support partial ESS installations, but the design of the controller will permit the implementation of complete standard ESS configurations and the integration of optional sensors. A number of the ESS installations that they have in place are standard ESS configurations built around streaming video cameras.

One of the impressive capabilities of mobile video and communications capabilities is streaming video from cameras located in the cab of maintenance vehicles. Only one provider at this time can deliver continuous video imagery from in-vehicle. In-vehicle controllers would need to be configured to extract data from devices on the vehicle but the capability is present in the controller. However, future modifications to the controllers may enable the use of a MDC/AVL unit. The unique streaming video capability they have has the potential to serve as a solid foundation for a mobile data acquisition system.

3.4 Camera Options

3.4.1 Low Light Camera

Figure 3-2: Example Displays from Thermal Cameras

With the advancements in camera technology, several manufacturers have developed a low light IP CCTV cameras that perform well in low ambient light conditions (0.04 lux). These cameras may also include built in infrared illumination devices that eliminate the need for an externally mounted unit. With a built-in IR, the camera can provide full streaming video or image snapshots in HD. Some vendors make a thermal traffic detection camera that couples thermal and visible-light imaging in a single rugged PTZ system to get complete roadway coverage. Thermal cameras provide the ability to detect vehicles and roadway regardless of outdoor temperature and though snowy conditions.

3.4.2 Improved Video Detection Capabilities

High efficiency video codec (HEVC), also known as H.265 is a new encoding technology that improves the video from a roadway CCTV. This new encoding method enhances the existing H.264 protocol by providing higher quality video at lower data transfer speeds. With H.265 the ability to stream video on cellular networks becomes less of a challenge since more frames can be achieved. H.265 technology is very new and may take time before many vendors are able to integrate the video. However most new cameras and encoders are backward/forward compatible, allowing for the switch from H.264 or MPEG-4 to H.265 to occur seamlessly when the systems are ready.

3.5 Forecasting

Road weather forecasting incorporates two separate prediction systems, each with its own set of numerical modeling techniques: straight weather forecasting and pavement condition modeling. Weather forecasts provided by today's weather service providers use output from one or more numerical prediction models that are commonly adjusted by public or private sector meteorologists to form the framework for the local forecasts used to support end user decisions. Individuals and commercial interests desire guidance that impacts their specific needs. Therefore, forecasting has moved from regional forecasting closer to point specific forecasting techniques. The numerical weather prediction techniques that utilize three-dimensional spatial representations of atmospheric conditions are especially effective at generating point-specific forecasts rather than regional guidance. And this transition to point forecasting was a key step in the support and development of pavement condition modeling, which uses thermal energy and mass balance models at a specific highway location to simulate road condition changes driven primarily by the output of the weather prediction models.

Numerical modeling techniques that drive weather forecasting require extensive computing power and most models are run by NOAA or other meteorological centers throughout the world; however, their output is made available to all meteorologists in the public and private sectors. The modeling techniques within these models are adjusted on a routine basis as new approaches or parameterizations are integrated based upon research performed at universities or research foundations. Improvements in forecasting accuracy and reliability occur in an open setting and cause gradual changes in the modeling process over the entire weather support community.

Pavement condition forecasts are done using energy balance models that exist in both the public and private sector. Nearly all of the models used by private sector weather support providers (PWS) were either written by the provider or modified from models in the public domain. Most of the models in use are mature simulation approaches and are not likely to change substantially in design or parameterization. Minor adjustments in the computations may evolve as new research is published, but the fundamental modeling results are not likely to change. The one research area where new efforts may accrue is sub-pavement thermal and moisture relationships. Integration of additional logic in the pavement models to address the conditions beneath the pavement offers the potential to model the freeze-thaw

cycles and the pressures induced at the base of the pavement due to ice or overheated pockets of water vapor. However, the fundamental heat balance that impacts pavement conditions on top of the pavement will not change.

3.5.1 Weather Forecasting

Numerical weather forecasts generated currently have a spatial resolution of 20 - 60 km. The National Center for Environmental Prediction (NCEP) does run higher resolution models that have spatial resolution down to around 4 km. Many events that affect winter maintenance occur in spatial domains with dimensions smaller than this. Numerical models also have a time resolution. That is, the execution of the equations in the model is done at discrete time steps and the output delivered to the end-user at specific time intervals. This time step of the output from most nationally or internationally run models is typically one (1) hour.

3.5.1.1 Lake Effect Snows

Lake effect and lake enhanced snows often have a spatial resolution of a couple of kilometers and the concentration of heavier precipitation within the general snowfall pattern may change in less than the model's 1-hour time step. Several universities, research organizations, and PWS have research programs addressing techniques to provide better forecasts and analyses of lake-induced enhanced snowfalls. The challenges the meteorological community faces are the inability to measure the necessary initial conditions and the huge amount of computing necessary to model these fine-scale events. Higher resolution forecasting techniques and increased computer power to perform the necessary fine scale computations are gradually improving the modeling performance. The biggest hindrance currently is the inability to model the conditions that generate the enhanced snow bands. The source of the snow bands is typically below the level of the weather service radars and the snow bands are difficult to observe until they create enhanced snowfalls on adjacent land. But even when snow bands develop meteorologists may not be aware of the incident because the snow often occurs between observation points in the weather observation network. It is anticipated that connected vehicle and social networking offer the potential to create the observation network density needed to catch the development and position of snow bands and this information can then be used to initialize the forecast models and improve the ability to forecast lake effect snows.

3.5.1.2 Precipitation

Knowledge of precipitation in a fine scale in both the spatial and temporal domains is critical in the support of weather support activities. Maintenance decisions are highly dependent upon the start and end times of precipitation, the existing precipitation type and intensity on each route or route segment, and the accumulation of the various types of precipitation at distinct points over specific time periods. Pavement condition forecasts and MDSS recommendations must be able to properly define the precipitation patterns in near real-time and with fine scale resolution to effectively project the impact of the mass flux of the precipitation into pavement condition forecasts. At present, adequate precipitation information is difficult to acquire as real-time data. There are reasonably good sources of precipitation totals once a day from a network of cooperative observers but there is only a limited number of sources for reports of precipitation amounts at an hourly interval or less. The collection of precipitation via RWIS instrumentation has become an important source of dynamic precipitation information. This results from the inclusion of optical or radar-based precipitation and weather identification sensors in ESS instrument configurations. The challenge with these sensors is the assurance of reliable information. Precipitation sensors placed in the highway right-of-way exist in a harsh environment. Vehicle spray with embedded chemicals will coat all sensors on an ESS. This film gets on the lens of optical precipitation sensors and reduces their ability to "see" and report precipitation type and intensity properly. Servicing becomes a significant issue. The radar-based precipitation sensor is not as affected by this film and has a greater potential to provide reliable information without continuous cleaning.

One of the most effective ways to increase the performance of pavement condition forecasting and MDSS recommendations is to increase the density of functional weather identifier type precipitation sensors that measure precipitation type, intensity, and accumulation (or quantity). Looking to the future, MDC/AVL output, connected vehicle, crowd sourcing, and social networking applications offer the potential to create high resolution analyses of precipitation patterns that then can support short term weather and pavement condition forecasts

3.5.1.3 Radar Type Technology

Commencing in 2011 the NWS has upgraded its network of radars to dual polarization Doppler radars. This modification permits a better determination of precipitation type and allows the radar to discriminate between precipitation and air-borne dust. The new radars can better determine the intensity of the precipitation, which improves the estimates of precipitation amounts. This assists in the projection of heavy precipitation events and potential flooding issues. For winter transportation support the upgraded radars permit better definition of rain, freezing rain, ice pellets, and snow. As the meteorological community employs the new dual Doppler capabilities there will be improvements in the interpretation of the precipitation events and ability to better project evolving weather events.

The integration of dual Doppler into the NWS radars was particularly advantageous in the assessment of severe weather conditions (gust fronts, hail shafts, heavy precipitation, and tornadic wind signatures). Unfortunately, the known deficiencies of radar technology dealing with winter precipitation situations have not been resolved. Radars tend to receive return echoes from cloud layers above winter precipitation formation and therefore underestimate precipitation rates over well-defined areas. Discussions are underway to increase the density of the radar network but no concrete plans have been defined thus far.

3.5.2 Pavement Forecasting

Future improvements in pavement forecasting will be dependent upon improvements in weather forecasting and the initialization of the road conditions at each specific location. Some potential refinements in weather forecasting were presented in section 3.5.1. Approaches to improve the initialization of road conditions are addressed in this section.

3.5.2.1 Pavement Sensor Improvements

In-pavement passive sensors have had difficulty in certain situations assessing the proper road conditions and determining of the amount of snow, ice, and water on the pavement using the inference techniques employed in the sensor algorithms. In-pavement active sensors were introduced to better define the freeze point temperature of the layer of snow, ice, water, and deicing chemical, but these sensors were not able to resolve the mass of the components in the layer. Non-intrusive sensors introduced a new perspective of evaluating the road condition from above the pavement. The use of infrared lasers was able to determine the type of material in the layer atop the pavement and the depth of the components within the layer. This technique works as long as the depth of the components is thin enough that the laser energy can “see” the entire layer. The sensor tends to provide incorrect assessments when the layer is beyond its effective measurement depth or when snow blocks visual access to the other components. Nevertheless, non-intrusive sensors provide a much better characterization of the pavement condition during thin film situations, frost scenarios, and during cleanup operations.

3.5.2.2 Road Condition Analysis

The best source of information regarding the pavement condition at a specific location is visual observation. There are two ways to accomplish this: direct human observation and remote evaluation of camera images. Maintenance personnel and highway patrol officers provide ongoing assessments of road conditions that are available to support pavement condition forecasting. The most significant advancement in road condition reporting has come from the MDC/AVL programs that permit touch screen input of road condition observations. There are several potential technologies that offer the potential to greatly increase a real-time assessment of road conditions. These technologies include:

- Expansion of the MDC/AVL programs
- Use of voice technologies to permit entry of road condition information
- Implementation of the Connected Vehicle program
- Input of observations from travelers via apps on mobile devices
- Image analysis using camera imagery

The implementation of any or all of these technologies has the potential to greatly improve the analysis of existing road conditions and thereby extensively improve road condition forecasts and MDSS recommendations.

3.6 Traffic Detection

In recent years, many agencies have used traffic detection methods to correlate volume and speed data to weather data. While most of this correlation happens after an event or storm, and in the form of historical reporting, there is a still of benefit for monitoring real time speeds and weather conditions. For example, in the Metro Region, MDOT is using traffic detection sensors such as the Wavetronix Advance and HD sensors in conjunction with Vaisala weather sensors to provide warnings for slip hazards above 85th percentile speeds. In other areas of the state, the use of Microwave Vehicle Detection Systems or in-pavement traffic detection units such as ground hogs are used to provide traffic engineers traffic volumes at or near ESS stations.

A new type of Microwave Vehicle Detector is being used that has an optional built in camera to the unit. This IP camera option allows the user to verify roadway conditions during data capture and provide instantaneous traffic surveillance. The unit points directly at the roadway and could be used at ESS locations where full PTZ cameras are not required to verify pavement conditions. The vehicle detector will provide all of the same information that could be obtained from a traditional MVDS, with the addition of the video or image captures at user definable interval.

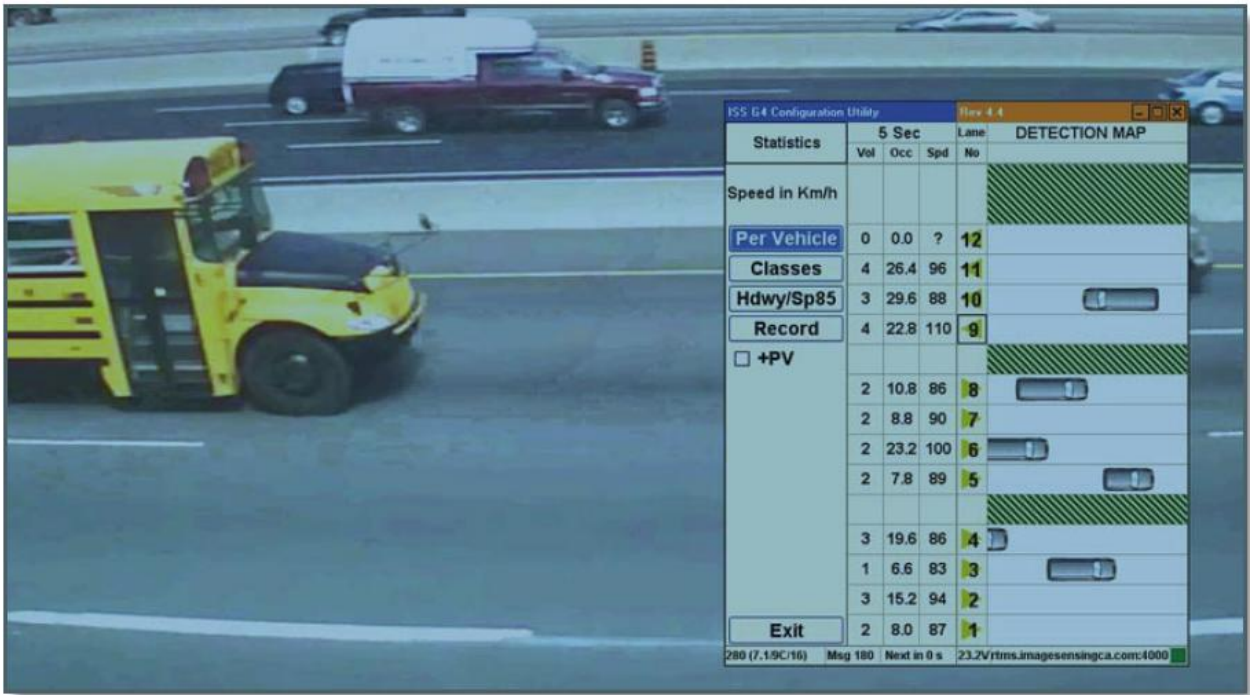

Figure 3-3: Example Traffic Detection Built Into MVDS

3.7 FAST

The objective of Fixed Automated Spray Technology (FAST) is to accurately detect and/or predict adverse road surface temperature and icing conditions and have the system automatically spray a deicing chemical immediately in advance of icing conditions. In order to meet this objective the FAST system utilizes three subsystems:

- The RWIS Detection and Activation System
- The Hydraulic System, and
- The FAST System Server.

FAST installations are installed on bridges and raised structures and have proven to be valuable resources when maintained properly. The technological approach of treating road surfaces only when treatment is necessary has the potential of being a viable method of snow and ice control. The obvious limitation to this approach is the expense of the system, especially the hydraulic system.

FAST will continue to be employed to address critical locations that are prone to frost or rapid development of ice that can be anticipated with good RWIS information, especially road temperature information where frost or freezing are likely. FAST may have greater potential if road condition assessment programs improve to provide high density, real-time reports of road conditions and pavement temperatures.

3.8 Automated Road Condition Assessment

The North/West Passage PFS consortium recently completed an evaluation of potential technologies to automate their road condition reporting requirements. Their interest focused on mobile road condition monitoring devices and MDSS techniques to perform the road condition analyses automatically. The report indicated that each of these approaches has the potential to achieve the desired automation but both have substantial limitations that must be resolved before they can provide an automated generation of road conditions. Specifically, mobile road condition detection systems need to resolve their inability to assess surface conditions under all surface condition states (see section 3.5.2.1) and MDSS needs a better mechanism to define the existing state of the road surface. MDSS is currently limited in its ability to accurately assess road conditions because it uses existing precipitation detection techniques and RWIS road condition assessments that have limitations in type and material depth. As these deficiencies decrease MDSS could become a resource for automated road condition assessment.

The best short-term solution is a complete end-to-end reporting system using the existing road condition reporting techniques used in most states. The most feasible short-term solution would put interactive voice recognition systems in the vehicles where the field observations are made. The voice recognition system would transform the voice signals to digital codes and send the digital packets to a central processing server via the available communications carrier and Internet links. The central processing server would convert the reported observation of road conditions into a standard road condition report format for that agency and organize the reports from different routes into a road condition report bulletin. The bulletin(s) would then be disseminated to end user access locations.

3.9 Next Generation RWIS Summary

Table 3-1 summarizes next generation RWIS technologies and applications that can either meet existing RWIS program needs or should be followed to see if the evolve to meet current or future needs.

Table 3-1: Summary of Next Generation RWIS

Technology Advancement	Relevance to MDOT RWIS Program/Function	Available on MDOT's System
Connected Vehicle Data	Ability to provide real-time vehicle data for performance measurement and operational data.	Yes – Testing with IMO is currently underway
Virtual RWIS	Virtual RWIS can assist MDOT target high problem areas without full-scale deployment. Ability to provide detection and condition verification at the edges of area of responsibility (AOR).	Yes – The initial hour of all point-specific forecasts represent vRWIS values.
MDC/AVL	Ability to provide real-time vehicle data	Yes – Planned MDC/AVL contract statewide.
IR & Thermal Cameras	Ability to detect roadway conditions during night hours especially in areas with low ambient light. Rural roadways.	Yes – IR are readily available in North and Superior. Thermal has not been tested or used.
Forecasting & lake effect snow reporting	Ability to determine lake effect snow bands in along lakeshore roadways in Michigan.	Yes – Research is underway with the PFS MDSS to demonstrate the ability to monitor & predict lake

		effect snow along Lake Michigan shoreline in Indiana and southwest Michigan. - General forecasting is available but not coupled with highly accurate sensors to detect or provide lake effect snow reporting/forecasting
Vehicle Detection with Camera	Ability to provide visual verification of MDOT roadway condition at vehicle detection locations.	No – standalone vehicle detectors and standalone cameras are currently being used.
FAST	Ability to automatically treat key bridge locations in Michigan that are prone to collecting ice.	Yes - There are some implementations of FAST in Michigan.
Automated Road Condition Assessment	Provides an ability to enhance road condition assessment across the state, specifically where MDSS is being deployed.	No

MDOT is aware of all of the new technologies presented in this section and several are in use or are being evaluated on a trial basis in small pockets across the state. The rapid development of new technologies creates new opportunities for MDOT to enhance their RWIS program. However, adopting new technologies in their infancy can create challenges with integration to existing equipment and back-end systems. It is highly likely that a combination of one or more technologies identified above may be practical if they are deployed strategically (targeted locations based on needs) to obtain the greatest benefit from the deployment.

4.0 NEW RWIS TECHNIQUES

There are some new techniques that came up in the best practice review. These are techniques that other states or provinces are using that may meet or supplement current MDOT RWIS program needs or are worth following because they could meet future needs as the program continues to evolve.

4.1 Performance Measurement

Performance measures are becoming a major focus for state's road weather program. The current statewide performance measure is to maintain traffic speeds within 10 mph of normal speeds 80% of the time when a storm event impacts the peak morning traffic. With a performance measure such as this, it is essential to be able to obtain several measurements from one central RWIS location. This information paired with the knowledge of when resources were deployed to treat winter weather road conditions will allow the Department to effectively achieve their goals. MDOT is evaluating the ability to measure the onset and departure of a storm event based on historical data that is available to agencies through their meteorologist, state-owned weather repository and/or public sources such as NOAA. MDOT's RITIS program offers the state personnel historical traffic data overlaid with weather from public sources. However, the need to be able to measure accurate start and end times of a storm is limited statewide and improvement in techniques to determine these times will further enhance the ability to maintain traffic speeds.

The determination of the beginning and ending time for a storm requires precipitation tracking that is more data intensive as compared to traffic. Specific criteria are needed to define when a precipitation sensor accurately defines the beginning and end of an event. The end of an event may require a period with no measurable accumulation of additional water equivalent and the specific time will need to be determined in retrospect. The criterion for cessation of an event must receive considerable review and agreement between transportation officials. This approach will require the use of a high-resolution precipitation sensor and the requirement is likely to impact procurement specs in the future. Non-invasive sensors can also help determine the percentage of snow, ice, and water and transform these conditions into an equivalent grip value or coefficient of friction. The non-invasive sensors are currently the only sensors that can make fairly accurate assessments of grip values. Sections 2.2.1.3 and 2.2.1.4 describe recent advancements in precipitation and non-invasive sensors that will aid in a more robust performance measurement system for MDOT.

4.2 Applications for RWIS on Arterial Networks

MDOT has invested significantly in to a statewide traffic management system that aims to provide operators, first responders, the public and stakeholders the ability to manage and communicate what is happening on Michigan roadways. The integration of traffic cameras, vehicle detection sensors and dynamic travel signs into a consolidated traveler system is an essential tool in monitoring and reporting real time conditions. Traffic detection data that feeds the MDOT's performance monitoring database enables efficient performance monitoring. Road weather information from MDOT's existing weather statewide repository can be used to enhance operations and performance monitoring of the trunklines and arterial networks. However, the lack of a consolidated traffic and weather system limits the state's ability to communicate with the traveling public about roadway conditions. The integration of road weather information (and specifically RWIS-derived data) has become a rapidly developing trend across the country in recent years.

When weather data is consolidated with traveler information systems, applications for improving freeway and arterial operations during weather events become possible. For example, one way active weather data can be used is to enable the ability for operations staff to improve vehicle progression on key arterial roadway segments during a weather event. By maintaining an acceptable level of vehicle throughput for the given weather condition, MDOT can improve current performance for reducing user delay costs on key arterial corridors across the state. To leverage this application, MDOT might consider active management of their traffic signals at one of the many MDOT TMC's. This application can be achieved by triggering weather responsive signal timing plans enabling a progression sequence on a particular roadway. There are many inputs to the decision making changes to the signal timings, including evaluating performance metrics, projecting roadway and system performance, verification of conditions via video

surveillance and current weather data. All sources of data should be present in a consolidated database to assist operations staff in their decision-making.

The management of signals will be closely related to connected vehicle testing and interests around the state. Based on decisions from NHTSA, MDOT may elect to start updating traffic controller firmware and types to support signal phase and timing capabilities in support of connected vehicle applications and active traffic management. Application support for signal timing updates automatically/manually will be driven based on the needs of active traffic management on arterial roadway segments.

4.3 Summary of New RWIS Techniques

The recent trend of integrating weather data into ATMS systems yields highly beneficial techniques for maximizing MDOT's weather resources for operations, maintenance and public information. As discussed in section 3.1.2, MDOT is piloting a Motorist Advisory Warning system using weather resources to provide notifications to traveling public via their ATMS systems. Table 4-1 below summarizes the various technology options that are available, planned in ATMS, and how weather resources can augment the existing system.

Table 4-1: Technology Options for ATMS

Technology Options for ATMS	Available	Planned	Potential Uses/Benefits
Traffic Cameras	X		- Operations - Public Viewing
Dynamic Message Signs	X		- Dissemination of current conditions (traffic and weather) - Travel Time
Traffic Detection	X		- Travel Times - Traffic backups
Pavement Condition and Temperature	X		- Real-time pavement condition reporting on DMS and MiDRIVE - Forecasted pavement condition/temperature reporting to operations Performance of roadway based on grip value
Precipitation	X		- Real time weather conditions on DMS and MiDRIVE - Performance Monitoring – Start/End to Storm
Sub-surface Conditions	X		- Frost depth conditions (weight restrictions reporting)
Visibility	X		- Real time visibility reporting on DMS and MiDRIVE
Air Temp/RH	X		- Real time frost advisory on DMS and MiDRIVE - Forecasted frost advisory on MiDRIVE
Wind	X		- Real time wind reporting on DMS and at Bridge Crossings
Incident Corridor Management		X	- Emergency route planning and notification to motorists for weather or non-weather related incidents - Traffic signal timing/control
Automated Incident Detection		X	- Rapid detection of incidents (weather or non- weather related
Active Traffic Management		X	- Activation of traffic management systems such traffic signal progression on arterials. Can be coupled with weather resources if needed.

5.0 TECHNOLOGIES TO MEET USER NEEDS

This section presents technologies, applications, and techniques that will meet MDOT RWIS user needs that were identified as gaps in the existing system evaluation report. The technology evaluation related to the fifteen (15) needs derived from the MDOT workshops are presented in Table 5-1 on the following pages.

Table 5-1: RWIS Technology Evaluation

MDOT RWIS Technology Evaluation			
Need, Gap, or Opportunity	**General Observation**	**Existing Michigan Practice**	**Recommended Approach**
Define Region MDOT Champions	States/provinces with strong RWIS champions have maintained relatively good data and strong RWIS programs.	Typically ITS Region leads.	MDOT management at the State and Region level know the probable candidates to serve as champions. The development of a champion will require selection of someone who has a positive attitude toward RWIS and will be augmented by making the responsibility a designated assignment and titled position.
Better Information Lake Effect Snow Locations	The primary need identified was to have a better forecast of lake effect snow. Having sensors placed to better observe lake effect snow was also an important need.	Some lake effect forecasting is available through MDOT's weather service provider and as part of the PFS MDSS research project.	Work with ongoing research programs (e.g., MDSS) that are exploring techniques to more effectively model lake effect snow. Explore precipitation monitoring resources, both internal and external to MDOT, that may be used to acquire more detailed analyses of current precipitation patterns and rates.
Improved Information on conditions in outlying areas	This will help efficiently identify where resources need to be deployed.	Overlapping coverage in Metro Region Deployment of ESS on the borders of AOR.	- Use of camera on borders of AOR. - Expand AOR boundaries - Consider coverage from a statewide basis, not just a regional basis.
Integrate with ATMS (especially to provide historical data)	511 programs have included road condition reports or links to data.	Integration of weather data is underway between MDOT's ATMS and weather platforms	Continue efforts to integrate weather information into ATMS.

Determine Frost Depth Measurement Sensor Locations	Many maintenance areas use frost depth tubes in the pavement	Use of 6 or more individual probes to collect spot information of frost depth	Use of probes with a local RPU to obtain temperature below the pavement layer Coordinate information between RWIS and maintenance crews responsible for frost depth measurement. Evaluate the vRWIS projection of sub-pavement conditions or the EICM approach from Clarus to continually display and project frost conditions.
Define Performance Measurements	MDOT currently has a Sub Wildly Important Goal (WIG) to maintain traffic speeds within 10 mph of normal speeds 80% of the time when a storm event impacts the AM peak.	WIG on maintaining traffic speeds during morning storm events.	Define “end of storm”. Continue to integrate weather information into ATMS to expedite determination of traffic speeds. Use RWIS precipitation information to define the start and end of a winter-storm event and traffic speed information to determine the difference between current and normal speeds. Consider adding grip factor as performance measure. Use this project to define additional performance measures.

Determine/define begin and end of storm	Need for measurement of traffic speeds for MDOT's WIG	Clear definition of the start/end of the storm has not been defined yet. May be calculated differently across the state based upon operations experience.	The start and end of a winter storm event require determination of: - the beginning or ending of the mass flux of snow, freezing rain, or ice pellets on the pavement - the initiation of ice on the road or the elimination of ice on the road A program to assess this correctly requires a precipitation sensor that measures precipitation type and rate, a pavement condition sensor that determines the depth of snow, ice, and water on the pavement, and/or a high resolution camera image. In addition, the agency needs a program or a team that can integrate the resource information the DOT has available from RWIS to derive a best estimate of the start and end time of a storm.
Provide Training and Awareness	Training for temporary or seasonal operators and for MDSS.	Training for ESS was only completed in North and Superior during the initial installations in 2011 and 2008, respectfully. Training using MDOT's statewide AVL mapping software and MDC data for MDSS is underway statewide. Expected completion by December 2013 and deployed in all statewide garages.	Develop or adopt specific curriculum. Train the trainer courses to facilitate internal training.

Defined High Priority Areas	Identify important locations for sensor stations.	High priority areas are identified during project scoping meetings, safety meetings, and/or maintenance planning meetings.	MDOT needs to identify what RWIS parameters and criteria are critical to their support program. From these criteria a set of defining guidelines can be derived (e.g., sensor density to achieve an analysis to support the decision support requirements for that parameter). Once the guidelines for each independent parameter are completed, a synthesis can be done to determine the best solution to satisfy most or all of the independent measurement requirements.
Determine Grip Value Calculations	To aid maintenance in their day-to-day operations to treat segments of roadway that see recurring icy conditions during the winter months	Limited use of non-invasive technology in Metro, North and Superior.	- Deploy non-invasive on existing ITS infrastructure such as camera and detector poles. - Extract data from MDC units (fleet vehicles) - deploy temporary or permanent leased options where power/communications is difficult - integrate camera imagery as a confirmation or correction tool for road conditions
Better Storm Forecasting	To enhance the ability of maintenance engineers to better plan road treatment on specific routes	Forecasting is available through MDOT's weather service provider.	This requirement implies better "local" and/or "route-specific" forecasts. Assess available meso- or microscopic weather models and forecasts available. If any are available, assess cost-effectiveness. Continue to provide RWIS data to weather forecasting services to improve forecasts. Assess what instrumentation will improve forecasts.

Improve Mobile Observations	Capture mobile observations in real-time across the state and for these observations to be a usable benefit for all regions of the state. What we need to further understand is the intent or purpose of the mobile data collection program to fulfill the needs of the RWIS requirement for mobile data.	MDC/AVL deployment currently underway statewide in fleet vehicles. Integrated Mobile Observation currently under study on the I-94 corridor.	- Enhance MDOT's central reporting system to include observations from mobiles Continue to follow improvements in MDC/AVL to determine cost-effectiveness of adding to more maintenance fleet vehicles. Evaluate MDC/AVL options and weigh "build or buy" options. Look particularly at performance-based data delivery agreements.
Maximize/improve weather related conditions to travelers	May include areas in which snowplows are operating. There is a scarcity of DMS in outlying areas. Are there other effective ways to effectively get weather information to drivers?	Weather reporting from MDOT's RWIS is done via DMS when data is readily available. Metro, North, Superior, and University.	MDOT needs to determine what information they want to share with travelers and then develop programs to assure they can deliver the desired information. This plan should include what data collection resource is needed, how long it will take to deploy the resource to a point where the data density is sufficient to permit delivery to the traveler, and what it will take to maintain the information at a level of accuracy and reliability travelers will accept. In addition, MDOT needs to evaluate what media end users will use in five to ten years and develop delivery mechanisms that will satisfy the most probable media formats.
Weather reporting and information on smartphones and tablets	Helps field personnel know conditions throughout their area of responsibility when out in the field.	MDOT personnel are using their own smart phones or tablets for monitoring of roadway conditions. Access to weather reporting tool is available in a mobile format.	Further enhancement of mobile applications from weather service provider system to allow for seamless data monitoring from mobile devices.

Sharing weather information with other organizations	Includes weather data in a standardized format to make sharing weather information more efficient.	Data feeds provided to MADIS, Weather Data Environment (WxDE) and 3rd parties via FTP through MDOT's weather service provider. Partner Agencies such as road commissions currently have access to the online weather service tool for viewing MDOT stations as requested.	Continue to make RWIS data available to third parties.

6.0 NEXT STEPS

The evaluation, as presented in this report, of technologies identified in the best practices review sets the stage to develop and evaluate alternative RWIS program elements for the State of Michigan. From that evaluation, the project team will recommend the most effective approach for MDOT to take in the continuing development and improvement of their RWIS program. The team will assess various deployment options including advances in the support technologies (next generation technologies) and new RWIS program techniques, against institutional trends and the ability of the potential program elements to meet user's expectations and unmet needs. The assessment will specifically look to maximize benefits while leveraging shared infrastructure for mixed sensor deployments, communication alternatives that are cost effective, and procurement options that provide MDOT the most value while minimizing pressures from traditional delivery methods and timeframes. The project team will assess various contracting methods that have been successful in Michigan and around North America to increase efficiency of the road weather system and reduce overall deployment cost to the Department.

The assessment of alternatives will lead to a recommended phased deployment strategy. The team will develop deployment scenarios that will be comprised of different phases that address the most effective timeframe in which to implement the technologies and techniques identified. The project team will develop timelines and cost estimates for the development of each of the phases within each scenario. The components of this analysis and the thought process involved in developing the scenarios will be incorporated into the final technical memorandum evaluating and recommending deployment strategies.

7.0 REFERENCES

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