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Evaluation of Portable Road Weather Information Systems

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16. Abstract

Recent advances in weather sensing technology, cellular communications, and solar panel technology have enabled the development of portable road weather information systems (RWISs). In this project, a full analysis of the state of the art for these types of systems was performed, providing insights into best practices. Two prototype portable systems based on commercial weather sensors, cellular communications equipment, and solar energy were developed and tested to better understand the challenges and tradeoffs of RWIS design. The prototype systems were deployed on roadways in the Commonwealth of Massachusetts and evaluated for 12 months. As a result of testing, three additional RWIS units were developed for roadway use. This report provides a comprehensive look at the background, decision making, and lessons learned from these research activities. The availability of the five systems created for the project for continuous use in winter road monitoring will benefit the Commonwealth for years to come.

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Evaluation of Portable Road Weather Information Systems

Final Report

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Disclaimer

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Executive Summary

This study of the Evaluation of Portable Road Weather Information Systems was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

Effective highway winter maintenance programs, specifically snow and ice operations, depend on timely and accurate information to make good decisions relative to the placement of anti-icing and deicing chemicals. Weather indicators, such as pavement temperature, air temperature, precipitation type and intensity, and other variables, are used in the decision process. Currently, the Commonwealth of Massachusetts has invested in a series of permanently placed road and weather information systems (RWISs) throughout the state. These 27 RWIS stations have been strategically placed to cover the interstate highway system. These stations are considered vital to snow and ice operations. With increased sensitivity to environmental concerns, many other areas in the state are without monitoring capabilities. These permanent RWIS sites require power and communication cables at their sites.

The purpose of this project was to evaluate portable (e.g., trailer-based) RWISs to determine their suitability for use in Massachusetts. RWISs collect information such as pavement temperature, air temperature, precipitation type and intensity, and other variables and make them available to users via standard web browsers. In the early stages of the project, an effort was made to identify portable, commercially available RWIS technologies designed to capture and analyze weather data to help determine the appropriate application of sodium chloride, magnesium chloride, and any other deicers used in winter operations. This effort involved a complete literature survey of portable RWIS applications used by other state DOTs.

Following a full literature search, the development of two fully functional prototype RWISs based on weather sensing technology from two different companies (Vaisala, Inc. and High Sierra Corporation) commenced. One system was constructed using sensors from Vaisala, while the other system was constructed using sensors from High Sierra. Following initial data analysis and comparison, the RWISs were moved to roadsides in the Commonwealth for an extended test under winter driving conditions. As part of the project, the results of the field tests in terms of portable RWIS reliability, accuracy, and cost were assessed. Subsequently, three additional Vaisala-based RWISs were constructed and delivered to MassDOT for roadside use.

As a result of project research activities, the state of the art in portable RWIS technology has been assessed and a fleet of portable RWISs has been created for MassDOT use. These systems provide an understanding of weather indicators used in the winter maintenance/snow and ice decision process. Data collected from the RWISs have the potential to assist

MassDOT in making decisions to apply sodium chloride, magnesium chloride, and any other deicers used in winter operations, which, in turn, help achieve broader safety, fiscal, and sustainability goals.

In conclusion, the project team's effort to build practical, easy-to-use, and accurate portable RWIS units has resulted in five deployable systems that are highly accurate. The systems have been tested on roadways for an extended period of time (nearly 12 months) to determine their long-term effectiveness. Future work could involve increasing the portable RWIS fleet size beyond five and examining new energy and communication alternatives for the portable RWISs. It is the team's belief that portable RWISs can serve a vital role in providing roadway information for roads in isolated locations in the Commonwealth. Only cellular communication capabilities are required in the deployed location to transfer collected data. The availability of portable RWIS information can assist MassDOT in deploying road maintenance teams in a more efficient and cost-effective manner.

Table of Contents

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List of Tables

List of Figures

1.0 Introduction

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Weather conditions have a significant impact on road safety as well as roadway and highway maintenance operations. Costs associated with winter road maintenance are very high. Winter road maintenance alone accounts for about 20% of state DOT maintenance budgets *(1)*. State and local transportation agencies spend more than $2.5 billion each year on snow and ice control operations, and more than $5 billion to repair weather-damaged roadway infrastructure *(1)*. Snow and ice control techniques involve the application of millions of tons of salt to road surfaces each year. The usage of salt causes corrosion, affects vegetation, and has detrimental effects on the environment *(2)*. It is desirable for transportation agencies to find sustainable and cost-effective techniques for better roadway maintenance throughout the year, especially during winter months. Transportation agencies nationally and internationally are working on employing such techniques to improve operations related to road management, road safety, and emergency management. Real-time weather information also increases the preparedness of travelers for driving in inclement weather conditions.

Road weather information systems (RWISs) play a significant role in providing weather and surface conditions to transportation agencies to monitor weather events. Using this information, roadway operators can efficiently plan road operations, reduce chemical, sand, and salt usage, and provide a better level of service by using anti-icing practices. A RWIS consists of pavement sensors and meteorological sensors to determine road condition and weather events. The weather and pavement condition data collected by the weather sensors is typically processed using sophisticated technology in the RWIS and sent on a network for weather forecasting and pavement condition monitoring. Traditionally, most RWISs have been employed in the field as permanent fixtures. In contrast, a portable RWIS consists of trailer-mounted equipment that can be strategically relocated to different monitoring sites.

1.1 Problem Statement

Weather forecasting and roadway condition monitoring are of paramount importance for roadway safety and operational decision making. These actions require collection of accurate, real-time atmospheric data. Both current and historic atmospheric data greatly affect the decision-making processes of weather forecasting, road maintenance, construction projects, rescue operations, and the installation of future permanent RWISs at planned sites. The accuracy of the data collected by the weather sensors and the placement of these sensors are critical issues. Pertinent weather information can either be directly obtained or extrapolated to a central location by a permanent RWIS. However, there are concerns that make permanent fixtures prohibitive. These concerns include cost, accessibility to sites, site terrain, and permitting issues. Under these circumstances, portable RWISs are an attractive solution to transportation agencies due to their mobility and ease of relocation. Portable RWISs are cost-effective systems and can be used to monitor specific weather conditions for a specific duration at the site of deployment.

This research project involves development of multiple portable RWISs to be used by MassDOT. These systems have the potential to assist MassDOT in making decisions to apply sodium chloride, magnesium chloride, and other deicers used in winter operations. The systems should help achieve broader safety, fiscal, and sustainability goals. The project involves deploying trailer-based RWIS systems in the field for monitoring weather data. These systems are tested for accuracy and feasibility. Weather data is visible on vendor websites. A full literature survey of the state of the art in RWIS usage and portable RWIS technology is also provided.

1.2 Research Objectives

The following goals have been achieved in the completion of this project:

- Examination of the state of the art in RWIS usage in both domestic and international environments.
- Evaluation of best practices in the existing use of RWIS equipment.
- Identification of portable, commercially available RWIS technologies designed to capture and analyze weather data and pavement data. This action involves selection and evaluation of sensors that are suitable for the portable RWIS. Non-invasive pavement sensors are typically suitable for a portable weather station.
- Development of two portable RWIS prototypes consisting of weather-sensing equipment procured from two different manufacturers, and identification of issues involved in building and using these systems. The systems are contrasted for their usability, accuracy, and maintenance.
- Analysis of the results of field tests of the two prototypes. The results obtained from the prototype RWISs are compared and documented.
- Construction of three additional portable RWISs for delivery to MassDOT.

1.3 Report Outline

The remainder of this report is organized as follows. Chapter 2 reviews the state-of-the-art in worldwide RWIS use, with a specific focus on portable RWISs. Chapter 3 describes the equipment used to build the five portable RWISs developed for this project. Each weather sensor is described in detail along with a discussion of trailer requirements. A comparative analysis of results obtained from the systems and results collected from a stationary weather system is provided. In Chapter 4, recommendations for further use of the portable RWISs and the development of additional systems are provided. Chapter 5 provides conclusions for this project.

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2.0 Literature Synthesis

This chapter first provides a review of RWISs, which are deployed around the globe for a variety of applications. After introducing RWIS concepts, the project team examines previous portable and mobile systems in an effort to provide a contrast for its work.

2.1 Introduction to RWISs

In general, the types of RWISs are as diverse as their applications. Although portable RWISs, which can be mounted on vehicles or rapidly deployed in the field, are increasing in use, most RWISs are permanent, expensive installations installed at airports or along major roadways. In general, most RWISs contain a variety of environmental, atmospheric, and precipitation sensors. RWISs deployed on roadsides often contain pavement temperature and road moisture sensors that are embedded in the pavement or make remote measurements. Applications that use RWIS data depend on several RWIS characteristics, including the following.

- **Sensor data.** Timely and reliable information regarding wind speed and direction, surface and atmospheric temperature, and road condition are critical for use by applications.
- **Communications.** Information must be sent from the RWIS to a central location, where it can be processed and made available to users. The amount of time needed for processing is often less than several minutes.
- **Correct RWIS functionality.** Most RWIS applications only function properly with information from numerous RWISs that can be collated and analyzed. In some cases *(3)*, even the failure of a few RWISs can significantly impact the availability and accuracy of RWIS applications.

2.2 Typical Implementations of RWISs

RWIS data has been used for a broad spectrum of applications, ranging from evacuation planning to automated roadway deicing. The most popular use of RWISs to date is to provide assistance in road maintenance and to inform the public of weather-related driving hazards. Typical uses of RWISs for winter road maintenance were reviewed.

Germany. A current German system *(4)* provides a good example of modern RWIS data collection and use. Temperature and precipitation data are collected every 15 minutes from a series of 1,200 RWISs deployed throughout Germany. This information is used to provide long-range weather forecasts and hazard warnings for road maintenance staff. Road treatment both before and during storms is determined from this data. In general, RWIS data is not provided to the general public. Currently, information is provided for a range of road trouble spots, including bridges, railroad crossing points, and city intersections. Figure 2.1 shows a screenshot of an RWIS-driven road weather application in use in Germany and parts of Denmark *(5).* The display system appears a little simple, and weather forecasts are generally interpreted from the provided data by human experts or third-party vendors. Information is accessed via text file download from a central server.

Figure 2.1: Example of an RWIS-driven road weather application

Switzerland. The current Swiss RWIS network *(6)* is also focused on providing data for road maintenance (See example shown in Figure 2.2; “Vpad” is a personal communications device and “VLS” is used for signage update). Although it is not clear how frequently RWIS information is polled, the information is used to issue road weather forecasts. All maintenance centers for the national roads use information from the RWIS network. The system combines measurements and warnings from road sensors, road weather stations, and the local road weather forecast issued by MeteoSwiss. Road sensors and road weather stations generally provide the following parameters *(7)*:

- Air temperature 2m above ground
- Surface temperature
- Humidity
- Dew point
- Freezing temperature
- Precipitation
- Wind: direction and intensity
- State of the road: dry or wet, and residual salt

Although primarily used for maintenance, the information is distributed to the public three times a day, via the web, using a text (non-map) interface. During nighttime, the group leader on call can get advance RWIS information at his or her home on a laptop.

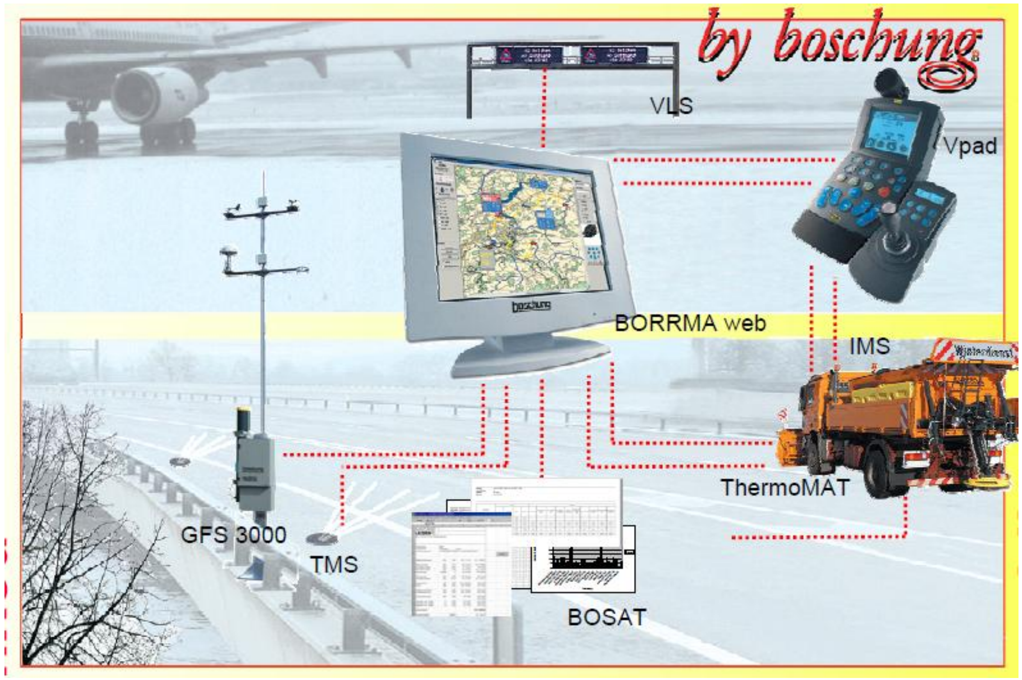

Figure 2.2: Interconnection of RWIS and road maintenance components in Switzerland

Maryland. Over the past 20 years, Maryland has developed a sophisticated winter road management system *(8)* that uses integrated RWIS data from 62 sites located around the state. Collected RWIS information includes temperature, fog detection data, and wind information taken from monitors on bridges *(9)*. An interesting aspect of the system is the use of a commercial ScanWeb interface for presenting polled RWIS data (recently renamed ChartWeb, http://www.chart.state.md.us/).

Montana. The Maryland interface is also in active use in Montana (http://rwis.mdt.mt.gov/). Atmospheric data and pavement temperatures are presented on this interface, and the information is automatically inserted into incident reports via the Emergency Operations Reporting System (EORS). This information is also provided to Telvent Corporation for real-time forecasting. The provided documentation indicates an interest in using RWIS data to better deploy salt brine, calcium chloride, and road pre-treating, although this goal has not yet been accomplished.

Ohio. Ohio has also installed a new web interface for RWIS data that is customized for winter road managers *(10)*. This interface includes historical information (e.g., same-date temperature and precipitation) for specific RWIS deployments and is available to every district in the state. To support this effort, RWIS units transmit data to the State of Ohio Computer Center (SOCC) every five minutes via cell phone communications. The public can access RWIS information, but this data is now presented using a separate web server to prevent server overload from affecting roadway managers.

Massachusetts. The literature *(11)(12)* shows that Massachusetts has been aggressive in the use of RWIS technology for winter road maintenance. An interface based on Telvent MxVision software displays information collected from 26 RWIS locations for MassDOT personnel. Long-range forecasts based on this data are updated every hour. Recently, RWIS data and images from cameras mounted on RWISs have played important roles in pre-conditioning roads for impending bad weather. RWIS data is used by MassDOT personnel in each district to determine when initial deicing should be performed based on temperature and road condition trends. To augment permanent fixed-position RWISs, MassDOT has recently deployed mobile pavement temperature sensors to collect additional temperature data. It has been found that pavement temperature changes much more slowly than air temperature, impacting deicing conditions. Information from these sensors is used by the computer-controlled application systems in liquid-deicer spreader trucks. Recently, MassDOT has moved to the use of liquid deicers for ice removal and road pre-wetting *(12)*.

California. Many RWIS data systems used for winter road maintenance rely on RWIS information interspersed with detailed maps. Caltrans contracted with the Western Transportation Institute *(13)* to develop the WeatherShare System, which aggregates current and forecast weather into a web-based interface for use primarily by Caltrans personnel, although it has more recently become available to the public. Web-based alerts regarding icy conditions are based on information from RWIS pavement surface sensors, and wind sensor information is used to generate wind advisories and alerts. The WeatherShare interface (see http://www.weathershare.org) is based on Google Maps (Figure 2.3). RWIS stations can be found at various zoom levels.

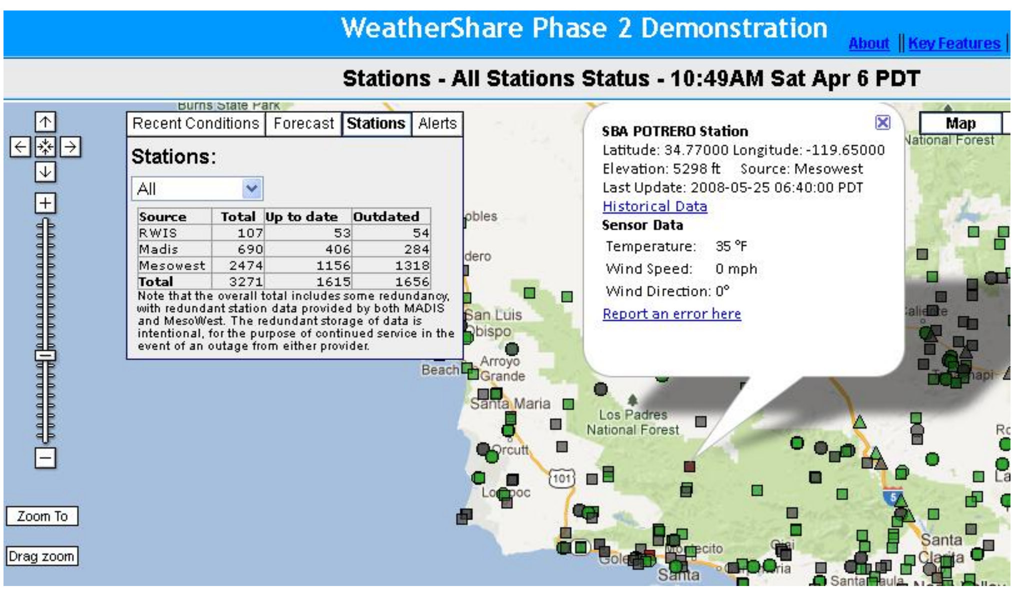

Figure 2.3: Google Maps view of the Caltrans WeatherShare system

Michigan. A recent deployment in Michigan *(14)* notes the use of RWIS in the collection of data used for a variety of road maintenance applications. This information is also superimposed on maps. The presentation notes that RWIS applications can be expanded to include information for infrastructure such as casinos, schools, and emergency response organizations. Although no specific data is provided, it is indicated that the effectiveness of RWIS applications can be measured by a number of metrics, including maintenance response times, RWIS website usage, and traffic volumes and speeds during weather events, among others.

Sweden. The Swedish Road Weather Information System (RWIS) *(15)* provides an early warning system to road maintenance crews when travel conditions become critical. This information system is based on data obtained from RWIS units, many of which were initially designed and tested in Scandinavia. The described system is used by road managers to moderate the disbursement of road chemicals for ice and snow. In a recent innovation, radar and RWIS information can be combined together to track weather fronts. A telecommunications network, including mobile phones and Internet connections, is used for communications between field equipment and the central data processing location. Extensive weather information collected as part of RWIS can be accessed by third parties (e.g., contractors) via a password-protected website. Information regarding wind, temperature, or RWIS camera images is available for free via web pages administered by the Swedish Transport Administration (Trafikverket).

Finland. In Finland, information obtained from RWISs is augmented with camera images from RWIS sites *(16)*. This information is displayed on graphics-optimized workstations. A main focus of the system is quality management of the roadway information and RWIS data. The effectiveness of the quality management made it possible to migrate some of the road treatment decision making to algorithms powered by RWIS data. An effort has been made to quantify the quality of the road data using validation approaches (human visitors to RWIS sites and post-confirmation using weather reports from additional sources).

New Hampshire. As data processing and communications technologies have improved, it has been possible for many governments to make RWIS data available to both departments of transportation and the traveling public. For example, New Hampshire's RWIS network was developed to provide traveler information and support winter road maintenance *(17)*. This system is optimized to track storms and generate alert notifications for district offices *(18)*. The severity of the storm can be tied to the number of personnel notified. The system also allows for the identification of appropriate time periods for road construction in addition to winter road maintenance. Several ozone sensors are included that allow for targeted warnings. The system, which polls RWIS units every 20 minutes, also is used to minimize roadway chemical application during the winter and issue travel advisories. Data is formatted using the National Transportation Communications for ITS Protocol (NTCIP) standard to allow for data sharing across platforms, including across state boundaries.

Iowa. Iowa has extensively examined the use of RWISs and the use of their information in pre-treating roadways with deicing chemicals and making information available to the traveling public *(19)*. Since 2009, the IowaDOT Weatherview website (http://weatherview.iowadot.gov/) has provided real-time RWIS information to the public and road managers, as shown in Figure 2.4. In addition to RWIS information, this system incorporates data from road cameras and traffic flow monitors. This information is overlaid on a map to assist planners. RWIS-based prediction can be compared to weather prediction based on radar that is performed four times a day. Another interesting use of RWIS data is the calculation of expected values of required salt deployment for certain storm characteristics *(20)*. Values for pavement temperature over time were correlated with the amount of deicing treatment used for several storms. During subsequent storms, deployment values were tuned based on previous averages. In the described study, pavement temperature values were recorded every ten minutes. RWIS data can also be used to verify the functionality of the RWIS itself. RWIS reliability can be determined by examining the frequency of communication and the accuracy of the data when compared to information obtained from collaborative sources, such as the Clarus Initiative *(21)*.

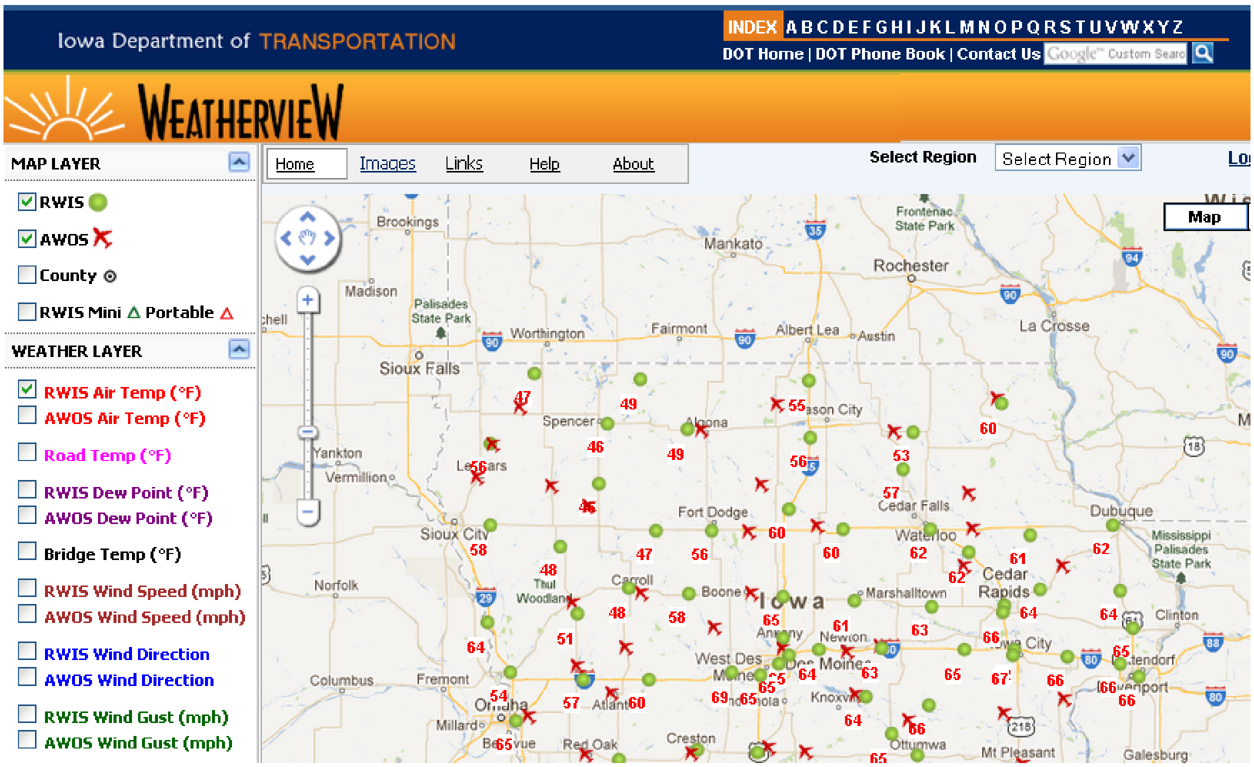

Figure 2.4: Iowa Weatherview RWIS Web Interface

Denmark. The Danish Road Institute has developed a system to integrate data from all RWISs in Denmark *(22)*. The system uses a protocol defined by the World Meteorological Organization (WMO) for fast and frequent data collection. Internet protocol is used to collect data from the RWISs, which have both wired and wireless connections. One dataset is collected every five minutes from the RWISs. The RWIS network in Denmark has been actively used for winter road maintenance and to provide traveler information since at least 2004 *(23)*. Information from the RWISs is displayed on a centralized website, and a human operator uses the information to call out salting operations. An alert regarding the risk of icy roads is given via a user interface. The system, including RWIS information, is able to track the application of salt on roadways and payment of fees to contractors.

Alaska. Alaska has developed an extensive RWIS network over the course of the past decade. These systems are used to track environmental information and winter road maintenance, and to provide traveler assistance *(24)*. The information is not only consumed by the Alaska Department of Transportation, but also by the Federal Aviation Administration, National Weather Service, and the Alaska Fairbanks Geophysical Institute. Information is provided to travelers via a website (http://511.Alaska.gov), dynamic sign boards, and radio/TV broadcasts. The system interface (http://www.dot.state.ak.us/iways/roadweather/forms/IndexForm.html) provides a wealth of information.

British Columbia. British Columbia recently revised its traveler information system to a unified, map-based system. This implementation is user friendly and allows for straightforward access to weather, travel, and traffic alerts (http://www.drivebc.ca/#mapView). The integration of these technologies on a single website was predicted five years ago *(25)* and appears to be the trend for all departments of transportation.

2.3 Novel Applications of RWISs

This section presents some novel applications of RWIS information that go beyond traditional uses in winter road maintenance and road condition travel updates to the public. It appears that the breadth of applications has particularly expanded over the past few years as RWIS communications via cellular connections have become more stable.

Route-based Forecasting. As a research area, the use of RWIS data is becoming more sophisticated. Recent research *(26)* has shown that road temperatures and geographical data (e.g., elevation, exposure to the sun) can be used to extrapolate known data to intermediate points. For example, if individual RWIS deployments are located 20 miles apart, a combination of known temperatures and geographical data can be used to estimate road conditions at an intermediate point 10 miles between them. This route-based forecasting technique, sometimes termed XRWIS for next-generation RWIS, has been shown to lead to improved decision making for the pre-treatment of icy roads. Continuing research is examining the required resolution of RWIS data (e.g., how many systems are needed along a route) to provide more effective prediction results.

Low-Visibility Warning System. In addition to reporting temperature and wind values on roadways, RWISs can be effective at detecting fog and triggering appropriate alerts *(27)*. The low-visibility warning system based on collected image data is now used by the state of Alabama on the seven-mile-long Bay Bridge near Mobile. Closed circuit visibility sensors are located at intervals of one mile along the bridge. A management system is tied to feedback from both vehicle detection systems and the fog detectors. Internet protocol is used to transfer data from the sensors to the management facility. As a result of detected fog, speed limits on the bridge are reduced and visual warning signs are posted online (Figure 2.5) and on roadways.

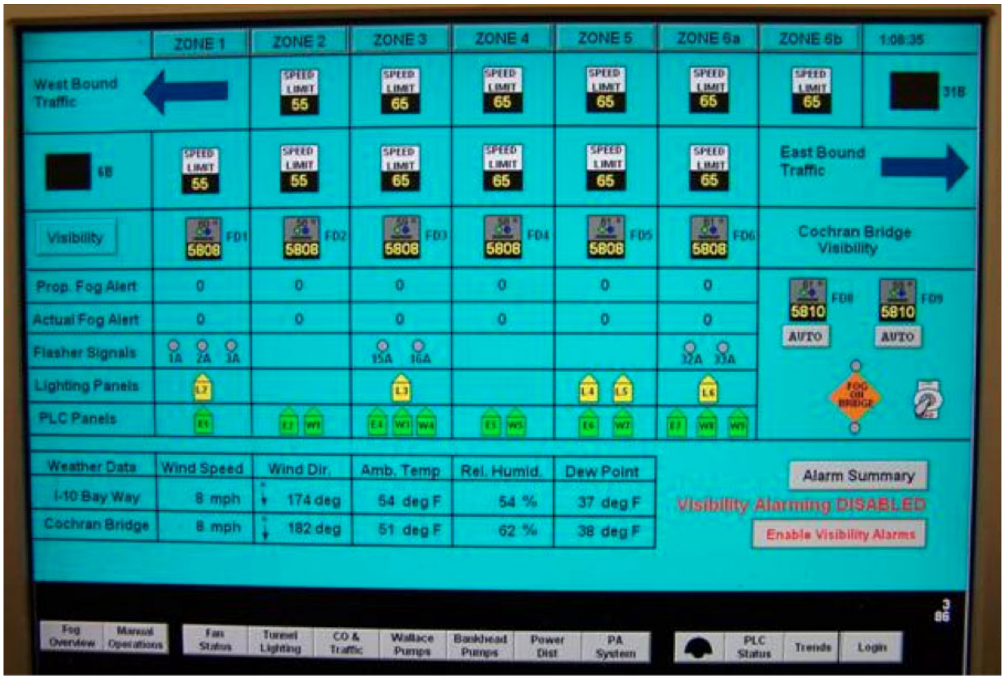

Figure 2.5: Low-Visibility Warning System Interface

Pre-storm Impact Assessment. In addition to weather prediction and road condition reports, the Utah Department of Transportation (UDOT) uses information from multiple sources *(28)*, including road weather information systems, to provide road weather impact forecasts. Weather impact graphics accompany text forecasts and are posted as Road Weather Alerts on the UDOT traffic website. Each segment of Utah's state highways receives a manually composed forecast, which provides details pertinent to travelers. Information is updated hourly. The cost of the forecasting service using RWIS and other data is about $140,000 a year, although this total does not include the cost of setting up and maintaining the RWIS.

Emergency Management. Another interesting use of RWIS information is in emergency management. In Germany, the Fire Brigades Emergency Weather Information System (FeWIS) uses real-time weather information to make decisions regarding emergency response *(5)*. Weather information is forwarded to six regional centers and various levels of warnings are provided, from "early warning" to "severe weather warning." In addition to the weather information, FeWIS includes information regarding the possibility of forest fires (e.g., temperature and relative humidity) and the potential for flooding and lightning strikes (precipitation and barometric pressure). An advanced system that uses RWIS data for emergency management was also recommended for use in Pennsylvania *(29)*. Weather information obtained from RWISs is used in a series of roles, including traffic management, road closure reporting, and emergency response. Based on information found on Pennsylvania's transportation website (http://www.511pa.com/), it does not appear that these recommendations have been implemented.

Inter-vehicle Communication of Weather Information. An interesting new idea that may impact RWIS use in the future is the use of motor vehicles as interconnected mobile road weather sensors *(30)*. The idea considers including air temperature and barometric pressure sensors in a vehicle as part of standard equipment (Figure 2.6). This information is shared with other vehicles and roadside readers using vehicle infrastructure integration (VII) protocols. It is argued that the information could ultimately be augmented with pavement temperature and precipitation information and transferred to state DOTs to fill the gap in information obtained from state-owned RWISs.

Figure 2.6: Prototype RWIS-enabled vehicle under consideration in Connecticut

Environmental Management. A 2010 report advocates for the use of RWISs in areas of environmental management *(31)*. The report documents potential uses of wind and pavement temperature information for road repair, herbicide spraying, bridge painting, and highway striping. It was even mentioned that a history of wind information collected from RWISs could be used in developing evacuation plans for nuclear power plants. The use of RWIS data has also been proposed for wildfire tracking (using cameras or RFID readers, presumably) and an assessment of environmental conditions due to spills of hazardous chemicals *(32)*.

Climate Change Tracking. An interesting use of RWIS data was the long-term study of climate change in Finland and Sweden based on recorded weather parameters *(33)*. Weather data (precipitation, road surface and air temperature, and wind speed) were collected by Swedish and Finnish road management departments over a ten-year time period. Data from a total of 99 RWIS facilities were used. Precipitation was measured using infrared light sensors at an accuracy of millimeters. Road surface temperatures were measured at 1 cm into the road bed, and air temperature was measured 2 m above the ground. Following the end of data collection in March 2008, data processing was performed to develop a database that could be analyzed with statistical methods. At the writing of the report, data analysis was still in progress to assess the degree of climate change in the three climate zones that cover the countries of Sweden and Finland.

Fixed Automated Spray Technology. Several domestic departments of transportation *(34)(35)* have explored the use of fixed automated spray technology (FAST) in conjunction with RWISs. These systems either automatically enable the deployment of anti-icing chemicals or enable their application after interpretation of RWIS data by a human operator. A recent study from North Dakota determined that an automatically enabled system is 95% reliable *(34)*. Pavement condition and temperature values are read from environmental sensors (see example of Buxton Bridge in Figure 2.7), and a computer algorithm can then trigger spraying. A significant reduction in motor accidents was recorded after the installation of the system on two bridges in 2002. The specific algorithm parameters can be triggered using the Vaisala ScanWeb interface. A second study *(35)* determined that the use of FAST can be cost beneficial if used with supporting RWISs. According to the report, proactive treatment is best performed with automated systems that enable spraying after the evaluation of road surface condition. Experiments with calcium chloride applied at a rate of 8 gallons per use were particularly effective. Nebraska has a similar FAST deployment on a bridge that is part of an interstate highway *(36)*. An RWIS at the location collects air and surface temperature, precipitation, dew and freezing points, and wind speed and direction. A fixed automated spray system that uses a deicing chemical is then deployed under likely icing conditions. It is not clear if the spraying is triggered automatically or manually.

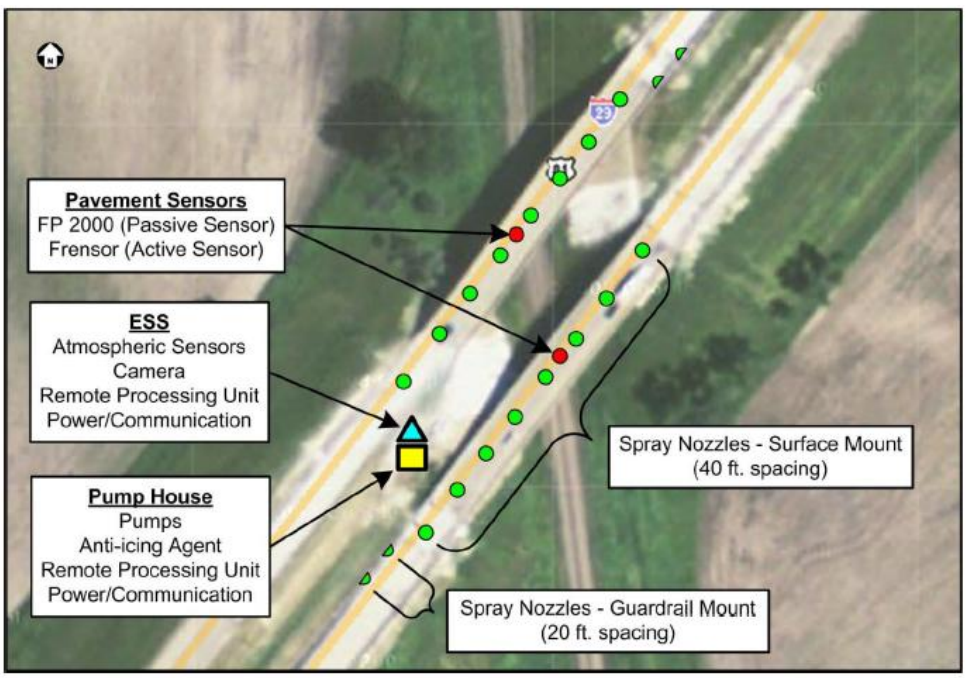

Figure 2.7: I-29 Buxton Bridge FAST system components

Load Restrictions for Roadways. RWIS data has also been used to develop a set of load restrictions on roads for trucks and other vehicles at different times of the year *(37)*. RWIS data is used to evaluate the amount of frost on pavement under various climate conditions. An evaluation of this data and a series of physical measurements determined a correlation between these RWIS parameters and measured frost depth. This information was then used to estimate the impact of thawing to help estimate load restrictions on trucks and other vehicles on the roadway. Software was used to determine how much pavement was stressed by loading under various frost/thaw scenarios in an effort to increase pavement service life. Information from three separate RWIS stations was collated to estimate pavement conditions for a specific experimental location.

Road Repair. The State of New York has recently decided to upgrade its RWIS system to move beyond simply collecting information for snow and ice response to include paving, crack sealing, and pavement striping *(3)(38)*. In several recent public releases, the state has requested information on ideas for improving the use of information from fixed and portable RWISs for forecasting, data sharing with neighboring states, and integration with a current 511 system.

2.4 RWIS Collaborations

According to a 2010 report by J. Rall *(1)*, there is increasing interest among the 44 states that use RWISs in enhancing collaboration and sharing weather data. Currently, at least 33 states are part of the FHWA-sponsored Clarus Initiative *(21)*, which allows for the integration of weather information from many sources. The abundance of data allows for robust quality checks and increased confidence in using the data to make road maintenance decisions. The real-time availability of Clarus information makes RWIS stations important aspects of the initiative. The initiative also aims to encourage partnerships across the transportation and weather communities via the sharing of the data *(29)*. Clarus data can be accessed in many ways, including via a web-based interface.

Two other national programs promote the sharing of RWIS information across state borders. The Clear Roads project encourages the field testing of improved approaches for winter road operations *(39)*. The effort currently includes participation from 26 states. The project aims to deliver useful data and recommendations about winter road treatment, although not in real time. The One-Stop-Shop web application (http://oss.weathershare.org/) provides travelers in California, Oregon, Nevada, and Washington with comprehensive, real-time data that can be employed in planning their trip. Previously, this data was only available separately from various state DOT websites. This information consists of both traditional information (routing, imagery, weather, etc.), as well as points of interest and other route-specific information (elevations, rest areas, etc.).

The Aurora organization is an international partnership of public agencies working together to perform road weather–related research. Its main objective is the improved development of RWISs *(40)*. Started in 1996, the program focuses on the integration of RWIS data to support highway maintenance and provide real-time information for travelers. Support for open architectures is particularly encouraged. Aurora has become a tremendous resource of RWIS information, through its knowledge base (http://www.aurora-program.org/knowledgebase).

2.5 Emerging RWIS Technology

The expanding range of RWIS applications is driven by the availability of new RWIS technology. In this section, recent advances in communications, data processing, RWIS sensors, and other technology are documented.

Communications equipment. Transportation departments typically support a variety of communication mechanisms to transfer data from distributed RWIS equipment to centralized processing facilities. A recent survey of wired and wireless technologies is presented in Geiseman's final report of the Aurora Project *(41)*. Wired technologies generally consist of dial-up telephone or fiber-optic links. Dial-up phone lines, although widely accessible, have strict bandwidth limitations, making video and image transfers difficult. Fiber optic transmission, although much faster, is generally not accessible in areas where RWISs are situated. Most RWIS systems use wireless communications for data transfer. Cellular service generally provides the most reliable way to transmit data. For example, 3G cellular protocol offers up to 7 Mb/second transfer rates. An alternative approach is the use of spread spectrum technology, which typically requires customized communication equipment. According to Gieseman, "Spread spectrum methods allow for denser subscriber counts, reduced channel interference, and higher noise immunity, supporting greater range for a given transmission power." Additional advantages of the spread spectrum approach were detailed by J. Stickel in a 2006 report *(42)*. This presentation noted that the use of spread spectrum technology eliminates the cost of cellular service and does not require licensing (communication is in the public 902-925 MHz band). However, the communication installations require line of sight communication, which may be difficult for many RWIS deployments. A low bandwidth of 38,400 bits/second was reported, although the communications platform was able to handle Internet protocol (IP). Earlier experiments in Florida *(43)* showed that 900 MHz spread spectrum communication is particularly effective for systems that include both permanent and portable RWIS installations. Communication takes place over a distance of 10 miles, using transmission towers of 200 feet in height at the permanent sites.

The Utah DOT reports that RWIS communication can be a challenge in hilly or mountainous terrain *(44)*. Although cellular communication is preferred due to its relatively low cost, communication with National Weather Service satellites is necessary in at least three locales. Denmark has developed a robust communication infrastructure for maintaining communication with an RWIS *(22)*. A specialized software system (GateManager) constantly evaluates the state of the communication lines and monitoring equipment associated with the RWIS. Data from the RWIS are collected every 5 minutes, using Internet protocol. Interestingly, Denmark still relies heavily on wired communication (95% of connections use wired communication). There is a 2-minute delay from when data is received from an RWIS until it is processed and made available to road managers.

Support for webcams. Recently, Iowa has installed high-end color cameras on its 62 RWIS locations *(45)*. These devices are used to capture high-quality video and still images of the surrounding landscape and roadways (note the Images tab at http://weatherview.iowadot.gov/).

Modern RWIS instruments. Given the large volumes of data generated by RWISs, efficient techniques to store, process, and manage the data are necessary. In general, all RWIS components (including those from different vendors) should use similar data formats to allow for straightforward integration *(44)*. The use of NTCIP-compatible equipment *(46)* greatly helps in this effort. Iowa has recently invested in new precipitation sensors, weather identifiers, and visibility sensors (WIVIS) *(45)*. These sensors assess the rate and nature of precipitation (e.g., rain and snow), along with visibility. New Hampshire has a collection of advanced RWISs that provide wind speed, barometric pressure, air temperature, and visibility, among other values *(17)*. Precipitation sensors determine the type and extent of measured precipitation. In some cases, RWISs were instrumented with equipment to perform traffic counts. Each RWIS includes a computerized processing unit that collects and collates information from up to 31 RWIS sensors. All communication is compliant with NTCIP regulations. Advanced modern RWISs can contain sensors that have extensive capabilities beyond their predecessors. The ASFT RWIS from Cotelsa, Inc. *(47)* includes advanced sensors for ambient temperature, cloud height, and relative humidity.

Pavement temperature sensors. Key statistics in many RWIS applications are pavement temperature and moisture. In a comprehensive study, the accuracy and usability of data from pavement sensors were examined *(48)*. Measurements from an RWIS puck sensor were compared with a sensor based on infrared measurement technology. The existing sensor was a flush-mounted puck capable of detecting pavement surface temperature, dry, wet, and chemical wet, as well as snow and ice conditions. It requires no recalibration, although periodic cleaning is recommended to prevent buildup in the sensor’s well. This sensor was connected to a software package that allows users to monitor surface conditions over the Internet. At the same location, an infrared camera capable of measuring spectral differences to distinguish among various phases of water was installed. The results of the comparison demonstrate that measurements from any sensor require interpretation. While the embedded sensors appeared to perform better in detecting slush, the infrared sensor was superior in detecting snow and ice. In Iowa, a new type of embedded pavement temperature sensor *(45)* was recently tested that provides more accurate temperature readings. The temperature data probe (TDP) is a state-of-the-art probe that measures road subsurface temperatures every 3 inches for the first 18 inches of depth, and then every 6 inches down to 6 feet below the surface. This data provide a broader spectrum of information regarding road condition.

Display technology. As the use of RWISs has become more diverse, the technology used to disseminate the information to users has advanced as well. For example, new communication media, such as Twitter and smartphone text messaging applications, have been used to effectively communicate real-time road weather information to users, in addition to the traditional 511 traffic information phone line. An example of the types of weather alerts that are available are shown in Figure 2.8 *(49)*.

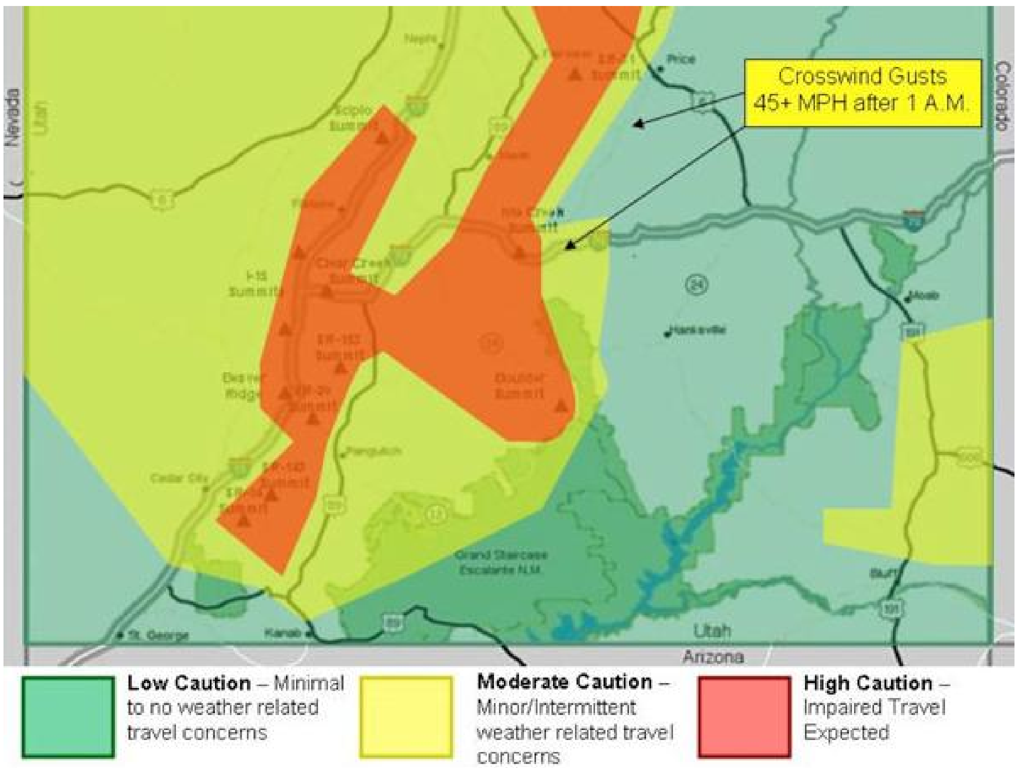

Figure 2.8: Weather impact graphic, Utah Department of Transportation

Japan has been a leader in the formatting and dissemination of weather data collected from RWISs, per Pisano et al. *(50)*. Recent work has focused on improving communications platforms and the data formats used to send data between remote RWISs and operations centers. The increasing use of Internet browsers and the web has led some DOTs to consider special data formats to make it easier to manipulate data. Japan has pioneered the development of a special language for road data, the Road Web Markup Language (RWML). This language is based on the widely used eXtensible Markup Language (XML), but it is optimized for road data. According to Pisano et al. *(50)*, "Road-related information is grouped into four categories: road information, weather information, disaster information, and regional information. RWML enables road weather information to be distributed easily on the Internet to PCs in road administration offices and maintenance garages."

Although RWIS information is primarily used for road management during the winter, it can also be used for traffic control. Values are often confirmed by patrols and information from cameras. In addition to data formatting, specialized database formats have been created for RWIS data. In Sweden, an open server SQL database and web server for road weather data was created *(51)*. This server allows for straightforward access to RWIS installations in the field and expedited retrieval of data stored in the database. According to the reference, one server can support numerous RWIS installations. A personal computer can be used to access information in the database and display the output.

2.6 RWIS Cost Considerations

The use of real-time RWIS information to condition roadways has been demonstrated to achieve significant cost savings. In general, the overhead of installing and maintaining RWISs is small relative to the cost savings for more precise deployment of labor and road treatment chemicals prior to and during storms. A detailed cost-benefit analysis *(1)* estimated that cost-to-benefit ratios of between 2:1 and 10:1 were achieved in the 44 states with RWISs that were surveyed. The report estimates that Utah saved $2.2 million in labor and materials as a result of RWIS use. In Idaho, labor and materials costs during storms were reduced by over 60% and crashes by about 80%. Similar safety improvements were observed in other states. A typical RWIS installation is estimated to cost about $35,000, with annual maintenance costs of about $3,000 per site on average *(1)*. Communication costs (e.g., cell service) typically run about $500 per site annually. A separate report *(52)* noted similar cost-benefit numbers for RWIS usage. For example, about $1,500 per RWIS location per storm was saved in Kansas by using information from an RWIS in deploying personnel and equipment. The return on investment in RWIS stations in Minnesota was between 13:1 and 2:1. The Oregon Department of Transportation reported that it expects to save $7 million over 25 years due to a reduction in labor and decreased deicing chemical cost. In 2003, the Ohio Division of Highway Operations extended their current RWIS system by 86 sites *(10)*. The cost of this expansion was $3.69 million, for an average per-site cost of about $43,000. This figure included the cost of the RWIS components, power, and communication. After deployment, this system allowed for pre-storm preventive care that reduced costs by a 5:1 ratio versus post-storm ice removal. It is noted that the use of RWIS information is particularly important for rural areas.

Specialized RWISs, such as fixed automated spray technology systems, also can lead to cost savings. North Dakota State University examined the cost benefits of using automated FAST technology *(34)*. Cost savings were a result of reduced labor costs and chemical deposition. Societal benefits included fewer crashes. For two bridges, benefit-cost ratios of 4.3:1 ($1,257,869) and 1.3:1 ($675,184), respectively, were achieved, versus alternate ice treatment approaches.

Communications costs between RWISs and a central data repository can be a significant recurring cost for the systems. Satellite communication is an alternative for RWISs situated in remote locations that do not have cell coverage *(17)*. Unfortunately, satellite communication is often three to four times more expensive than even the most low-cost cellular plans (e.g., $60 versus $15 per month). It is mentioned that satellite coverage does allow for data polling every 15 minutes. Pennsylvania assumed that communications costs are approximately $40 a month and are likely to grow to $120 per month as the diversity of data to be transmitted grows. Optimizing communication data protocols also makes a significant difference in system reliability and cost. The cost savings associated with converting all RWIS communication to Internet protocol (IP) is particularly appealing *(22)*. After conversion to IP, data can be compressed and transmitted more reliably. After a communication protocol conversion to IP, data communication costs per installation dropped by more than $1,000 per year. Additionally, webcam images from 15% of the sites were easily integrated into the new protocol.

Weather-related information and warning services distributed via mass media to roadway users were shown to reduce all accidents involving personal injury or death on public roads in Finland by about 1% to 2% *(53)*. For example, the report indicates that when presented with accurate roadway information regarding impending bad driving conditions, about 6% of drivers will change their route or allow for more time to reach their destination. After the use of road signs indicating fog, typical drivers will reduce their speed by about 2 mph. Overall, the availability of travel data reduced the risk of injury by about 8% on Nordic roads. The authors of the report generated an analytical model that assesses the likely decrease in accidents as a function of the availability of weather information from sources such as RWISs. The Utah Department of Transportation provides hourly updates to travelers based on information obtained from RWISs *(49)*. It is estimated that it costs $140,000 per year to provide this information to the public via a web-based interface.

2.7 Portable RWISs

In this section, portable RWISs are surveyed. A summary of the information in this section is shown in Table 2.1. As each system is described, it is assigned a shorthand code (e.g., P1 for Portable System 1), which is included in both the text and in the table. This code is used in later sections to refer to specific systems.

Table 2.1: Summary of documented portable RWISs

Label	Location	Company	Sponsor/ Standard	Communica-tion Interface	Power	Sensors	Cost per unit
P1	Kansas/ Colorado	High Sierra 5721	NTCIP	unclear	Traffic cabinet	Pavement temp., precipitation, road surface	$2,800, not including traffic cabinet cost
P2	Texas	High Sierra 5470	NTCIP	Ethernet	Traffic Cabinet	Water level, flood data	$28,800 total. 5470 and software costs $12,150
P3	Manhattan, Kansas	High Sierra 5470	NTCIP	Ethernet	Traffic Cabinet	Flood, wind, road surface status, rain gauge	$28,800 total. 5470 and software costs $12,150
P4	Iowa	Vaisala MAWS/ WXT520	Aurora/ Clarus	Cellular	Solar/ battery	Wind, air, and surface temp., rain, pressure	$3,000
P5	Missouri	Vaisala					$21,000
P6	Utah	Vaisala/ Campbell		Cellular	Solar/ battery	Wind, temp., rain, humidity, pressure	$14,000
P7	Nevada			Cellular/ WIFI	Solar/ battery	Camera/flow detector	$18,000 (not including trailer)
P8	Florida			Radio	Solar/ battery	Undefined weather	

Several commercial offerings have served as the basis of portable RWIS installations that have been deployed by transportation departments.

Systems based on the High Sierra 5721. This road sensor station *(54)* is a NTCIP-compliant system used to warn of icing conditions on roadways. As seen in Figure 2.9, the system contains a signal processing unit, a road surface wet/dry/ice sensor, and an optional embedded road temperature sensor. Power and communications capabilities are obtained from the traffic cabinet that holds the sensor station, and the station can be quickly installed or removed. The unit is low-cost ($2,800) and not expandable and only supports very low-speed 9600 baud serial communication to an attached host processor. The 5721 has been used in several locations (P1), including Denver, Colorado *(55)*, and Overland Park, Kansas *(56)*, to evaluate pavement conditions. Although cost effective, the system's lack of expandability and need for a "puck" sensor embedded in roadway pavement to determine roadway temperature limit its application space.

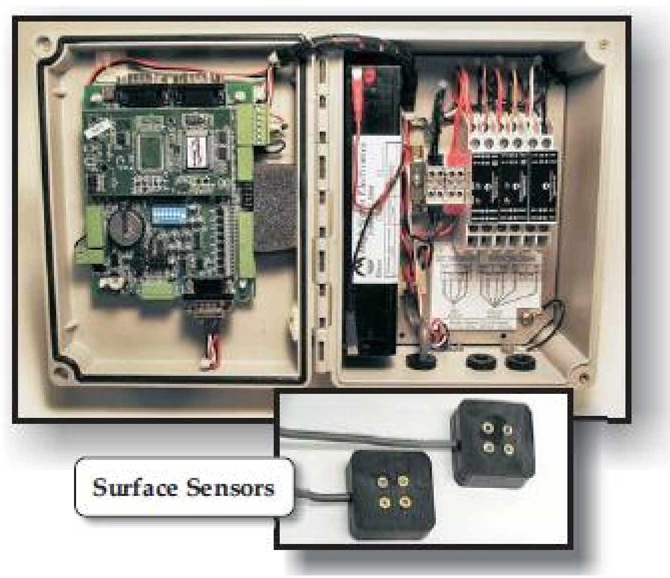

Figure 2.9: High Sierra 5721 RWIS Road Sensor Station

Systems based on the High Sierra 5470. This remote processing unit (RPU) *(57)* is the basis of more advanced portable RWISs. The NTCIP-compliant system is typically mounted in a traffic cabinet, and it contains an Ethernet interface for attachment to a high-speed communications interface. The expandable system can be used with a wide range of sensors, including an optical road surface sensor (determines surface and air temperature and coefficient of friction), visibility sensor, and wind speed sensor. In Harris County, Texas *(55)*, the system (P2) is deployed using a semi-permanent setup, including a 10-foot-high pole, traffic box including network connection and AC power, and flood indicator. The unit also forms the basis of a system (P3) that has recently been ordered by the Traffic Division of Manhattan, Kansas *(58)*. The ordered system, which includes a precipitation sensor, wet/dry pavement sensor, road surface temperature sensor, and the 5470 RPU, costs $28,850 in total. Interestingly, the RPU ($4,150) and associated software ($8,000) cost half of the total.

Systems based on Vaisala weather station products. Several years ago, a portable RWIS installation (P4) was implemented based on a Vaisala mobile weather station. The system, developed for the Iowa Department of Transportation *(59)*, includes a Vaisala MAWS *(60)* data logger and a WXT520 all-in-one sensor that can record wind speed and direction, air temperature, precipitation level, and barometric pressure. The logger, sensor, battery, and solar panel are mounted on a 10-foot collapsible pole. Figure 2.10 shows this system, which includes a Vaisala MAWS data logger (see box attached to pole) and WXT520 all-on-one sensor unit (top). In total, the system costs about $3,000 *(61)*. Data is communicated with a central server every ten minutes via a cellphone modem included in a separate cabinet. The Iowa DOT has recently decided to mount the system on a trailer and add a non-contact infrared pavement temperature sensor to the system. The accuracy of the sensors in the system versus more expensive alternatives is not provided. More extensive portable RWISs based on Vaisala products, which include trailers, communications equipment, and multiple sensors, are considerably more expensive. Although specific system details are not provided, the state of Missouri has recently contracted with Vaisala *(62)* to purchase seven portable RWIS systems (P5) at a cost of $150,000.

Figure 2.10: Iowa portable RWIS

Systems based on defunct products. The OmniWeather system by Systems Innovations *(63)* is a portable weather station which can be quickly assembled in the field. An interesting aspect of the system is its use of satellite communications to transmit weather data. After an extensive literature search, no further information about the product could be found and Systems Innovations appears to have ceased operations.

A number of organizations have developed portable RWIS stations by combining off-the-shelf components from various sources and customizing the systems to their needs.

Utah Department of Transportation. In 2007, the Utah Department of Transportation deployed four RWISs (P6) using traffic trailers *(64)*. The systems include sensors for wind speed, temperature, precipitation, humidity, and barometric pressure. System power is provided by a battery and a solar panel. A wireless communication device provides connectivity to the Verizon cellular network. The total cost of a system (not including the trailer and a traffic counter) was about $14,000. Sensors were purchased from Vaisala and Campbell Scientific.

Nevada Department of Transportation. An interesting set of trailer-based portable systems (P7) was developed by the Nevada Department of Transportation *(65).* Although these systems are used for traffic flow management rather than roadway weather monitoring, their power and communications frameworks are of interest. Power is provided by a combination of batteries and solar panels. A 4.9 GHz cellular router is used for communications, although a Wi-Fi connection can also be used if a hotspot is available. The total cost of components, not considering traffic cameras, was about $10,000, with an additional $18,000 needed for the trailer.

Florida. The State of Florida *(66)* has proposed using portable, solar-powered, wireless weather sensors (P8) to augment fixed tower locations. Specialized radio communications are used to allow for weather information transmission. Limited information regarding system organization, communications, and power is available.

2.8 RWIS Summary

Road weather information systems are increasing in importance for a wide variety of roadway operations. In this chapter, the latest technology was reviewed and benefits and limitations were identified. This information provided a solid basis for the selection of prototype equipment for this project. More background information on mobile, portable, and stationary RWISs can be found in two 2013 reports by Tessier et al. *(67)(68).*

3.0 Results of State DOT Review and Field Tests

This chapter details the two portable RWIS prototypes that were constructed by students and faculty at the University of Massachusetts. The results of field tests using the equipment are also presented. The selection of RWIS components was performed in consultation with officials at MassDOT. The two prototype systems were constructed using equipment from High Sierra Electronics and Vaisala Corporation. Throughout this chapter, the systems are referred to as the High Sierra RWIS and the Vaisala RWIS.

3.1 Vaisala RWIS

This section describes the operation, function, installation, and connectivity of the Vaisala RWIS components. A connectivity diagram of the Vaisala RWIS developed at UMass is given in Figure 3.1, and Table 3.1 gives a summary of Vaisala sensors chosen for the portable RWIS.

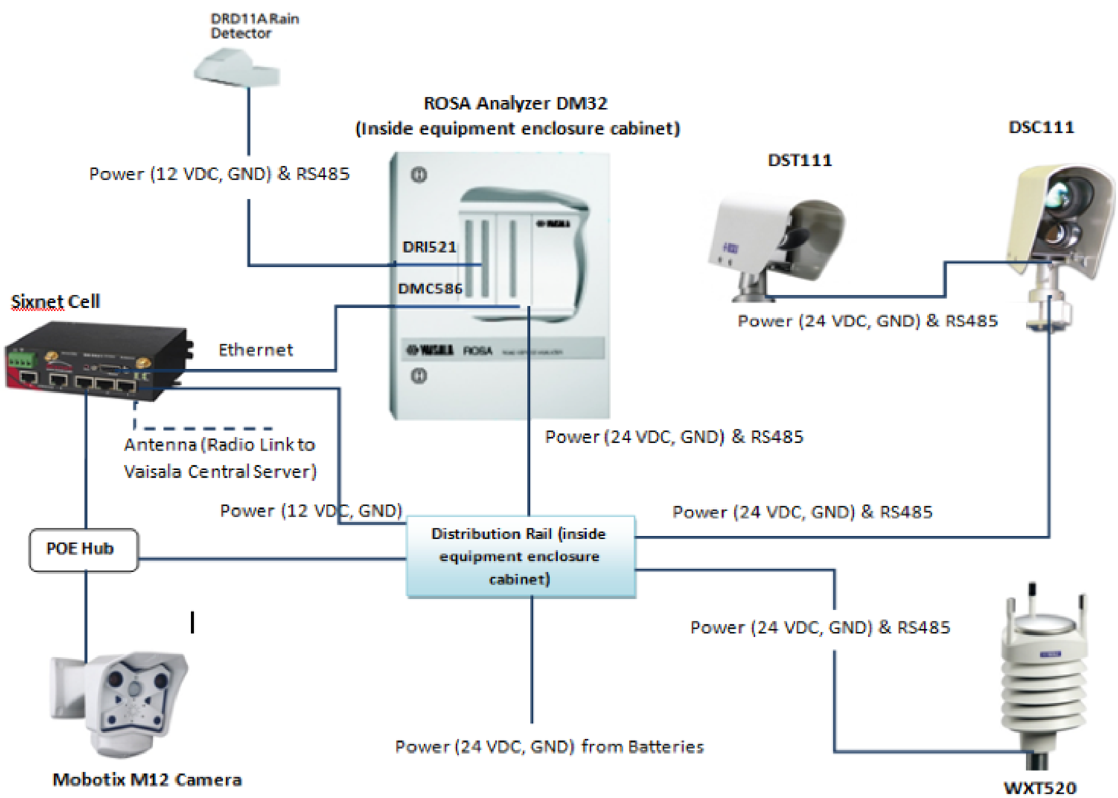

Figure 3.1: Connectivity diagram of Vaisala RWIS components

Table 3.1: Sensor configuration in Vaisala RWIS

Unit Name	Function	Communica-tion Interface	Voltage Requirements	Power
ROSA Analyzer	RPU	Ethernet, RS485, RS232	24 VDC	0.8 W (DRI521) without sensors
DSC111	Road Surface State Sensor	RS485, RS232	24 VDC	1.2 W (above -10˚F) max 1.9 W (below -10˚F)
DST111	Road Surface Temperature Sensor	RS485, RS232 (via DSC111)	24 VDC (via DSC111)	33 mW
DRD11A	Precipitation Sensor	-	12 VDC	0.5–2.3 W
WXT520	Wind, pressure, temperature, relative humidity,	RS485	5-32 VDC	max 1.1 A @ 12 VDC max 0.6 A @ 24 VDC
M12 Camera	Camera	Ethernet	Power over Ethernet	3W
Sixnet BT-6621	Modem	Ethernet	8–30 VDC	125m @ 24 VDC (standby) 175m @ 24 VDC (transmitting) 290m @ 24 VDC (peaks)

The ROSA analyzer is a remote processing unit/data logger for the Vaisala RWIS. It analyzes data received from sensors and gives necessary warnings to users if unusual conditions are noted *(33)*. It is the heart of the system, since it polls all sensor data; raw data is processed and converted to NTCIP format for dissemination to remote servers. Thus, communication with the sensors is made through the ROSA analyzer. It also acts as the power distribution unit to the sensors, keeps records of the sensor data, and issues alarms and warnings for maintenance. The DRI521 interface card contains all necessary software packages for measurements, algorithms, and other procedures to fulfill the road state analysis and communication in a ROSA network.

Hardware Structure and Connectivity. DM32 is the product name of the ROSA analyzer unit. Power distribution circuitry is housed in this unit. The DM32 consists of two modules: the DRI521 interface card and the DMC586 processing unit. The DMF133 is the frame that holds the DRI521 and DMC586. A wide variety of sensors can be connected to the DM32.

The unit is polled by the Vaisala central server every ten minutes via a cell modem. All sensors draw power from the ROSA analyzer and communicate using an RS485 interface.

DRI521 Interface Card. This card provides data collection, intelligent road state analysis, and communications and system support. It has an interface to both analog (precipitation) and digital sensors. The DRI521 card has a DC power supply input and multiplexed serial lines for RS232 and RS485 connectivity. The DRI521 has a microprocessor with additional I/O circuits and an A/D converter. The card contains a calendar clock and a RAM memory with battery backup. The flash memory includes history storage for 144 message blocks. In addition, the DRI521 consists of electrically reprogrammable FLASH EPROM (128 kb) for program memory, for remote program update download.

DMC586 card. This module has communication interfaces for RS232, RS485, and Ethernet protocols. The ROSA analyzer communicates with a cell modem using an Ethernet connection. The ROSA analyzer requires 24 VDC for operation. Power from a battery/solar panel system is connected to the power input port on the DRI521 through the distribution supply rail.

Remote Road Surface State Sensor (DSC111). The DSC111 is a non-invasive pavement sensor that uses spectroscopic methods to determine pavement condition and water film depths. It can report the state of the road surface as dry, moist, wet, snow, frost, ice, and slush *(69)*. The slipperiness of the road surface due to ice can also be measured. It can also detect visibility conditions using an optional integrated visibility sensor.

The DSC111 has an infrared transmitter and receiver. The transmitter aims at a selected spot on the road surface, and the receiver receives the reflection of the transmitted light from the measurement spot. By measuring the wavelengths of the reflected light, the sensor can distinguish between the different states of the road surface. By measuring the depth of ice and some other parameters, the DSC111 can measure the slipperiness of the road surface. It calculates a scaling index called “grip,” which is based on friction under different road weather conditions.

The unit is a processor-based system, connected to the Vaisala data logger (ROSA analyzer) using the RS485 bus. The data from the sensor is polled automatically by the ROSA using the RS485 bus. This bus can also be accessed remotely or locally by a user. A user can interrogate DSC111 data through the ROSA using specific commands. The DSC111 can also be accessed with a PC or a laptop using an RS232 port. The DSC111 has integrated power and a RS485 interface connector (M12), which is connected to the distribution supply rail in the ROSA equipment enclosure cabinet. The DST111 is connected in a daisy chain connection with the DSC111 for power and RS485 communication. A connectivity diagram showing the connections between the DSC111, DST111, and ROSA analyzer is given in Figure 3.2 *(70)*. The average power consumption of DSC111 is between 1.2 W and 1.9 W. The operating voltage for the unit is 24 VDC *(69)*.

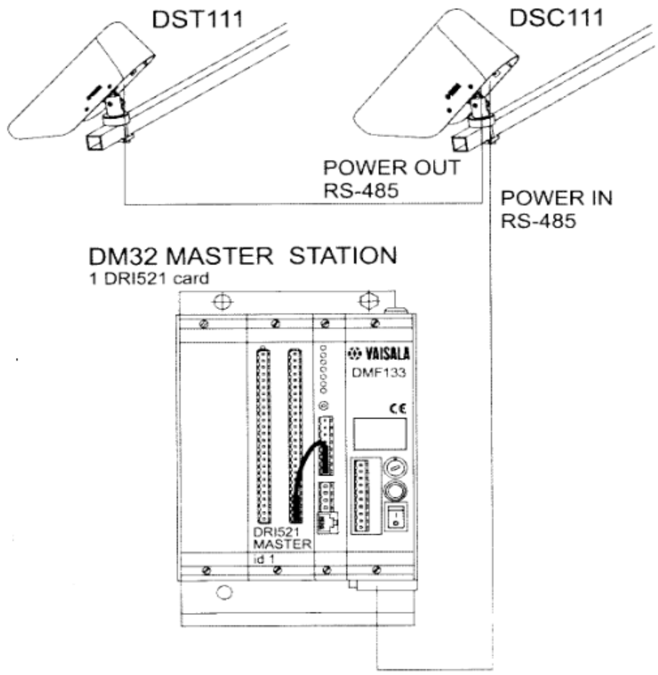

Figure 3.2: DSC111 and DST111 connected to the ROSA analyzer

Remote Road Surface Temperature Sensor DST111. The DST111 is a non-invasive pavement sensor from Vaisala that is used for measuring road surface temperature *(71)*. It also measures the relative humidity and air temperature. The DST111 is based on long-wave infrared radiation. It measures the emissions from the road surface at a selected wavelength range and determines the temperature difference between the unit and the road surface. The change in emissivity for different road surface states has minimal effect on the sensor's performance.

The unit is a processor-based sensor that is connected to the DSC111. The DSC111 sensor gathers data from the DST111 and makes it available to the ROSA analyzer or a host computer. The ROSA analyzer automatically polls the DST111 through the DSC111 at fixed intervals to gather its data and make it available to an end user. The average power consumption of the unit is 33 mW at 24 VDC *(71)*. The unit requires 24 VDC for its operation.

Vaisala Rain Detector DRD11A. The precipitation sensor selected for the Vaisala portable RWIS is the Rain Detector DRD11A. The unit is a capacitive sensor and can be used for detection of rain and snow. Figure 3.3 shows a picture of DRD11A.

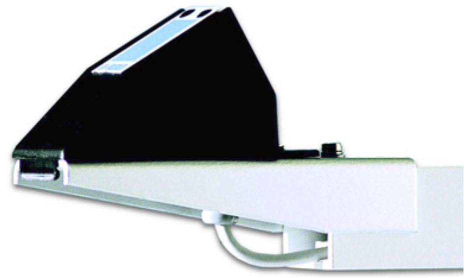

Figure 3.3: Vaisala Rain Detector DRD11A

The sensor detects the presence of rain on the active portion of the sensor plate. The DRD11A consists of a thick layer sensor RainCap^{TM} that works using capacitive principles *(72)*. There is an internal heater to keep the sensor plate dry and reduce the effects of dew or fog. The DRD11A can also detect the presence of snow, since the heater melts the snow on the sensor plate by keeping the temperature of the plate over freezing. The unit has two different outputs, Rain On/Off and Analog Out. The Rain On/Off output is based on droplet detection. Delay circuitry inside the sensor allows a two-minute interval between raindrops before assuming an OFF (no rain) position. This enables the sensor to distinguish between rain cessation and light rain. Analog Out is an analog signal that estimates the rain intensity. The amplitude and variation of this signal is directly impacted by the percentage of moist or wet area on the sensor plate.

For the portable RWIS, the DRD11A is directly connected to the interface card DRI521 in the ROSA analyzer. This allows the sensor data to be polled by the ROSA analyzer, which can be accessed using a host computer, or transmitted directly to a remote server for further processing. This sensor is mounted using a mounting plate. A windshield is also installed around the sensor. Since the sensor plate is capacitive and highly sensitive, it should not be touched without being grounded. The sensor may require cleaning to prevent dust accumulation. The operating voltage for the unit is 12 VDC. It draws power from the ROSA analyzer. The power consumption is mainly due to the heater and varies between 0.5 and 2.3 W *(72).*

Vaisala Weather Transmitter WXT520. The Weather Transmitter WXT520 unit is a compact transmitter that measures six weather parameters. It measures wind speed and direction, precipitation, atmospheric pressure, temperature, and relative humidity. It consists of three wind transducers, a precipitation sensor, a pressure sensor, and humidity and temperature sensors *(73)*. The WXT520 for the portable RWIS has an integrated heating element to keep the precipitation and wind sensors clean from snow and ice. Figure 3.4 shows a picture of the Vaisala WXT520.

Figure 3.4: Vaisala Weather Transmitter WXT520

Horizontal wind speed and direction are measured using ultrasound *(73)*. The wind sensor has an array of three equally spaced ultrasonic transducers on a horizontal plane. Wind speed and direction are determined by measuring the time it takes the ultrasound to travel from each transducer to the other two. The wind sensor measures the transit time (in both directions) along the three paths established by the array of transducers. This transit time depends on the wind speed along the ultrasonic path. For zero wind speed, both the forward and reverse transit times are the same. With wind along the sound path, the upwind direction transit time increases and the downwind transit time decreases.

The precipitation sensor comprises a steel cover and a piezoelectrical sensor mounted on the bottom surface of the cover. Precipitation is measured one raindrop at a time. Whenever a raindrop hits the precipitation sensor, an electrical signal is produced that is proportional to the volume of the drop. The measured parameters are accumulated rainfall, rain current and peak intensity, and the duration of a rain event. The sensor is also capable of distinguishing hail from raindrops.

The pressure, temperature, and humidity (PTU) module contains separate sensors for pressure, temperature, and humidity measurement. It contains capacitive sensors for barometric pressure measurements, air temperature measurements, and humidity measurements. The PTU is housed in a radiation shield that protects it and reflects solar radiation. The measurement principles of the pressure, temperature, and humidity sensors are based on an advanced RC oscillator and two reference capacitors against which the capacitance of the sensors is continuously measured.

The WXT520 can be accessed through four different serial interfaces: RS232, RS485, RS422, and SDI-12 *(73)*. Only one serial interface can be used at a time. For this study, the sensor communicates with the ROSA analyzer using the RS485 serial interface. The eight-pin M12 connector and cable is connected to the distribution supply rail in the equipment enclosure cabinet for the ROSA analyzer to supply both power and RS485 connections. The unit can be configured directly using a PC or a laptop through the ROSA, which automatically polls the device for data.

The operating voltage of the unit is in the range of 5 to 32 VDC. Typical DC current ranges are: maximum 1.1 A at 12 VDC and maximum 0.6 A at 24 VDC. The power consumption of the WXT520 varies significantly, depending on the selected operating mode or protocol, the data interface type, the sensor configuration, and the measurement and reporting intervals. In this case, the unit requires 24 VDC.

Mobotix M12 Camera. A Mobotix M12 network camera was selected for use with the Vaisala RWIS. The camera uses an Ethernet interface to allow remote access to the captured images and real-time videos using a web browser. Figure 3.5 shows a picture of a Mobotix M12 camera *(74)*. The camera model is 12-SEC-DNIGHT-D43N43. It is a weatherproof camera and supports night vision. The image sensor allows for both color and black and white images. The resolution is 1280 x 960 pixels, with up to 10 frames per second for a megapixel video.

Figure 3.5: Mobotix M12 Camera

The unit allows live streaming and supports Voice over IP, ISDN, and Video SIP communication protocols *(74)*. The ROSA analyzer accesses the images from the camera using file transfer protocol (FTP). The camera neither fogs up nor requires heating, and thus power can be supplied using power over Ethernet (POE). Power is connected to the distribution supply rail in the ROSA equipment enclosure cabinet using a POE cable.

Sixnet Cell Modem BT-6621. A cell modem is used for transmitting data from the ROSA analyzer and the camera to a central server over a 3G wireless medium. The cell modem used for the Vaisala system is a Sixnet BT-6621 model. This modem allows communication over a CDMA cellular data network. The modem has five Ethernet ports. An antenna is connected to the modem. The power to the modem comes from the ROSA unit directly from pins 5 and 6 on the DRI521 interface card. The Ethernet port on ROSA's DMC586 card is connected with the modem. The modem's IP is required for establishing a connection with the ROSA analyzer through the modem. A data pack from Verizon is being used for the 3G CDMA connection. The modem is easy to set up, and modem utility software is used to configure the modem.

3.2 High Sierra RWIS

This section describes the selected RWIS components from High Sierra Electronics. All data from the High Sierra Remote Processing Unit (RPU) is collected at a central server owned by High Sierra and displayed on a website. Table 3.2 gives a summary of the selected sensors indicating their functions. A connectivity diagram of the RWIS system, along with the camera and modem, is given in Figure 3.6.

Table 3.2: Sensor configuration in High Sierra RWIS

Unit Name	Function	Communication Interface	Voltage Require-ment	Power Consumption
5470 NTCIP mini-RWIS	RPU	Ethernet, RS485, RS232	24 VDC	Less than 4 W
5433 IceSight 2020E	Road Surface Condition Sensor	RS485, RS232	12 VDC	4.2 W
WS600	Wind, atmospheric pressure, temperature, relative humidity, precipitation	RS485	24 VDC (max.)	160mA @ 24 VDC 1.7A @ 24 VDC (heating)
Netcam XL	Camera	Ethernet	12 VDC	500mA @ 12 VDC
Sixnet 6621 modem	4G Cell Modem	Ethernet	8–30 VDC	125mA @ 12 VDC (standby) 175mA @ 12 VDC (trans.) 290mA @ 12 VDC (peaks)

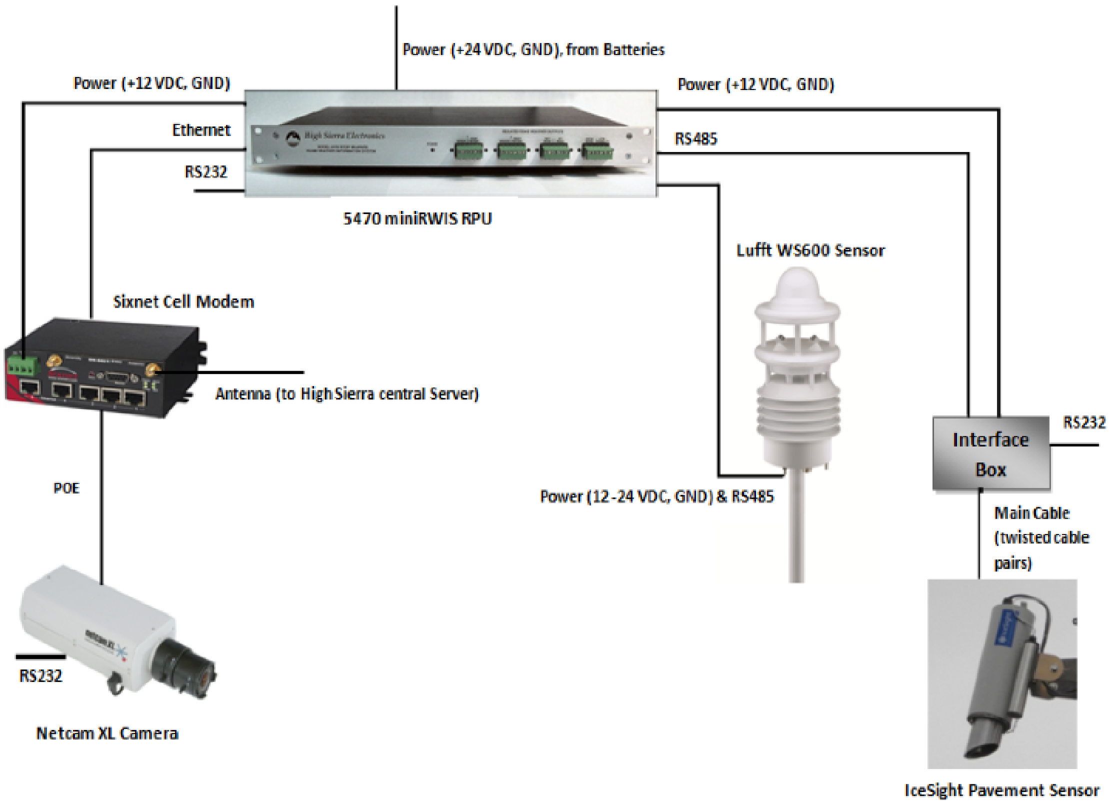

Figure 3.6: Connectivity diagram of High Sierra RWIS

5470 NTCIP RWIS Environmental Sensor Station Remote Processing Unit. The High Sierra 5470 NTCIP RWIS Environmental Sensor Station (ESS) Remote Processing Unit (mini-RWIS RPU) is a compact panel-based RPU used for RWIS applications, specifically weather responsive traffic management *(57)*. This RPU is the heart of the High Sierra RWIS. It supports NTCIP format. It has a 12-bit analog interface and road status detection algorithm for issuing warnings and alerts for the presence of ice. Figure 3.7 shows a picture of the mini-RWIS RPU.

Figure 3.7: High Sierra NTCIP mini-RWIS RPU

The heart of the system is the NTCIP controller board. There are eight internal analog-to-digital converters to convert analog sensor data to digital, as well as several RS485 and RS232 serial ports for connecting digital sensors. A Management Information Base has information regarding all sensors configured for a particular system. This information is stored as Object Identifiers (referred to as OIDs or Objects). The central server uses this database to configure the RPU and poll data from it. Once the sensor values are converted to digital values, the NTCIP controller processes the data and populates the appropriate OIDs.

The controller processes data from multiple input sensors and transmits stored sensor data when interrogated by central NTCIP-compliant software. Some of the weather sensors can be configured to activate relay outputs on the RPU to control traffic control equipment and public warning devices. For Objects with thresholds, the controller monitors the value, and once a high threshold value is exceeded, it will activate the designated output relay and front panel LED. Similarly, the output and LED are deactivated once the low threshold is reached.

The RPU distributes power to the various sensors. A nine-pin D-SUB connector on the front panel can be used for the IP set utility and RS232 communications. The Ethernet port on the RPU is connected to the cell modem in this portable system for data transmission using a cellular network. The RWIS is shipped from the factory pre-set for the sensors initially purchased with the unit. The WS600 and IceSight are connected directly to the input slots provided on the front RPU panel. The unit works at an operating voltage of 24 VDC. The power consumption is less than 4 W *(57)*.

Sierra Remote Road Surface Sensor: 5433 IceSight 2020E/EW. The IceSight is a non-invasive, remote sensing method of determining surface weather conditions on roads, sidewalks, and runways *(75)*. The sensor can detect surface ice, snow, and water and reports a condition of dry, damp, wet, snow, or ice. It can be connected to the mini-RWIS RPU in the prototype portable RWIS system. Instead of using two different pavement sensors (e.g., the Vaisala DSC111 and DST111), the IceSight alone can measure pavement temperature, pavement surface conditions, relative humidity, and surface grip. Possible reported surface states include one dry indication, three wet, two snow, and two ice indications. Additionally, a surface grip coefficient is also provided in two formats. It is suitable for both asphalt and concrete surfaces.

The IceSight uses laser and infrared electro-optical technology for its operation. It monitors the near-infrared spectral differences of the roadway surface to determine the condition of the surface *(75)*. The IceSight supports both RS232 and RS485 serial interfaces. It also supports direct connection to a WAP (wireless) or a local PC/Laptop for local debugging. The unit communicates with the mini-RWIS RPU via RS485 protocol. The power to the IceSight comes from the mini-RWIS RPU through the interface box. The RS485 terminal is also connected to the mini-RWIS RPU through the interface box. IceSight can be accessed locally using a Java Applet from a PC. The operating voltage is 12 VDC and the voltage range is 10 to 14 VDC. The power consumption is 4.2 W *(75)*.

Lufft Compact Weather Station WS600-UMB. The WS600 weather station from Lufft is an all-in-one weather station that measures precipitation, wind direction, wind speed, air temperature, relative humidity, and air pressure *(76)*. It uses a radar sensor for precipitation measurement. The WS600 has an integrated heater to avoid snow accumulation on the sensor surface. Figure 3.8 shows the hardware structure of the WS600 sensor.

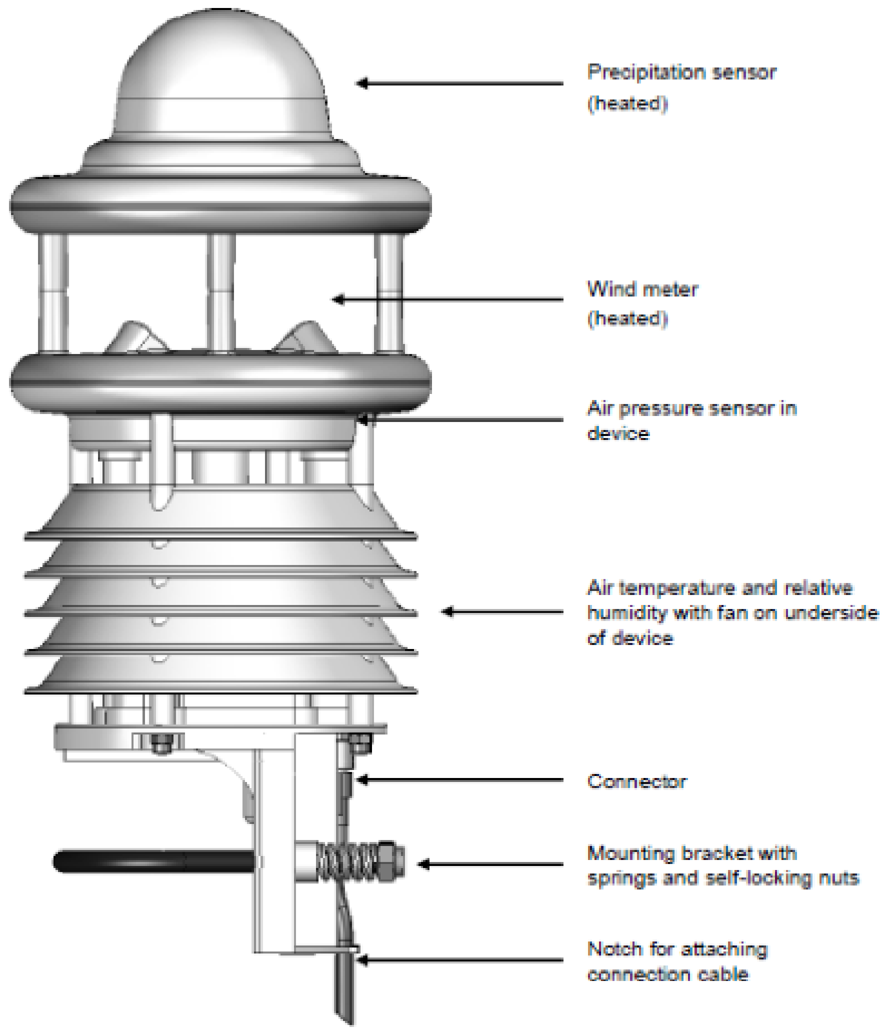

Figure 3.8: Hardware structure of Lufft Compact Weatherstation WS600-UMB

Operating Principle. The following discussion describes WS600 operation.

- Air temperature and humidity measurement. Temperature is measured using a highly accurate NTC-resistor, while humidity is measured using a capacitive humidity sensor.
- Air pressure measurement. Absolute air pressure is measured using a built-in sensor (MEMS). The relative air pressure is derived from the absolute air pressure.
- Wind measurement. The wind meter uses four ultrasonic sensors that take cyclical measurements in all directions. The resulting wind speed and direction are calculated from the measured run-time sound differential.

- Precipitation measurement. Radar technology is used to measure precipitation. The precipitation sensor works with a 24 GHz Doppler radar, which measures the drop speed and calculates precipitation quantity and type by correlating drop size and speed.

The WS600 is mounted vertically toward the top of the mast using the mounting bracket at the bottom of the sensor. The WS600 is aligned to the north upon installation. Readers are directed to the product manual *(76)* for details on the installation procedure for the WS600.

Connectivity. The WS600 communicates with the mini-RWIS RPU using an RS485 interface. The eight-pole screw connector (M8) on the WS600 is connected to the mini-RWIS RPU using a rugged cable. The cable provides connection for both power and RS485 communication. The sensor can be configured and accessed through the mini-RWIS RPU. The operating voltage range is 12 to 24 VDC. 24 VDC is drawn from the mini-RWIS RPU. The heater current consumption is 1.7 A at 24 VDC *(76)*. The WS600 has a power-saving mode for turning off the heater, and automatic activation of the radar rain sensor depending on precipitation detection, etc. The mode has certain restrictions on sensor operation.

Stardot Technologies Netcam XL Camera. The camera used with the High Sierra system is the Netcam XL, manufactured by Stardot Technologies *(77)*. This network camera is used for monitoring and visualizing live images of the surroundings. The camera can capture both still images and live video streaming. It can be easily set up to view the captured data from a web server using the camera's IP address. This camera can be connected over a LAN network or a cell modem. Figure 3.9 shows the Netcam XL camera. The resolution is 1280 x 960 (3.14 megapixels) at 11 to 225 frames per second (fps). The camera does not provide night vision.

Figure 3.9: StarDot Technologies Netcam XL Camera

The Netcam supports 1 x 10/100-baseT Ethernet and has two RS232 Ports (up to 115.2 kb/sec). Supported network protocols are TCP/IP, HTTP, FTP, DHCP, PING, TELNET, DAYTIME, NTP, SMB, and NFS *(77)*. The camera is mounted in an enclosure that is in turn mounted using a bracket toward the top of the mast. The camera can be configured remotely or locally using supporting software. The unit works in the 8 to 15 VDC range, and current consumption is 500 mA at 12 VDC *(77)*. The 12 VDC and GND for the camera is drawn from the connection on the RPU labeled "water depth." The camera is connected with a cellular modem using an Ethernet cable.

Sixnet Industrial Pro 6621 Modem. A cellular modem is required to transmit data wirelessly from the mini-RWIS RPU and the camera to a central server at High Sierra. The cell modem used for High Sierra system is a Sixnet Industrial Pro 6621 model. The modem communicates data from the WS600, IceSight, and the Netcam to the High Sierra facility in California via a 4G cellular telephone protocol. The modem has five Ethernet ports. A sim card is plugged into the modem for the wireless connection authentication and activation. A data pack from AT&T is used for the cellular connection.

The modem communicates with the RPU via Ethernet. 12 VDC power and GND for the modem is drawn from the connection on the RPU labeled "water depth." An antenna is connected to the modem. The modem unit must be protected from weather elements. The modem's IP is required for establishing a connection with the mini-RWIS RPU. The modem is easy to set up and utility software is used for configuration.

3.3 Framework for the Portable RWIS

This section discusses the requirements for the trailers that serve as the basis for the portable RWIS. For this work, Ver-Mac SST-320 trailers were used.

Electrical Requirements. The power for both Vaisala and High Sierra portable RWISs comes from batteries charged by solar panels. The system allows for up to 72 hours of continuous operation without battery recharge. Both the High Sierra and Vaisala RWISs require a 24 VDC supply voltage from the batteries. In practice, this amount of time has extended to over two weeks. A solar controller that regulates the voltage to the batteries is included in the electrical setup. A complete discussion of the energy consumption of the High Sierra and Vaisala components and battery life in the portable RWIS can be found in *(78)*.

Mounting Requirements of the Portable RWIS. The preferred mounting height for the Vaisala WXT520, DSC111, and DST111 and the High Sierra IceSight and WS600 is 20 feet. The lower portion of the trailer mast is non-telescoping at a height of 4 to 6 feet out of the overall 20-foot height. The extension and retraction of the mast is performed manually. The trailer includes a base for the mast so it can be supported in an upright position. It is expected that the trailer will be transported to field sites with the mast in a horizontal position.

Both RWISs require 24 VDC voltage input from AGM batteries. Based on electrical calculations, the portable RWISs require two 210 Ah, 12 VDC or four 210 Ah, 6 VDC batteries. The batteries are connected in series to provide 24 VDC for the system. A robust and waterproof enclosure is available to hold the batteries. AGM batteries do not freeze in winter conditions and provide maintenance-free operation. A solar controller to limit the output current at the batteries is needed.

3.4 Ver-Mac SST-320 Trailer

This trailer meets all the required specifications noted in Section 3.3. The trailer contains a square mast, which extends up to 20 feet. The top portion of the mast measures about 2 in. x 2 in. When retracted, the mast is about 4 feet tall. Each trailer has a metal box measuring 24-5/8” x 15-7/8” x 10-5/16” in. This box holds the solar controller. There is a dipole on/off switch in this box for the load. It acts as the main DC breakout unit for the RWIS. The trailer also includes two 85 W solar panels that allow the batteries to be charged (each of the three systems built at the end of the project include a 295 W panel).

Two plastic battery boxes are also present on the trailer. One of these battery boxes holds the RPU and the modem for the High Sierra system and the equipment utility cabinet for the Vaisala system. The other battery box on each of the trailers stores the batteries. Figure 3.10 shows the trailer before the equipment is mounted on it; the trailer measures 12 feet long and 7 feet wide. The mast is shown in a folded, horizontal position. The trailers contain eight 6 VDC, 210 Ah AGM batteries (from Amstron) to provide a 24 VDC system.

Figure 3.10: The SST-320 trailer

A solar regulator from Morningstar (model ProStar PS-30M with LCD screen for voltage reading *(79)*) is installed in the solar panel box. The controller is a Pulse Width Modulation (PWM) algorithm-based battery charge controller suitable for 30 A and 12/24 VDC photo voltaic (PV) systems. The function of the controller is to regulate the charge across the batteries, since the voltage coming from the panels often exceeds 35 VDC. The controller keeps the batteries from overcharging or undercharging. The solar panels and batteries are connected to the solar controller through a distribution rail in the solar panel box. There is an on/off switch at the load terminal to break the circuit when required. The controller displays the battery charging voltage, solar current (solar amps), and the load current (load amps). Figure 3.11 shows a picture of the solar panel box with the solar controller, Vicor DC-DC regulator, and the electrical connections.

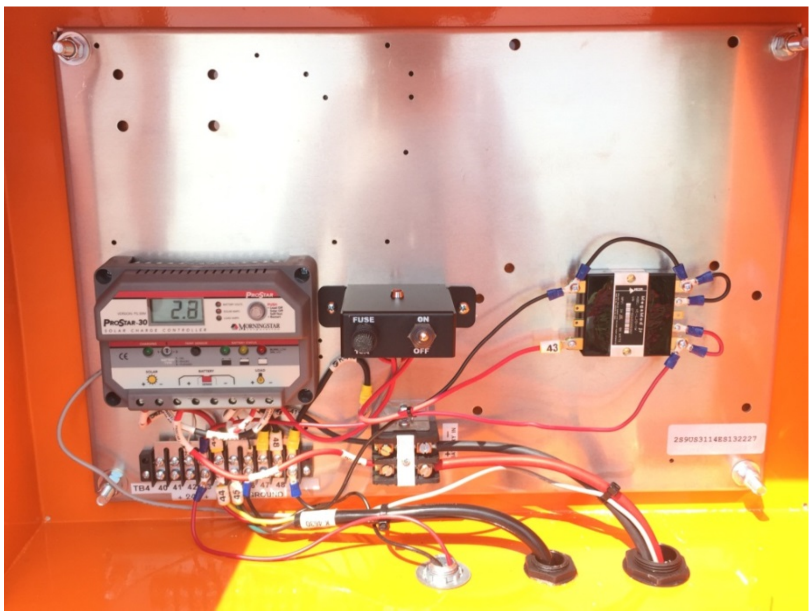

Figure 3.11: Solar controller box

It is common to have high charging voltage (> 30 VDC) across the batteries in cold weather if a solar controller is used. The temperature coefficient of the ProStar solar controller needs to be considered for charging. Since high voltage may damage the sensors (voltage must be kept < 30 VDC), a voltage regulator must be installed between the batteries and the load. The required voltage regulator for both RWISs has a maximum input voltage of 32 VDC, output voltage of 24 VDC, and maximum power at least 100 W. Two DC-DC voltage converters were procured from Vicor Electronics (one for each trailer) to limit the output voltage to the sensors to 24 VDC. Each converter is a chassis mount with custom input and custom output voltages, and each unit has four input pins and five output pins. The part number is VE-LJ13-IW. Each unit has dimensions of 2.58 in. x 2.5 in. x 0.62 in. The converters were installed between the load terminal of the solar controller and the weather sensing equipment on both trailers. This action limits the voltage at the load to 24 VDC. Figure 3.11 shows the DC-DC regulator installed in the solar controller box and connected to the solar controller and the load circuit.

Vaisala Trailer Installation. A four-foot long crossarm with sensor mounts was installed towards the top of the trailer's mast. The equipment enclosure cabinet was placed inside one of the battery boxes on the trailer. Other installation actions include securing the ROSA analyzer equipment enclosure cabinet inside one of the battery boxes. A half-inch hole is required in the lower plate of the solar panel box for the power cables, which are shielded by a conduit.

High Sierra Trailer. This trailer requires installation of mounting brackets for the IceSight, WS600, and Netcam XL camera on the trailer mast. The mini-RWIS RPU and Sixnet modem are placed inside one of the battery boxes. A circular metallic disc is installed toward the center of the mast (at around eight feet) for mounting the antenna. A half-inch hole is required in the lower plate of the solar panel box for the power cables, which are shielded by a conduit.

Additional details regarding the construction and mounting of the Vaisala and High Sierra sensors can be found in a 2015 technical report by Tessier et al. *(78)*.

Trailer Setup on the Roadway. For safety purposes, it is necessary to ensure that the RWIS sensors mounted on the trailers are secured for transport and field deployment. The measures to be taken for transporting and deploying the trailers at a field site are as follows.

- All sensors, except the DRD11A precipitation sensor and the M12 camera for the Vaisala system and the NetCam XL camera for the High Sierra system, should be un-mounted from the trailers prior to transport. The sensors should be transported in original shipping cartons to avoid damage.
- When deployed next to a roadway, the trailer should be positioned so that it is aligned to the flow of traffic (i.e., back of trailer faces oncoming traffic). The trailer should be level on the roadside surface. Solar panels should be oriented toward the south.
- The pavement sensors should be mounted on the trailer mast so that they face the road, but away from oncoming traffic. The trailer is typically positioned 10 feet from the edge of the shoulder of the road and 20 feet from the target road condition monitoring spot. The pavement sensors should be mounted facing away from the traffic to avoid obstructions due to reflections from vehicles.
- The trailer should have proper grounding. A grounding rod is attached to each trailer for this purpose.

Additional details regarding roadside system setup can be found in the Tessier et al. report *(78)*.

3.5 RWIS Data Analysis Introduction

The RWIS components from Vaisala and High Sierra were mounted on trailers selected for this project and parked next to each other in a parking lot at the MassDOT District 2 office in Northampton, Massachusetts, in the summer of 2015. Installation and calibration guidelines were followed carefully to ensure accuracy in data collection. A third, low-cost weather sensor, the Acurite Weather Station from Chaney Instruments *(80)*, was mounted about 160 feet from the two weather stations to provide a source of reference for atmospheric measurements.

The next few sections present an analysis of atmospheric and pavement data collected by the two portable weather stations and comparisons for atmospheric data against readings from the Acurite sensor over a roughly two-week time period in June and July 2015. The atmospheric data consists of parameters such as air temperature, humidity, atmospheric pressure, dew point, wind speed, wind direction, and precipitation. The pavement data consists of pavement temperature, surface friction, and surface state. It should be noted that while this analysis is scientific, many factors could have affected the results. These factors include the limited accuracy of the sensors, the positioning of the sensors, and the fact that data from the sensors were not obtained at exactly the same time instants. This analysis should be assessed with these conditions in mind. This report provides a summary of collected information and data analysis. A full discussion of all results and conclusions can be found in a 2015 technical report by Tessier et al. *(81)*.

Location of the Weather Stations. For this study, a location with similar conditions for both portable weather stations and the Acurite unit was used. The parking lot of the MassDOT District 2 office in Northampton, Massachusetts, was chosen for sensor deployment. The two portable weather stations were parked next to each other in a corner of the parking lot at the MassDOT District 2 office, as shown in Figure 3.12. The solar panels were rotated to face south. This location was chosen because there was enough space for the trailers to be parked next to each other and to provide similar environmental and pavement conditions for the sensors. Also, there was limited interference from other vehicles in the parking lot area, which reduced the chances of damage to the RWIS equipment or any kind of interference on the pavement being sensed by the pavement sensors. Both RWISs consist of compact weather sensors and pavement sensors that measure atmospheric conditions and pavement conditions, respectively. All sensors (except the DRD11A precipitation sensor) are mounted at a height of 20 feet on the mast of the trailers. The DRD11A is mounted at a height of 6 feet.

Figure 3.12: High Sierra and Vaisala trailers parked next to each other

The target spot on the pavement for High Sierra's IceSight sensing was about 23 feet away from the edge of the High Sierra trailer. The target spot on the pavement for Vaisala's DST111 sensing and DSC111 was about 6 feet away from the edge of the Vaisala trailer. The target spot for the High Sierra trailer was closer to a shelter than Vaisala's target spot. Both target spots had the recommended amount of pavement around them to generate accurate readings (about 3 to 4 feet in diameter), although shading from trees and shelters may have affected pavement temperature slightly. Both trailers had shelters on their sides (about 30 feet away on the pavement sensing side), and in general, this region is slightly more shaded than the region where the Acurite weather sensor is mounted.

The Acurite is mounted in an open area near one end of the parking lot at the MassDOT District 2 office and adjacent to Interstate 91. It was installed on a metal pole (shown in Figure 3.13) at a height of about 8 feet from the ground. The unit is far enough from the highway to avoid errors in readings from vehicles on the highway. The display unit is kept on the second floor of the District 2 office building, in a room next to the fence where the sensor was installed. The approximate distance between the sensor and base of the building is 50 feet. This weather station was installed at about 160 feet from the portable weather stations to provide a reference for the data collected by the Vaisala and High Sierra sensors.

Figure 3.13: Acurite unit mounted on the top of a pole

The atmospheric and pavement parameters measured by the Vaisala RWIS are:

- Surface temperature (Fahrenheit)
- Surface state (dry, wet, moist, slush, ice, snow, or frost)
- Air temperature (Fahrenheit)
- Dew point (Fahrenheit)
- Grip
- Water layer thickness / ice layer thickness / snow layer thickness (mm)
- Relative humidity (percentage)
- Rain state
- Wind speed (miles/hour) and direction
- Maximum wind speed (miles/hour)
- Rolling average precipitation for past 1, 3, 6, 12, and 24 hours (mm)
- Rain intensity (mm/hour)
- Atmospheric pressure (hPa)

The High Sierra web server polls the data from the RPU every 15 minutes. However, the data on the website appears at varying intervals between 5 and 25 minutes for different parameters, due to a delay in processing the data reported by the sensors. The reason for this issue is not known. The atmospheric and pavement parameters measured by the High Sierra RWIS are:

- Surface temperature (Fahrenheit)
- Surface status (dry, wet, trace moisture, standing water, ice, snow)
- Surface friction
- Pavement sensor air temperature (Fahrenheit)

- Pavement sensor minimum air temperature (Fahrenheit)
- Pavement sensor maximum air temperature (Fahrenheit)
- Wind direction
- Wind speed
- Wind gust and spot direction and speed
- Atmospheric pressure (hPa)
- Rain gauge level (inches)
- Precipitation rate (mm/hour)
- Air temperature (from WS600) (Fahrenheit)
- Dew point (Fahrenheit)
- Relative humidity (percentage)
- Rolling average precipitation for past 1, 3, 6, 12, and 24 hours (in inches)

In addition to these parameters, other status parameters are also reported on the website. The purpose of the status parameters is to create alerts and alarms for atmospheric and weather conditions under observation. Similar status conditions for the Vaisala RWIS can also be set up to create alerts and alarms. These status parameters include:

- Black ice signal
- Surface status
- Pavement sensor grip
- Pavement sensor status
- Pavement sensor error
- Wind situation
- Precipitation situation

The Acurite weather sensor was installed at the District 2 office on June 29, 2015, and the data from this unit is available for certain time periods. This weather sensor reports the data every 12 minutes on its display unit. The parameters measured by the unit are:

- Air temperature (Fahrenheit)
- Relative humidity (percentage)
- Dew point (Fahrenheit)
- Atmospheric pressure (hPa)
- Wind direction
- Current wind speed (miles/hour)
- Wind peak (miles/ hour)
- Wind average (miles/ hour)
- Rainfall (inches)

3.6 RWIS Data Analysis Methodology

This section describes the methodology used to conduct experiments and the statistical parameters used to analyze sensor data. Since stable pavement status information from the IceSight was only available after recalibration on July 8, 2015, pavement data from July 9 to

21 is considered for comparisons against data from Vaisala pavement sensors. Atmospheric data from the Acurite weather sensor from July 9 to 11, 2015, and from July 14 to 21, 2015, are used to support comparisons against Vaisala and High Sierra equipment during these time spans.

The following weather conditions were considered during this study. Note that these conditions reflect the summer season.

Pavement Conditions. Pavement temperature, friction, and state (condition) from the Vaisala and High Sierra pavement sensors were observed. The pavement conditions were limited to asphalt. Possible factors impacting pavement conditions during this period are as follows.

- Pavement temperature measurements with and without direct solar impact. Pavement temperature and surface state on a sunny day and a day without sun were observed.
- Pavement with rainfall. Pavement conditions observed during rainfall.
- Warm pavement with snowfall. Since natural snowfall is not possible at this time of the year, crushed ice was manually distributed over the pavement to simulate the condition of artificial snow. Surface condition was then observed.

Precipitation Measurement. Precipitation rate readings during rainfall from Vaisala and High Sierra precipitation sensors were observed and contrasted.

Wind Measurement. Wind speed values from the Vaisala, High Sierra, and Acurite wind sensors were observed and contrasted. In some cases, wind speed values for Vaisala and High Sierra may have been affected by trees located about 75 feet from the trailers, which could restrict wind flow. The Vaisala and High Sierra atmospheric sensors are mounted at a height of 20 feet, whereas the Acurite weather sensor is located in an open area at a height of 8 feet. Hence, it makes sense to compare data from the three sources for wind speed measurements in terms of general trends rather than absolute values.

Air Temperature, Atmospheric Pressure, and Humidity. Data values for these parameters were observed on sunny days and during rainfall. The data values from Vaisala, High Sierra, and Acurite sensors have been used to generate comparisons.

In order to quantify the data collected by the sensors, the following statistical parameters were considered for data analysis and accuracy:

Mean Absolute Difference. The average of the absolute values of the differences between the readings from each of the portable weather stations was used. It is a linear score; all individual differences are weighted equally, on average. Since the absolute value of each difference was measured, this value does not allow high and low values to cancel each other out.

Root Mean Square Difference. The differences between the readings from each of the two portable weather stations with reference to the readings from the Acurite weather sensor were squared and then averaged. The square root of the average is the root mean square difference.

This is a quadratic scoring rule that measures the average magnitude of the error. This parameter is more sensitive to data points that are further from the mean.

3.7 Data Evaluation

This section presents results from the analysis of data values collected by the portable weather stations and reported on vendor websites. Air temperature, humidity, dew point, wind speed, and atmospheric pressure from Vaisala RWIS, High Sierra RWIS, and Acurite sensors are compared. Precipitation intensity and pavement data values from Vaisala and High Sierra RWIS sensors are compared.

The team first considered the differences in readings recorded by Vaisala and High Sierra sensors. The mean absolute differences between the data values from the Vaisala RWIS and the High Sierra RWIS were calculated to quantify the data reported by these systems. These differences were calculated using data taken once per hour over 24 hours. The mean absolute difference for air temperature, atmospheric pressure, dew point, surface temperature, wind speed, and humidity are provided for the time periods between July 9 and 10, and between July 14 and 21.

Air Temperature. Figure 3.14 shows the mean absolute difference in the air temperature measured by the Vaisala WXT520 and the High Sierra WS600. The data were obtained on July 9 and 10, and July 14 through 21.

Most values are almost identical with a maximum difference of 1.26° F observed on July 9 and a minimum difference of 0.43° F on July 18.

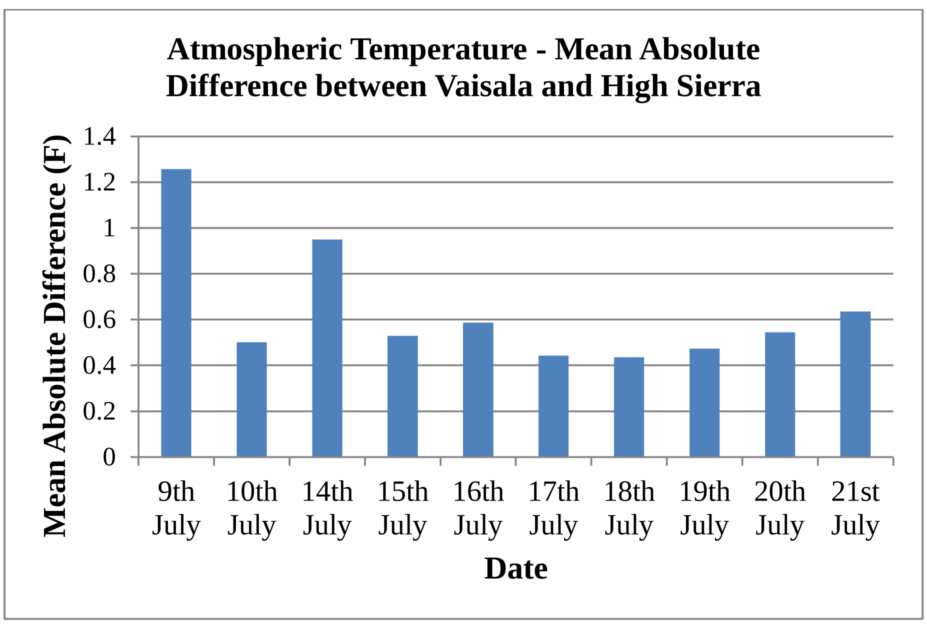

Figure 3.14: Air temperature comparison

Atmospheric Pressure. Figure 3.15 shows the mean absolute difference in the atmospheric pressure between the Vaisala WXT520 and the High Sierra WS600. The differences in the readings seem fairly constant on all days. The maximum difference of 0.7 hPa was observed on July 14, while a minimum difference of 0.36 hPa was observed on July 9.

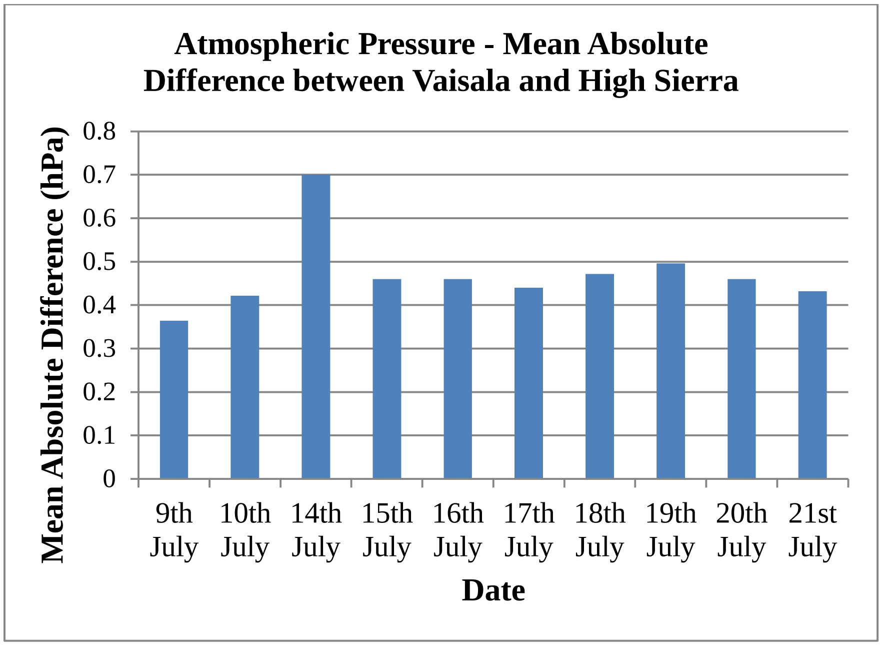

Figure 3.15: Atmospheric pressure comparison

Dew Point. Figure 3.16 shows the mean absolute difference in the dew point between the two systems. The difference in the readings seems fairly constant across all days. A maximum difference of 2.6° F was observed on July 20, while the minimum difference of 1.98° F was observed on July 19.

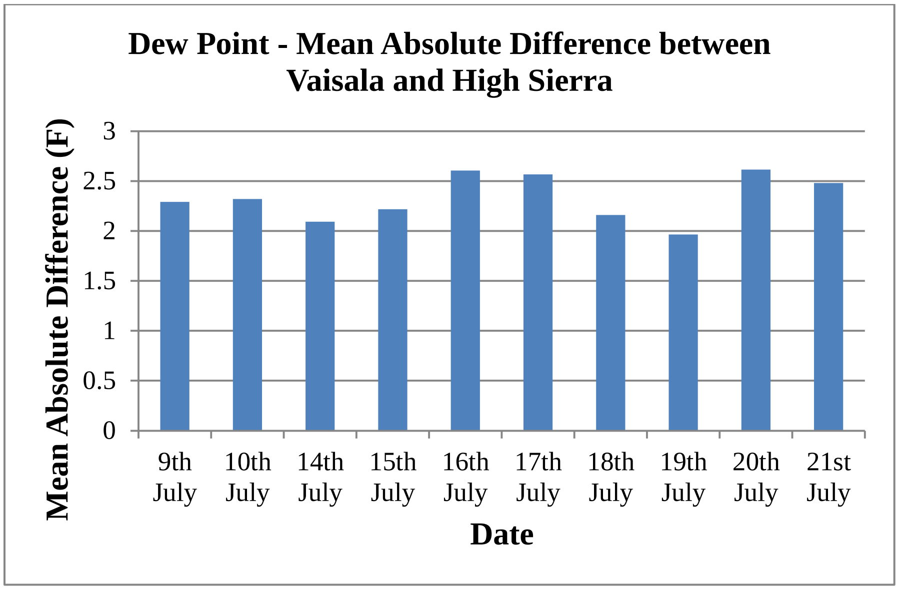

Figure 3.16: Dew point comparison

Humidity. Figure 3.17 shows the mean absolute difference in humidity. The difference in the readings seems fairly constant on all days. The maximum difference of 7.25% was observed on July 14, while the minimum difference of 5.79% was observed on July 16. These differences are somewhat higher than expected, although humidity readings are less of a concern for winter road condition prediction.

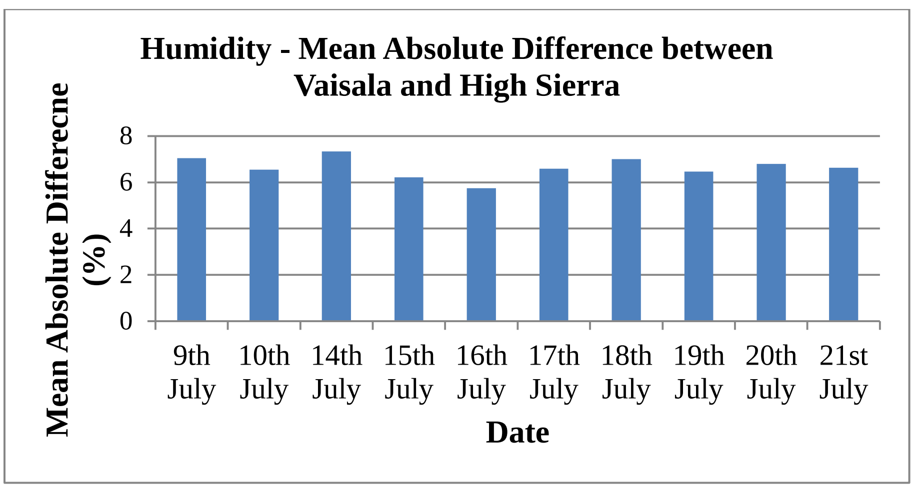

Figure 3.17: Humidity comparison

It has been observed that the Vaisala sensors read lower humidity values than the High Sierra sensors. In general, the maximum humidity value recorded by the Vaisala sensor is 95%, whereas the maximum value recorded by the High Sierra sensor is 100%. The tolerance and error margin vary for the different manufacturers. In the case of the Vaisala WXT520, the tolerance for humidity values above 90% is ±5% RH (relative humidity) and for values below 90%, the tolerance is ±3% *(73)*. For the High Sierra WS600, the tolerance for humidity values is ±2% RH. However, even for values below 90% humidity recorded by the Vaisala sensor, there is a difference of 5% to 6% when compared with the High Sierra WS600.

Surface Temperature. Figure 3.18 gives the mean absolute difference in the surface temperature. The maximum difference of 5.38° F was observed on July 16, while the minimum difference of 1.1° F was observed on July 19. One explanation for the variation in the values could be pavement shading. Despite the adjacent positioning of the trailers, the target spot for the High Sierra IceSight was in a more shaded region when compared to the target spot of the Vaisala DST111.

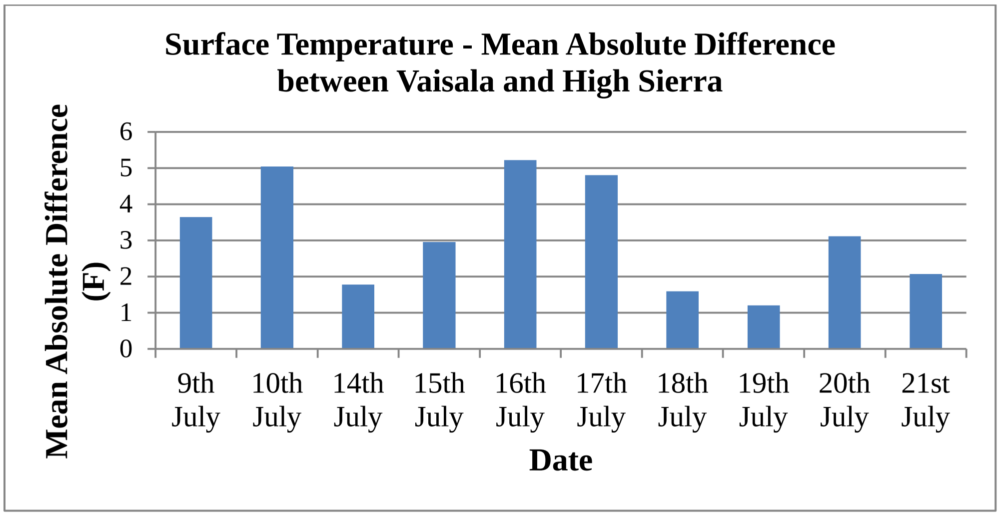

Figure 3.18: Surface temperature comparison

Wind Speed. Figure 3.19 shows the mean absolute difference in the wind speed. A maximum difference of 1.72 miles per hour was observed on July 18, while the minimum difference of 0.53 miles per hour was observed on July 14.

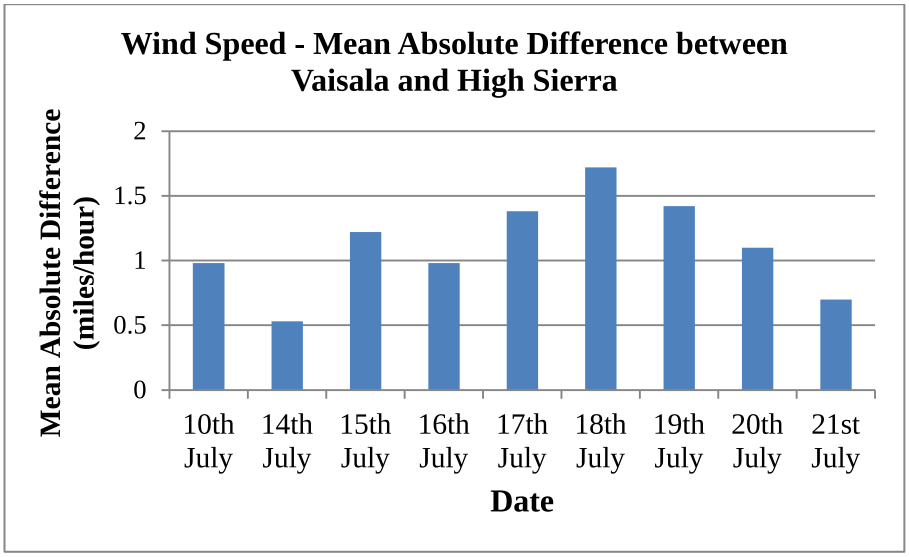

Figure 3.19: Wind speed comparison

A summary of the average mean absolute differences of the parameters for the two portable weather stations is given in Table 3.3. The average has been calculated by computing the mean of the mean absolute differences for all the days shown in the graphs.

Table 3.3: Average mean absolute difference for Vaisala and High Sierra RWIS sensors

Data Parameter	Mean Absolute Difference between Vaisala & High Sierra
Atmospheric Temperature	1.18 F
Atmospheric Pressure	0.47 hPa
Dew Point	2.31 F
Relative Humidity	6.64%
Surface Temperature	2.93 F
Wind Speed	1.11 miles/hour

The following section discusses the results of the Vaisala and High Sierra sensors in contrast to readings from the Acurite. There were heavy rains during the evaluation period, providing a spectrum of weather conditions for sensing. The mean absolute differences between the data values from the Acurite sensor and Vaisala RWIS and the Acurite sensor and High Sierra RWIS were calculated to quantify the data reported by these systems. These differences were calculated using data taken once per hour over 24 hours. The mean absolute difference for air temperature, atmospheric pressure, dew point, and humidity are given in following graphs for the time periods between July 9 and 10, and between July 14 and 21.

Air Temperature. Figure 3.20 indicates the mean absolute difference for the air temperature values reported by the two RWISs with respect to the Acurite sensor. The graph shows that this difference is slightly greater for the High Sierra system (WS600 sensor) as compared to the Vaisala system (WXT520 sensor) on all days except July 9, 2015. The maximum mean absolute difference reported by the Vaisala system is 2.89 F on July 17, 2015, and the maximum reported by the High Sierra system is 3.21 F on July 21, 2015. The graph shows that the mean absolute differences for both Vaisala and High Sierra systems are close to each other. It has been observed that the Acurite weather sensor reports higher temperatures than the two RWIS systems during 8:00 AM to 2:00 PM daily. It should be noted that the Acurite system is likely to be less accurate than the other two systems from an absolute sense, since it is cheaper and placed in a slightly different location than the trailers. The similar values for the two RWISs indicate a positive result for both systems.

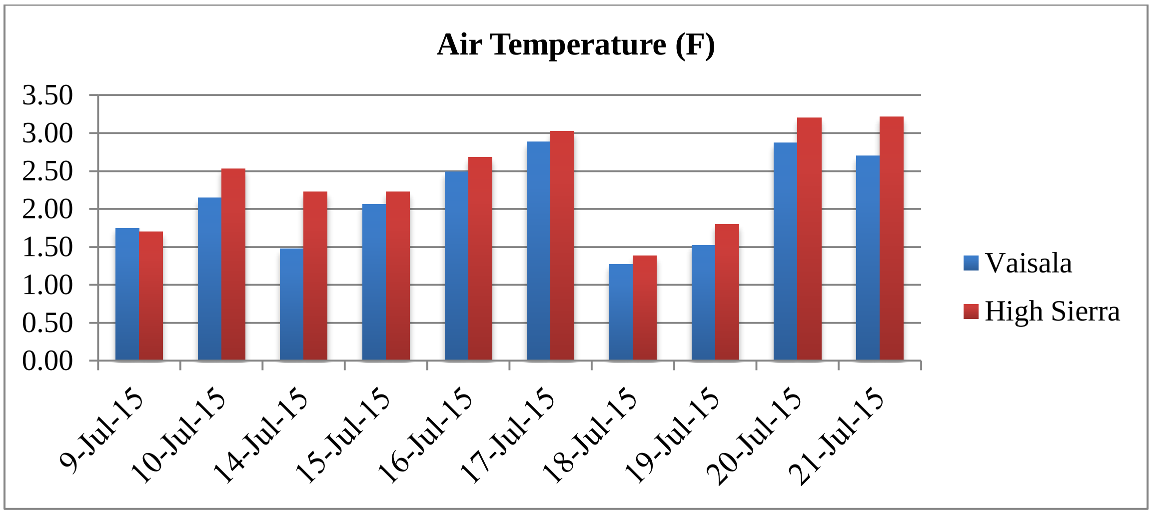

Figure 3.20: Air temperature comparison vs. Acurite (mean absolute difference)

Humidity. Figure 3.21 indicates the mean absolute difference for the humidity values reported by the two RWIS systems with respect to the Acurite sensor. The maximum mean absolute difference reported by the Vaisala system is 5.88% on July 17, 2015 and the maximum reported by the High Sierra system is 7% on July 14, 2015. It has been observed that even though the humidity values for the Vaisala sensor are typically lower than High Sierra sensor readings by about 6% on average, the values shown here indicate similarity between the trailer-based RWIS in regards to differences from Acurite readings.

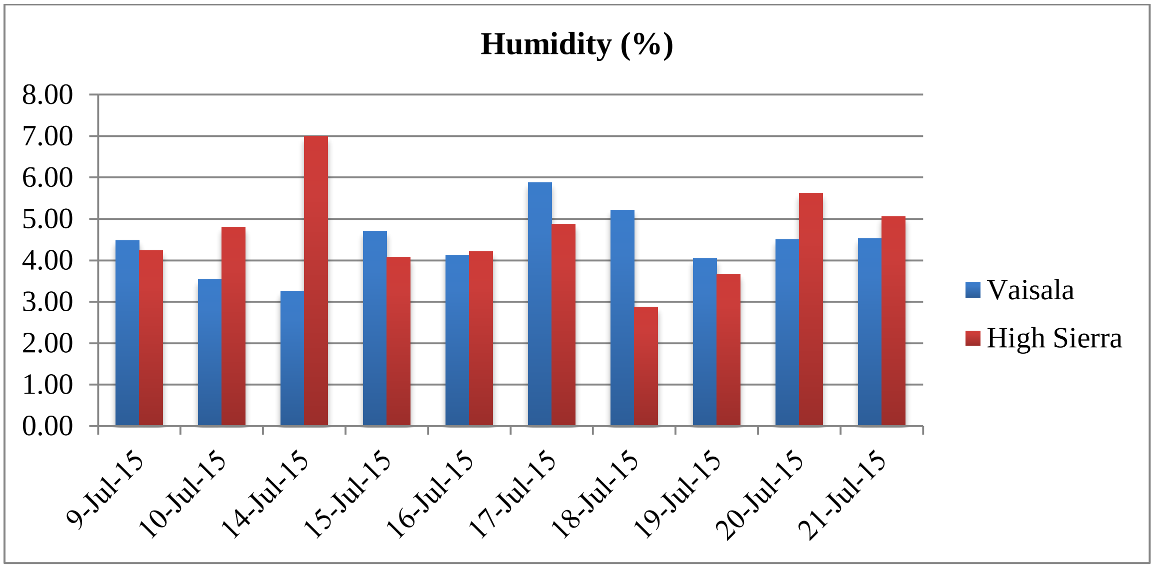

Figure 3.21: Humidity comparison vs. Acurite (mean absolute difference)

Dew Point. Figure 3.22 indicates the mean absolute difference for the dew point values reported by the two RWIS systems with respect to the Acurite sensor. Overall, the mean absolute difference reported by the Vaisala RWIS is slightly higher than the High Sierra RWIS values on all days. The maximum mean absolute difference reported by the Vaisala system is 2.77 F on July 17, 2015, and the maximum reported by the High Sierra system is 1.15 F on July 16, 2015. The difference between values for the two RWISs is small and can be explained by slightly different sample times for values by the sensors.

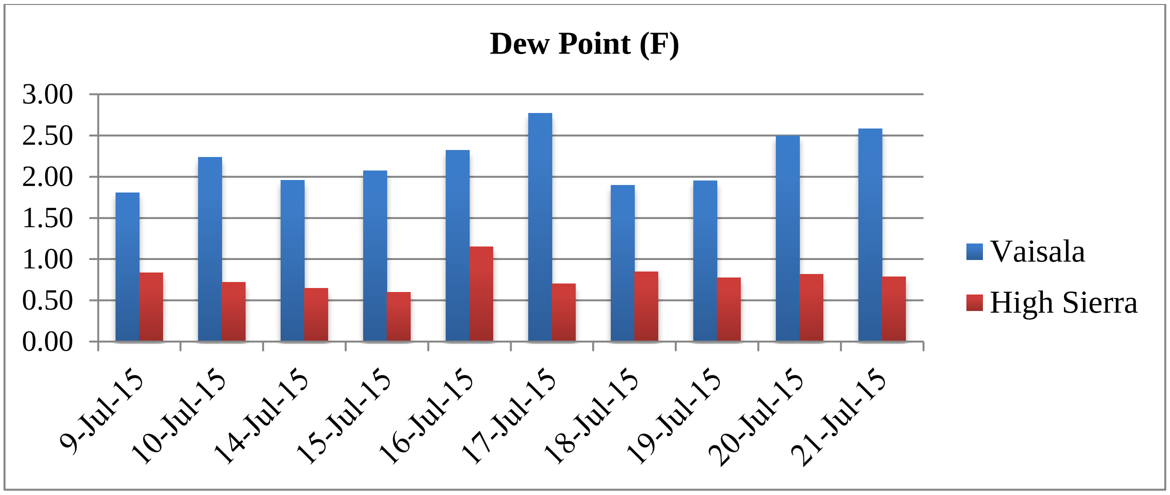

Figure 3.22: Dew point comparison vs. Acurite (mean absolute difference)

Atmospheric Pressure. Figure 3.23 indicates the mean absolute difference for the atmospheric pressure values reported by the two RWISs with respect to the Acurite sensor. Overall, the mean absolute difference reported by the Vaisala RWIS is slightly higher than that reported by the High Sierra RWIS on all the days. The maximum mean absolute difference reported by the Vaisala system is 1.03 hPa on July 15, 2015, and the maximum reported by the High Sierra system is 0.79 hPa on July 9, 2015.

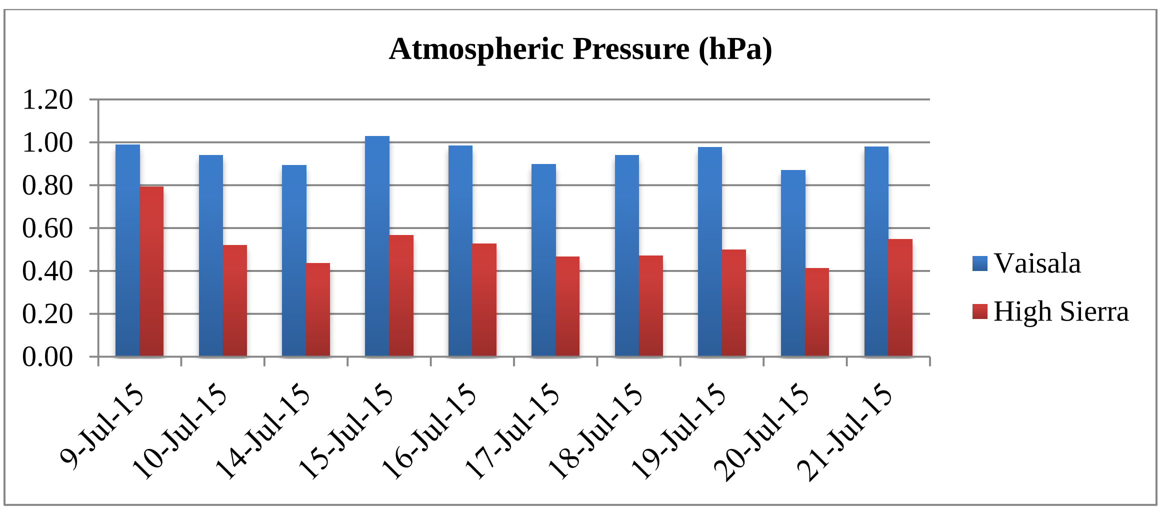

Figure 3.23: Atmospheric pressure comparison vs. Acurite (mean absolute difference)

The average mean absolute differences of these parameters for the two portable weather stations are given in Table 3.4. The average has been calculated by computing the mean of the mean absolute differences for all the days shown in the graphs.

Table 3.4: Average mean absolute difference for Vaisala and High Sierra RWISs vs. Acurite weather sensor

Data Value	Vaisala	High Sierra
Air Temperature (F)	2.12	2.40
Humidity (%)	4.42	4.64
Atmospheric Pressure (hPa)	0.95	0.52
Dew Point (F)	2.21	0.79

The average values indicate that the air temperature and humidity values for the two RWISs are very close to each other, further indicating that the values recorded by the two systems are comparable. A similar conclusion can also be drawn for the atmospheric pressure and humidity values. A larger difference between the two trailer-based RWISs is observed for the dew point values when using the Acurite unit as a reference.

The root mean square differences for the two portable weather stations as compared to the Acurite sensor are given in Figure 3.24. The root mean square differences give higher weight to larger differences. The values indicate that the air temperature and humidity values of the Vaisala RWIS are closer to the Acurite weather sensor, and the atmospheric pressure and dew point values of the High Sierra RWIS are closer to the Acurite weather sensor, although all values are similar.

Figure 3.24: Root mean square difference for Vaisala and High Sierra RWISs vs. Acurite weather sensor

Date	Vaisala				High Sierra			
	Air Temperature (F)	Humidity (%)	Atmospheric Pressure(hPa)	Dew Point (F)	Air Temperature (F)	Humidity (%)	Atmospheric Pressure(hPa)	Dew Point (F)
9-Jul-15	2.07	4.87	1.04	2.04	2.05	5.37	0.90	0.96
10-Jul-15	2.96	4.09	1.01	2.62	3.21	6.20	0.66	0.92
14-Jul-15	1.91	3.81	0.96	2.03	2.68	8.77	0.55	0.71
15-Jul-15	2.99	5.14	1.06	2.32	3.22	6.49	0.64	0.75
16-Jul-15	3.11	4.77	1.02	2.86	3.35	5.53	0.62	1.73
17-Jul-15	4.19	6.29	0.96	3.09	4.49	7.42	0.55	0.87
18-Jul-15	1.93	5.80	0.97	2.08	2.06	4.31	0.54	1.05
19-Jul-15	2.30	4.67	1.04	2.15	2.55	5.02	0.60	1.06
20-Jul-15	3.94	5.43	0.90	2.84	4.31	7.88	0.48	1.20
21-Jul-15	3.50	5.11	1.01	2.92	4.13	6.72	0.61	1.01

3.8 Ice Experiments

On June 25, 2015, experiments with ice were performed at the MassDOT District 2 office using both mobile weather stations. The experiments were conducted to show the performance of both systems in detecting icy surfaces. Approximately 15 pounds of ice was spread on the ground for each experiment to observe changes in pavement sensor readings.

Figure 3.25 shows a photo of the experiment setup; the High Sierra system is on the left and the Vaisala system is on the right.

Figure 3.25: Ice test performed at target detection spots for corresponding weather stations

Since optimum icy conditions cannot be generated on an 80° F day, the readings obtained were not exact, but they clearly indicate the change in the surface status from dry to wet (in the case of High Sierra) to slush (in the case of Vaisala). The target areas for both systems were not covered completely with a layer of ice, which is required for precise ice detection. In addition, the sensor also takes surface temperature into account, which was not at a freezing point value.

High Sierra Results. From Figure 3.26, one can see that the High Sierra pavement sensor (IceSight) recorded values close to ICY conditions. In Figure 3.26, the purple region indicates a Wet state (WET 3), the light-blue region indicates an Ice state (ICE 1), the pink region indicates a Snow state (SNOW 1), the blue region indicate a Wet state (WET 2), and the green region indicates a Dry state. The black spots in the figure indicate a change from a green region to a blue region to a pink region at the bottom, indicating the change of state from dry to wet to snow. Readings were obtained and the surface friction/grip was reduced to 0.2.

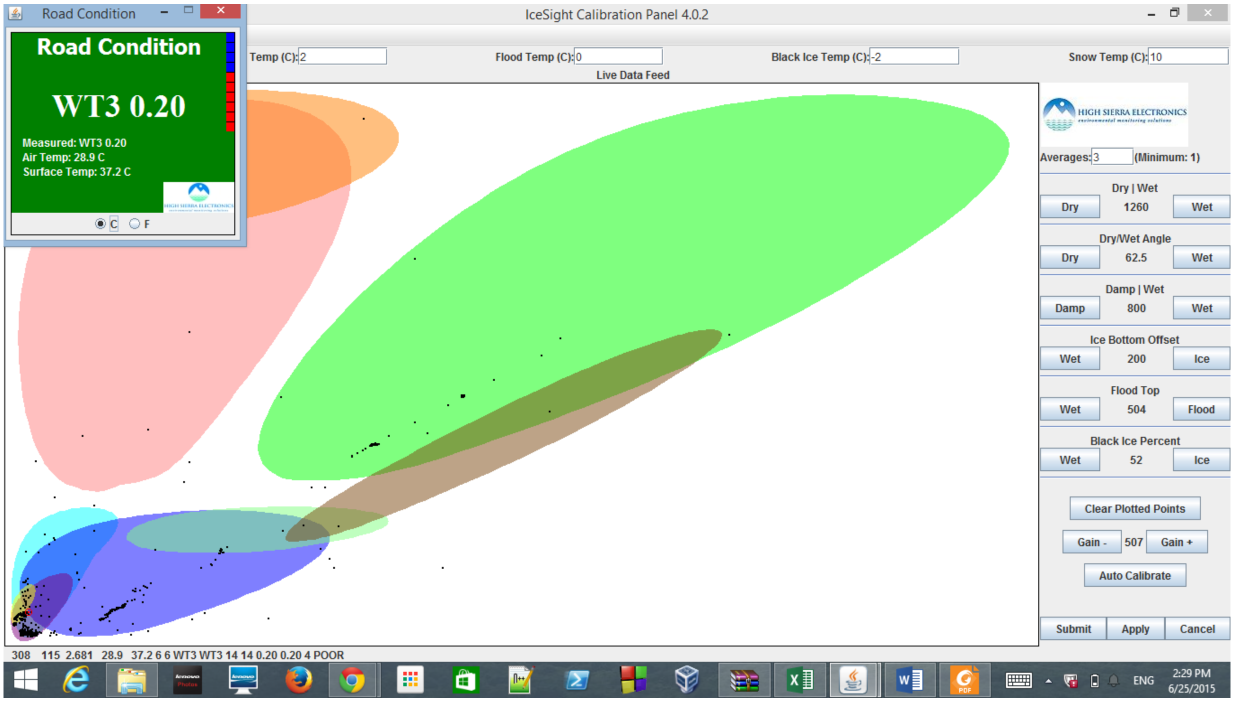

Figure 3.26: High Sierra Java Applet observations

Table 3.5 shows the changes in surface friction and surface state recorded by the IceSight during the experiment. The ICE/SNOW state did not appear in the polled data, since the transition in state was for a very short duration. The 15- to 25-minute polling interval of the RPU may be a limitation in reporting the surface status in some cases in the field.

Table 3.5: Changes in surface friction state recorded by IceSight during ice experiments

Date	Time	Surface Friction	Surface State
6/25/15	11:45:06 AM	0.5	wet
6/25/15	12:10:00 PM	0.6	trace moisture
6/25/15	12:25:01 PM		dry
6/25/15	12:40:01 PM	0.8	dry
6/25/15	12:55:01 PM	0.8	dry
6/25/15	1:10:01 PM	0.4	other
6/25/15	1:25:02 PM	0.1	other
6/25/15	1:45:05 PM	0.4	other
6/25/15	1:55:00 PM	0.5	wet
6/25/15	2:10:01 PM	0.5	wet
6/25/15	2:25:01 PM	0.5	wet
6/25/15	2:40:01 PM	0.7	dry
6/25/15	2:55:02 PM	0.7	dry
6/25/15	3:15:03 PM		dry
6/25/15	3:30:06 PM	0.8	dry

Vaisala Results. For the Vaisala DSC111 and DST111 systems, a screen shot of the report generated by the sensors is shown in Figure 3.27.

VAISALA

Observations for Mass DOT - Mc

25-Jun-2015 12:00 AM → 26-Jun-2015 02:00 PM

Timestamp	Surface Temperature (°F) Surface site 1	Surface State Surface site 1	Air Temperature (°F) Atmospheric site	Dew Point Temperature (°F) Atmospheric site	Level of grip Surface site 1
25-Jun-2015 01:40 PM	118.6	dry	79.2	52.5	0.82
25-Jun-2015 01:45 PM	122.4	dry	79.9	51.8	0.82
25-Jun-2015 01:50 PM	122.7	dry	79.7	52.3	0.82
25-Jun-2015 02:00 PM	108.1	wet			0.77
25-Jun-2015 02:05 PM	106.5	wet	79.3	52.5	0.75
25-Jun-2015 02:10 PM	108	wet	79.7	51.1	0.75
25-Jun-2015 02:15 PM	107.1	slushy	79.5	50.5	0.79
25-Jun-2015 02:20 PM	103.6	wet	79.7	51.1	0.75
25-Jun-2015 02:25 PM	104.7	wet	79.7	51.4	0.71
25-Jun-2015 02:30 PM	104.5	wet	79.5	50.5	0.69
25-Jun-2015 02:35 PM	104	wet	79.9	54.3	0.72
25-Jun-2015 02:40 PM	104.5	wet	79.9	52	0.69
25-Jun-2015 02:45 PM	103.5	wet	79.5	50.9	0.66
25-Jun-2015 02:50 PM	105.4	wet	79.5	52.5	0.66

Figure 3.27: Pavement data showing change in states during experiment with ice

This demonstrates that the surface state changed from dry to wet to slushy in about 15 minutes, from the time the ICE was spread on the target spot. It also shows a drop in surface grip. The results shows that the Vaisala sensors reported slush during the tests.

3.9 Winter Deployment Observations

This section describes some observations of roadside testing, which was performed in winter 2015–16.

High Sierra. The High Sierra RWIS was moved to its current position at the intersection of Routes 3 and 44 in Plymouth, Massachusetts, in July 2015. The system has been in continuous operation since then, except for a period of several days in December 2015 and four days in February 2016, when the battery drained. The following observations of the system have been noted.

- The High Sierra system is deployed in a position of maximum sunlight. No trees, buildings, or other obstructions are present to limit sun exposure to the solar panels. During winter 2015–16, the system remained active for about six weeks (mid-December to early February) with no battery recharge besides the energy provided from the two 85 W solar panels.
- The current draw for the system during normal operation is about 0.7A at 24 VDC. When the air temperature falls below 32° F, a heater in the WS600 sensor is activated for 30 minutes a day, regardless of precipitation. When the temperature is below freezing and precipitation is detected, the heater remains on continuously. The heater draws 1.7A at 24 VDC when active *(76).*
- The cumulative precipitation amount sensor in the WS600 gives incorrect readings during periods of heavy rain. It is unclear if the issue is a result of a problem with the sensor or the RPU. High Sierra has been investigating the issue since early October 2015.
- The road condition sensor seems to be sensitive to the presence of salt stains on the roadway.
- The system (including the associated website presenting sensor data and live video) worked well otherwise, throughout the winter trial period.

Vaisala. The Vaisala RWIS was activated in June 2015 and moved to its current position on Route 2 eastbound in Templeton, Massachusetts, in August 2015. The system has been in continuous operation since then, except for several days in December 2015 when it was moved to Canton, Massachusetts, for a media presentation. The following observations of the system have been noted.

- The Vaisala system is deployed in a position of limited sunlight during winter months. A tree line is located to the south of the trailer, which blocks sunlight after noon during the November to February time span. During winter 2015–16, the system remained active for about a month with no battery recharge, besides the energy provided from the two 85 W solar panels.

- The current draw for the system during normal operation is about 0.7A at 24 VDC. When the air temperature falls below 32° F, heaters in the DRD11A, DSC111, and WXT520 sensor draw about 0.1A *(72)*, 0.1A *(70)*, and 0.6A *(73)*, respectively.
- All data observed from the Vaisala RWIS appeared to be accurate throughout the duration of the test period.

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4.0 Recommendations

Any widespread implementation plan to replicate and deploy additional mobile RWISs should consider the following issues.

RWIS Placement. Each mobile RWIS has a self-contained power apparatus, removing the need for the trailer to be close to a power source. All data and video collected by the system is forwarded to a Vaisala web server using Verizon 4G cellular communication, so any RWIS placement should consider access to the Verizon 4G network. Fortunately, this network is well supported in the Commonwealth of Massachusetts. The RWIS trailers are typically positioned about 10 feet from the side of the roadway and about 20 feet from the target road-sensing spot in the roadway. Similar to the Vaisala RWIS deployed in Templeton, a fence can be constructed between the RWIS and the roadway to prevent snow from piling on the trailer during roadway snow removal procedures.

When deployed on the right of the roadway, the RWIS is positioned parallel to the road with the back portion of the trailer facing oncoming traffic. Since the trailer is reliant on solar panels to keep onboard batteries charged, the trailer should be parked sufficiently far from the tree line so that significant sunlight shines on the panels during winter months when the sun is low in the sky.

RWIS Power Consumption. All power for each of the mobile RWIS units is provided by a combination of batteries and solar panels. The High Sierra and Vaisala prototype units feature eight 6-VDC advanced glass mat (AGM) batteries configured to power 24 VDC (e.g., two parallel sets of four batteries connected in series). The solar panels for the two prototype systems can generate up to 170 W (about 5.5A at 24 VDC). For about $1,100 per trailer, the solar panels could be upgraded to 260 W. This change would extend the battery life of the systems in the winter. Only the solar panels would need to be replaced. All other system components (including the solar controller) would remain the same. The three Vaisala systems built later in the project include 295 W solar panels, which should be sufficient for continuous winter service.

RWIS Maintenance. User’s guides have been developed for both systems *(82)(83)* by staff at the University of Massachusetts. These guides provide recommended procedures for system setup and takedown. To date, all work on the High Sierra system, except for the web site setup, has been performed by UMass faculty and staff. The onsite calibration of the High Sierra equipment is described in the High Sierra RWIS User’s Guide *(83).*

The calibrations of the Vaisala DSC111 road condition sensor and DSC111 road temperature sensor are best performed by Vaisala staff. This calibration can be performed remotely, assuming that the two sensors have been aimed at an appropriate target spot on the roadway. The Vaisala RWIS User's Guide *(82)* discusses the selection of an appropriate roadway target spot.

The author recommends the following yearly maintenance schedule for the equipment.

- High Sierra RWIS: Once a year, the mounts for the sensors should be checked for tightness. The lens on the NetCam camera and the IceSight sensor should be cleaned with a soft cloth. In late December/early January, fully charged batteries should be swapped into the trailer. The old batteries can be recharged externally and reused at a later time.
- Vaisala RWIS: Once a year, the mounts for the sensors should be checked for tightness. The lens on the Mobotix camera and the DSC111 and DST111 sensors should be cleaned with a soft cloth. In late December/early January, fully charged batteries should be swapped into the trailer. The old batteries can be recharged externally and reused at a later time.
- The battery boxes on the RWIS trailers can contain up to sixteen 6 VDC batteries. For the three new Vaisala RWIS, it may be possible to upgrade the number of deployed batteries from 8 to 16. The two current prototypes are limited to 8 batteries per trailer, since computing equipment is stored in one of the battery boxes. Note that any added batteries should be AGM.

5.0 Conclusions

This study was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. The goals of the project included developing a better understanding of the state of the art in portable RWISs and the development of a fleet of such systems for use on roadways in the Commonwealth of Massachusetts.

Effective highway winter maintenance programs and, specifically, snow and ice operations depend on timely and accurate information to make good decisions relative to the placement of anti-icing and deicing chemicals. Weather indicators such as pavement temperature, air temperature, precipitation type and intensity, and other variables are used in the decision process. The Commonwealth of Massachusetts previously has invested in a series of permanently placed road and weather information systems (RWISs) throughout the state. These 27 RWIS stations have been strategically placed to cover the interstate highway system. Unfortunately, due to limitations in available power sources, many other areas in the state are without monitoring capabilities. Permanent RWISs require power and communication cables at their sites.

A major purpose of this project was to evaluate portable (e.g., trailer-based) RWISs to determine their suitability for use in Massachusetts. RWISs collect information such as pavement temperature, air temperature, precipitation type and intensity, and other variables and make them available to users via standard web browsers. In the early stages of the project, an effort was made to identify portable, commercially available RWIS technologies designed to capture and analyze weather data to help determine the appropriate application of sodium chloride, magnesium chloride, and any other deicers used in winter operations. This effort involved a complete literature survey of portable RWIS applications used by other state DOTs.

Following a full literature search, the development of two fully functional prototype RWISs based on weather-sensing technology from two different companies (Vaisala, Inc. and High Sierra Corporation) was commenced. One RWIS based on each company's products was constructed, following the selection of appropriate sensing equipment. Following initial data analysis and comparison, the RWISs were moved to roadsides in the Commonwealth for an extended test under winter driving conditions. As part of the project, the results of the field tests in terms of portable RWIS reliability, accuracy, and cost were assessed. Subsequently, three additional Vaisala-based RWISs were constructed and delivered to MassDOT for roadside use.

As a result of project research activities, the state of the art in portable RWIS technology has been assessed, and a fleet of portable RWISs has been created for MassDOT use. These systems provide an understanding of weather indicators used in the winter maintenance/snow and ice decision process. Data collected from the RWISs have the potential to assist MassDOT in making decisions to apply sodium chloride, magnesium chloride, and any other deicers used in winter operations, which, in turn, help achieve broader safety, fiscal, and sustainability goals.

In conclusion, this effort to build practical, easy-to-use, and accurate portable RWIS units has resulted in five deployable systems that are highly accurate. The systems have been tested on roadways for an extended period of time (nearly 12 months) to determine their long-term effectiveness.

Future work could involve increasing the portable RWIS fleet size beyond five and examining new energy and communication alternatives for the portable RWISs. It is the team's belief that portable RWISs can serve a vital role in providing roadway information for roads in isolated locations in the Commonwealth. Only cellular communication capabilities are required in the deployed location to transfer collected data. The availability of portable RWIS information can assist MassDOT in deploying road maintenance teams in a more efficient and cost-effective manner.

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