EVALUATING THE ACCURACY OF RWIS SENSORS

Showcase Evaluation #4

Final Technical Report

By

Christopher Marosek
Western Transportation Institute
College of Engineering
Montana State University

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ABSTRACT

State Department of Transportation officials rely on Road Weather Information Systems (RWIS) to obtain accurate real-time information in order to coordinate road maintenance procedures. The accuracy of such systems is imperative to prevent unnecessary and costly deployment of equipment. Pucks embedded in the pavement are commonly used to monitor the condition of the roadway. However, these sensors require lane closures during installation and cutting in to the pavement surface. Another technology available to transportation officials is infrared sensors that may detect the presence of water in its different phases. This type of sensor may offer significant advantages in maintenance and installation; however, the accuracy of the infrared technology relative to the puck sensor needs to be established before recommendation for broader deployment can occur.

An in-field comparison of existing RWIS puck sensors and infrared technology was conducted during the winter of 2004-2005. The comparison measured each sensor’s ability to accurately detect the phase and presence of water on a section of pavement. Measurements collected using each sensor were compared with visual observations to see how closely each technology measures actual roadway conditions.

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1. INTRODUCTION

Road weather information systems (RWIS) are field-based sensors capable of continuously recording road weather events. The purpose of the sensors is to assist transportation managers and the traveling public by providing real-time weather and road conditions accessible via the Internet. Roadway managers are able to use this information to assist with deployment of snow removal equipment and abrasive application. The traveling public is able to use this information to decide whether roadway conditions are safe for travel.

The most commonly used RWIS equipment are puck-shaped sensors installed in the tire path of the roadway surface (see Figure 1-1). They are capable of collecting roadway temperature, detecting presence of water in various phases and measuring percentage of de-icing agent. Of particular concern to roadway managers is the detection of snow and ice. Roadway management decisions are based on data collected by the RWIS sensors so it is essential that they function properly. Sensors overly sensitive to snow or ice can result in unneeded plow deployment, leading to increased labor and equipment expenses. Sensors not able to detect snow and ice make the traveling public more susceptible to weather-related accidents.

Figure 1-1: Embedded Puck Sensor

Typically, RWIS sensors are embedded flush in the roadway surface. Their installation and maintenance requires a lane of traffic be temporarily closed while work is performed. These sensors must be moved if a road is resurfaced or reconstructed. Scheduling work to be done during non-peak traffic hours can be difficult for roadway managers to accomplish, especially when work is often performed by sensor vendors or specially trained personnel. Currently, many of the sensors in use in the field do not require recalibration; however, they do need occasional cleaning to prevent misrepresentation of field data.

Because of the disadvantages associated with puck sensors, another detection technology has been considered because it is non-intrusive: infrared (IR) cameras. IR cameras have the advantage of being installed above the roadway surface, such as is shown in Figure 1-2. Both installation and maintenance can be performed with minimal disruption of traffic. In addition, the sensor can be easily moved or replaced. Many of the weather parameters measured by RWIS sensors can also be measured with the IR camera. Internet connections also allow roadway managers to receive real-time information on roadway conditions.

Figure 1-2: IceSight Installation on Roadway Shoulder

The Oregon Department of Transportation (ODOT) identified IR technology as a possible addition to improve their existing RWIS network. An initial investigation of the performance of a particular IR camera – Innovative Dynamics Incorporated’s IceSight – was conducted in a controlled environment using Montana State University’s weather chamber. Further investigation in a real-world environment was needed to confirm results and conclusions derived from laboratory testing.

This report summarizes a field investigation of the accuracy of pavement sensors with an IR camera. Chapter 2 reviews other studies which have investigated this issue. Chapter 3 describes the methodology used in this research project. Chapter 4 reviews the findings, and Chapter 5 provides conclusions and recommendations.

2. BACKGROUND AND LITERATURE REVIEW

This chapter provides additional background information on the research project, and also reviews studies done by other organizations. First, this chapter describes the initial laboratory investigation into the performance of the IceSight camera. This chapter then includes a summary of studies conducted on the accuracy of RWIS sensors, with a particular emphasis on the methodologies followed by the investigators.

2.1. Background

The Oregon Department of Transportation (ODOT) has deployed a network of road weather information systems (RWIS) to provide accurate weather and roadway condition information to travelers and roadway managers. In continuing efforts to improve the current system, ODOT is exploring the use of alternative road weather detection technologies. Currently, ODOT's RWIS network consists of standard puck sensors and meteorological towers. Other sensors may offer distinct advantages in ease of installation, maintenance, cost or possibly performance.

To help ODOT assess the potential for IR cameras to be used in road weather detection applications, the Western Transportation Institute (WTI) at Montana State University was selected to conduct a two-phase study to measure the accuracy of an IR camera in a laboratory and field situation. Using these results, a determination would be made if IR technology can be used instead of existing pavement-mounted sensors. WTI conducted experiments using the Infrared Road Ice Detection (IRID) "Ice Sight" B, an IR camera manufactured by Innovative Dynamics Inc. (IDI) which was identified by ODOT for possible deployment.

The IceSight B was first tested in a series of controlled laboratory experiments (1). The evaluation included seven experiments testing the camera's ability to accurately measure temperature and phases changes of water. These experiments tracked the IR camera's ability to detect changes of dry, snow, and ice covered pavement above and below freezing temperatures.

The results of these experiments are summarized in Table 2-1. The experiments showed that the IceSight performed well in the controlled environment of the cold lab. The camera successfully detected all phases of water; however, it failed to detect phase changes from water to ice during two experiments. There were also difficulties in accurately tracking the temperature, as the IceSight consistently overestimated the actual temperature of the pavement surface. Researchers speculated that the overestimated temperatures could result from the rapid temperature changes in the lab, which would be unlikely in field situations. There were also difficulties sensing phase changes from liquid to ice and determining the correct phase of slush.

Table 2-1: Summary of Laboratory Results of IceSight B Evaluation

Experiment	Start Condition	Temperature Changes	IceSight Results
1	Dry asphalt	▪ Start below freezing ▪ Raise to above freezing	▪ Correctly reported dry phase
2	2 cm of snow/ice	▪ Start below freezing ▪ Raise to above freezing until entire sample has melted	▪ Correctly reported snow to water phase change
3	2 cm of snow/ice	▪ Start below freezing ▪ Raise to above freezing until melt starts to occur ▪ Lower below freezing again	▪ Correctly reported snow to water phase change ▪ Missed water to ice phase change
4	2 cm of snow/ice (w/ second asphalt puck)	▪ Start below freezing ▪ Raise to above freezing until melt starts to occur ▪ Lower below freezing again	▪ Correctly reported snow to water phase change ▪ Missed water to ice phase change
5	Thin layer of bubble-free ice	▪ Start below freezing ▪ Raise to above freezing until entire sample has melted	▪ Confused phase change from ice to snow (slush) ▪ Correctly reported snow to water phase change
6	Dry surface	▪ Lower below freezing while spraying water to make ice	▪ Correctly reported dry to water phase change ▪ Correctly reported water to ice phase change
7	Dry surface	▪ Lower below freezing while spraying water to make ice ▪ Increase temperature until melt has occurred	▪ Correctly reported dry to water phase change ▪ Correctly reported water to ice phase change with lag ▪ Correctly reported ice to water phase change

Source: (1)

Upon completion of the experiments, researchers concluded that the IceSight had enough promise as a roadway weather detection system to receive additional testing. It was recommended that the IceSight undergo field testing against other types of pavement sensors and visual inspection to access the IceSight's accuracy.

2.2. Literature Review

A review of existing literature was used to help develop a testing methodology for the comparison of the two sensors.

2.2.1. Aurora Consortium, 1999

Researchers from the Aurora Program investigated existing procedures for calibrating and testing RWIS pavement sensors (2). The research had two main objectives: first, to make a thorough examination of existing evaluations and testing procedures of RWIS pavement sensors through reviewing published literature and sensor manufacturer technical manuals; and second, to examine knowledge of standards and protocols for testing RWIS pavement sensors amongst experts in academia, manufacturing, and transportation.

The investigation revealed that most state agencies lack the experience and knowledge necessary for testing and calibrating RWIS pavement sensors. Kansas DOT is one state which has implemented a testing and calibration program due to their frustration with RWIS vendors. Still, most states rely on the “good faith” of the vendor technology. It was also noted that some international agencies that have conducted research into long-term reliability of RWIS sensors have found a diminished accuracy over time, especially if routine maintenance is not performed. Many European nations have seen enough evidence of diminished performance over time that they have implemented testing and calibration programs. Currently France, Sweden and the United Kingdom have such programs in place.

The perceived need for standards and methodologies for testing and calibrating RWIS pavement sensors received mixed reactions among transportation officials. While some said it was a positive and necessary development in the future of RWIS systems, others saw it as an unnecessary burden. Many of those with a negative opinion would prefer to see the responsibility left with vendors. Others point to the benefits of such standards such as seamless testing across states which share RWIS technology, and the increased reliability of data as a result of routine maintenance standards.

The Aurora Program recommended that a copy of France’s Ministère de l’Equipment des Transports et du Logement (METL) procedures for testing and calibrating sensors be translated for use by other agencies. METL’s procedures were among the most comprehensive among the agencies surveyed. It was also recommended that Kansas DOT’s procedures be used as a baseline by which Aurora would develop standards for testing and calibrating pavement sensors.

2.2.2. Gustavsson & Bogren, 2002

Determining the quality of data collected by RWIS sensors and how well an existing network of in-pavement sensors and tower-mounted climate-measuring devices records accurate weather was the goal of the study conducted by Gustavsson and Bogren of the University of Götenburg, Sweden (3). Using a section of test road, sensors mounted on towers at varying heights and distances relative to the road and ground were measured against a highly accurate and quick responding IR thermometer. Results indicated that sensors mounted at least two meters above the roadway surface tended to be more accurate. Sensors mounted at heights less than two meters were discovered to perform less accurately on account of weather conditions associated with the ground adjacent to the roadway surface.

Pavement sensors were tested in a fashion similar to the tower-mounted devices. An IR thermometer was also used as a basis for comparison. Other influences explored by researchers included the color of the coating used to seal the sensor in the pavement and visibility of the sensor on the pavement surface. Results showed that overall performance of pavement sensors indicate a tendency to report temperatures greater than actual conditions. This over-reporting of temperature occurred most often on clear days and nights with sensors sealed by black sealant. Sensors covered by grey sealant showed the smallest disparity between actual and reported temperature. Results also showed that the greatest errors in measurement occurred when there was a rapid fluctuation in temperature.

Researchers concluded that placement of RWIS, especially the installation of pavement sensors, is essential for optimum performance of the systems. Depth of placement can also have a significant effect on the speed at which the sensor is able to respond to temperature changes.

2.2.3. Rios-Gutiérrez and Hasan, 2003

Like ODOT, the Minnesota Department of Transportation (Mn/DOT) has been seeking to improve the reliability of its weather detection technology in detecting ice. As part of an investigation into various ice detection technologies, Mn/DOT contracted with the University of Minnesota-Duluth to evaluate the IRID IceSight camera (4). Key to the selection of this particular make and model was its low installation and operational costs compared to similar technologies.

The objective of the project was to improve the understanding of the IceSight's ability to detect water, snow and ice on the pavement surface as well as to determine its overall accuracy. Tests were performed to determine if the sensor could be used to determine thickness of precipitation accumulated on the pavement surface, and to determine if the IceSight could detect the presence and concentration of freezing point depressants.

Testing of the IceSight in a controlled environment started by simulating wet and icy conditions at various thicknesses. Water was poured over a testing area at increasing quantities and measured for thickness using a feeler gauge. A similar procedure for testing ice conditions was used after the pavement was cooled using blocks of dry ice. Measurement from naturally occurring snow and ice conditions were measured during the following winter. This also provided the opportunity to examine the effect freezing point depressants had on IceSight readings.

Results from these experiments showed the IceSight was able to distinguish between various roadway conditions including snow, ice and water. It also successfully measured spectral differences resulting from application of freezing point depressants and ice occurring at various thicknesses. Although the IceSight seemed to perform well in a controlled environment, more testing in real-world conditions was recommended.

2.2.4. Zwahlen, Russ, Badurdeen and Vatan, 2003

In this project, researchers hoped to determine the accuracy and overall performance of RWIS pavement sensors using data collected from trials conducted in a climate laboratory on the campus of Ohio University (5). Three sensors were used to conduct the experiment, each of which monitored temperature, wet or dry conditions, degree of salinity, freezing point of liquid solution and depth of liquid on pavement surface. The sensors were installed in a 14”×14” section of concrete block recovered from a bridge deck used to simulate roadway surfaces.

The three pavement sensors were connected to external computers used to collect and monitor data. Thermistors were also added to collect temperature data used as a basis for comparison of temperature readings. A series of tests were run using solutions of common de-icing agents and water. Each test would begin at room temperature and gradually drop to -17° C over 15 hours.

Results showed that all three pavement sensors had difficulty accurately reporting conditions over the course of the test period. The best performing sensor was accurate 92-97 percent of the time. The worst performing sensor was accurate only 19 percent at the start of the trial and 47 percent at the end of the trial. A common trait among all the sensors was a lag time from actual temperature changes. Researchers noted that the rapid and sustained cooling of the chamber would be uncommon but not entirely impossible in real-world application of the sensors.

Results from freezing point tests and chemical percentage tests showed a wide range of variability across the three sensors. The most accurate sensor reported freezing points higher than actual for salt concentrations, while calcium chloride concentrations resulted in pavement temperature readings off by 5° C or more. The same sensor was also most accurate for determining chemical percentages on the concrete surface; however, results were still noticeably low for salt solutions.

Researchers concluded that none of three sensors performed well enough to receive an endorsement for deployment. In fact, the recommendation was made to the state of Ohio to delay future installation of RWIS pavement sensors until more accurate technology is available.

2.2.5. Aurora Consortium, 2004

The objective of *Laboratory and Field Studies of Pavement Temperature Sensors* was to evaluate the performance of various mobile and stationary pavement temperature reporting sensors (6). Using Mn/DOT’s testing facilities, investigators intended to establish the performance of temperature sensors while also establishing a standardized testing methodology. Evaluations of these sensors were conducted in both laboratory and field settings using readings from highly accurate thermistors as a basis for comparison.

Laboratory investigations were conducted in a climate-controlled test chamber in which test sections of asphalt and concrete were used as sample roadway surfaces on which sensor performance was tested in simulated weather conditions. The real-world conditions simulated in the laboratory were snowfall, rain, frost, sun and de-icing agent. Field investigations were conducted on concrete and asphalt portions of a closed roadway at Mn/DOT’s research facility in Monticello, Minnesota. Six stationary sensors were installed in the roadway surface while the mobile sensors were mounted to a test vehicle. Again, various roadway conditions were simulated, tested and recorded using the various sensors.

The error resulting from the mobile sensor reading ranged between 0.5° and 2.0° C (0.9° and 3.6° F). It was noted that the mobile sensors tended to have greater temperature variability, longer acclimation times, and a tendency to report ambient air temperature on account of the sensor not being in contact with the pavement. It was also noted that the mobile sensor performed more accurately on asphalt than concrete.

Stationary sensors typically produced error less than 1.3° C (2.3° F). It was noted that much of this error was due to the fact that the sensor was not reporting temperature changes as quickly as they were taking place. This lag time was pronounced in field situations in which clear skies were prevalent. The study provides recommendations and through evaluations for each of the evaluated mobile and stationary sensors.

2.2.6. Summary

A review of existing literature suggests there is no standardized testing methodology for RWIS puck sensors, or infrared ice detection systems. Although testing of RWIS puck sensors has been conducted, most of the research has been in a laboratory setting. Results from these studies indicate that the RWIS puck does accurately record temperature within 1-2° F. This suggests that the RWIS sensors can be used as a basis of comparison for IceSight temperature readings.

3. METHODOLOGY

This chapter describes how field testing was conducted for the IceSight camera. Location of this study was a key aspect of the testing. Both reliable winter weather and proximity to a RWIS puck technology were available at the study location. Further details of how the site was set up and how data was gathered are outlined below.

3.1. Location

The field test for this project was conducted on Bozeman Pass, east of Bozeman, Montana on Interstate 90. This particular site allowed for side-by-side comparison of two technologies on the same area of roadway. At an elevation of nearly 6,000 feet, the study site also afforded the opportunity for the sensors to experience a wide range of rapidly changing weather patterns common to the mountain environment. The frequency of weather events allowed visual observations to be made when roadway conditions may be deteriorating or improving rapidly. These observations would be used as a baseline for comparing the accuracy of each sensor in such conditions.

The study site on Bozeman Pass consisted of existing RWIS instrumentation, including a meteorological tower, and a series of puck sensors embedded into the driving lane of westbound I-90. The existing infrastructure allowed the IceSight camera to be powered from electrical supply boxes (see Figure 3-1), and mounted on a mast in close proximity to a puck sensor, as shown in Figure 3-2. This setup allowed for the IceSight to be aimed at an area of pavement less than three feet from the area monitored by the puck sensor.

Figure 3-1: IceSight Electrical Supply

Figure 3-2: IceSight Installed on Mast above RWIS Sensor

3.2. Equipment

This section describes each type of equipment used: weather sensors and data collection. Each piece of equipment was designed to function 24 hours a day continuously throughout the study.

3.2.1. Weather Sensors

An existing RWIS puck sensor was located near the top of Bozeman Pass in the driving lane of traffic on westbound Interstate 90. This location also provided an existing mast which could accommodate IceSight instrumentation and power requirements.

RWIS Puck

The RWIS puck sensor installed on Bozeman Pass is manufactured by Surface Systems Incorporated (SSI). Model FP 2000® is a flush-mounted puck capable of detecting pavement surface temperature, dry, wet, chemical wet, as well as snow and ice conditions. The FP sensor requires no recalibration, although periodic cleaning is recommended to prevent buildup in the sensor's well. This sensor is connected to a software package which allows users to monitor surface conditions over the Internet.

IRID IceSight B

The IceSight B manufactured by Innovative Dynamics Inc. (IDI) is an infrared camera capable of measuring spectral differences to distinguish between various phases of water. Water and ice have slightly different reflectance spectra in the near- to mid-infrared wavelength region. The near infrared band works as an ice detector because the spectra have dramatic changes over a relatively small wavelength range (7). The unit also includes a temperature gauge capable of measuring pavement and air temperatures.

The manufacturer recommends installing the camera less than 100 feet from the pavement surface with a mounting angle as near vertical as possible. During this study, the IceSight was installed at an angle 53˚ from vertical facing an easterly direction. The installation is shown in Figure 3-3. Software needed to run the IceSight allows users to have a live video feed and active monitoring capabilities using Internet communication, although neither capability was used in this project.

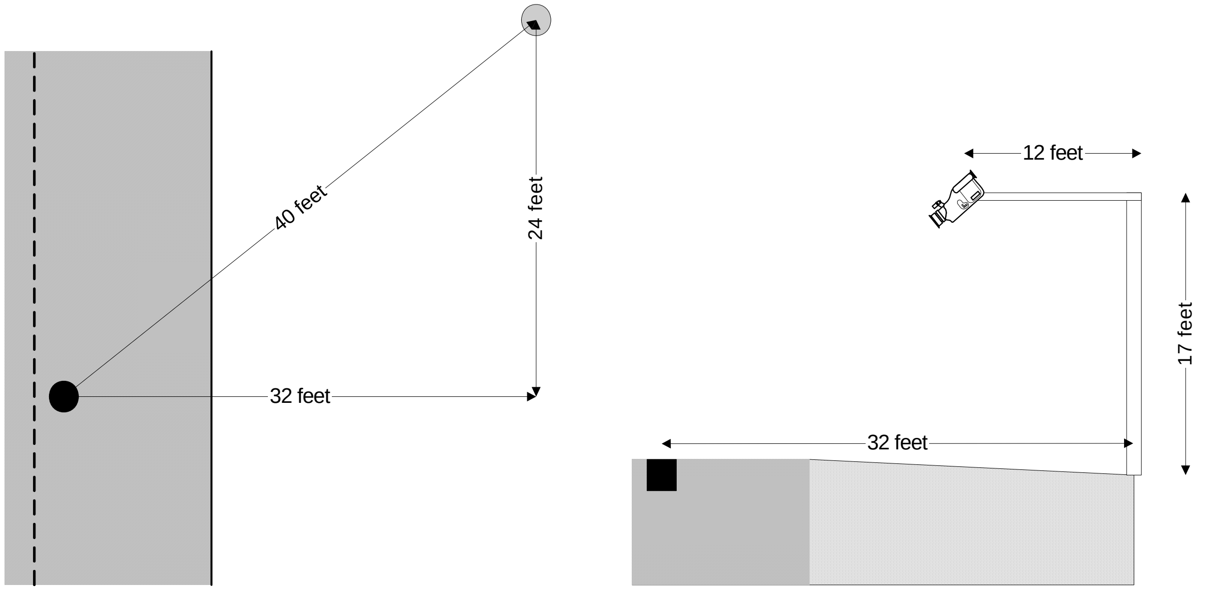


Figure 3-3: IceSight Installation

3.2.2. Data Collection Equipment

Each sensor had its own system of recording road and weather data during the study period. The RWIS puck sensor archives information to a State of Montana-run FTP site. Data is kept on a 24-hour rolling basis, necessitating a daily download of information from RPU 2 sensor 1 – the specific puck sensor nearest where the IR camera would aim – to a personal computer.

Deployment of the IceSight in a remote setting would have made it cumbersome to have a direct connection to a computer offsite. Instead, on-site data collection was provided by a data collection computer (DCC) manufactured by IDI. The unit consisted of a weather-proof box housing a processing unit, wireless router, antenna, and USB storage card. The DCC was directly connected to the IRID at all times and mounted on the same tower, using power provided by the existing electrical service box. The IceSight sends data on current conditions to the DCC every minute. The DCC was designed to operate in all weather conditions and to record up to twelve days worth of data.

The DCC allows the user to communicate with the IRID through a laptop wireless connection. This connection makes it possible to calibrate the unit, initialize data collection, actively monitor roadway conditions, stop data collection, and download results.

A wireless notebook adaptor card was used to modify an existing laptop computer to communicate with the DCC. The connection has a range up to approximately 100 feet, although communication quality and download rates drop off significantly with increasing distances. The steps used to connect to the DCC are listed in Appendix A.

3.2.3. Calibration

Puck Sensor

The SSI puck sensor installed at the study location does not require calibration. A periodic cleaning of a well on the sensor surface is recommended to prevent buildup of dirt or gravel. During the study period, cleanings were conducted on an as-needed basis.

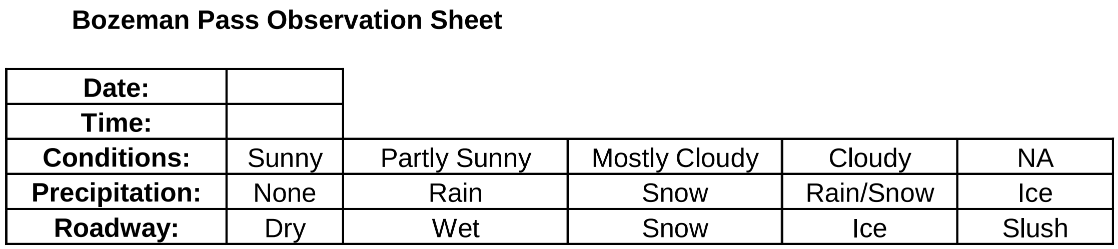
IceSight Camera

The IceSight's software is the control mechanism for all camera operations including calibration, monitoring, and data collection. Details on use of the software for calibration are provided in Appendix A. The camera was calibrated at the start of data collection, and was also recalibrated during the project.

3.3. Collecting Visual Observations

A key aspect of this study was to use visual observations conducted at the study location to confirm readings taken by both the RWIS puck sensor and the IceSight. Observations were timed to coincide with winter weather events leading to water, snow or ice on the roadway surface. From an observation point above the roadway, observations were taken every three to five minutes, or when a change in roadway conditions occurred. A sample observation sheet is shown in Table 3-1. At each observation, one value was selected for each of the three parameters: conditions, precipitation and roadway.

Table 3-1: Bozeman Pass Observation Sheet



Bozeman Pass Observation Sheet

Date:					
Time:					
Conditions:	Sunny	Partly Sunny	Mostly Cloudy	Cloudy	NA
Precipitation:	None	Rain	Snow	Rain/Snow	Ice
Roadway:	Dry	Wet	Snow	Ice	Slush

The RWIS puck sensor recorded data approximately every three minutes, while the IRID recorded every minute. A Visual Basic program was used to sort the thousands of data points to be analyzed according to date and time stamps and merged in a Microsoft Excel worksheet. This allowed for side by side comparison of the two sensors. Visual observations matching these dates and time were then added to confirm each sensor's reading.

4. FINDINGS

Findings from the study period consist of data gathered from the IceSight, RWIS puck sensor and visual observations. Examination of the results has been grouped together in two ways, first using the RWIS puck as a basis for comparison, secondly comparing both results to visual observations.

The RWIS puck sensor reports a greater variety of conditions than the IR camera. Consequently, certain simplifying assumptions have been made to correlate data from the RWIS puck sensor with the IR camera in order to allow for a side by side comparison. These are shown in Table 4-1.

Table 4-1: Mapping of Puck Observations to IR Camera Observations

RWIS Puck Condition	Condition used for comparison
dry	dry
wet	wet
chemical wet	wet
damp	wet
slush	wet and snow/ice
snow/ice warning	snow and ice
frost	ice
black ice warning	ice

Further examination of data was required when reviewing conditions which were observed as slush. Because of the somewhat subjective nature of determining the difference between a slush condition and water, or slush and snow conditions, results have been examined in such a way to give a range of results. This will be presented in further detail in the following paragraphs.

4.1. RWIS Puck Sensor Results

Results from the RWIS puck sensor showed unexpected trends in its ability to measure key winter weather conditions. Conditions which should have been reported as a snow/ice warning or slush were reported as a chemical wet condition. In general, the sensor did have ability to measure dry and wet conditions and accurately report them. Although the percentage of correct dry results presented in Table 4-2 are somewhat low, this number may be misrepresentative of actual conditions. Further explanation is presented in the analysis section.

Table 4-2: Recorded vs. Actual Readings: RWIS Puck

Condition	# Observations	Correct Readings	Accuracy
Slush	70	0	0.0%
Snow/Ice	59	0	0.0%
Wet	183	123	67.2%
Dry	119	61	51.3%

4.2. IceSight Results

Using the RWIS puck sensor as a basis for comparison, the IceSight matched the puck sensor's reading an average of 62.4 percent of the time. As represented in Table 4-3, there is a slight increase during the month of March. This would seem to be due a cleaning procedure conducted to clean the lens of the IceSight after obvious misreadings were discovered. February data is not available due to a Data Collection Computer (DCC) software malfunction.

Table 4-3: RWIS Puck vs. IceSight Comparison

	# of Observations	# of Matching Observations	Matching Observations
January	1,827	1,096	60.0%
March	2,780	1,802	64.8%
Average			**62.4%**

Table 4-4 indicates the overall accuracy during specific roadway conditions. Based on visual observation conducted over the study period, the IceSight seemed to perform better than the RWIS puck sensor under most conditions.

Table 4-4: Recorded vs. Actual Readings: IceSight

Condition	# Observations	Correct Readings	Accuracy
Slush	68	0	0.0%
Snow/Ice	55	54	98.2%
Wet	178	110	61.8%
Dry	101	86	85.1%

4.3. Analysis

As a winter weather detection system, the IceSight detected snow and ice conditions accurately during 98 percent of visual observations. During these same time periods, the RWIS puck sensor generally reported a chemical wet condition. Although the IceSight seemed to report snow and ice well, slush situations leading to a snow or ice covered road are not able to be detected. The IceSight simply reports either a wet condition or a snow or ice condition. This is not a reporting error, but a limitation of this version of the IceSight. The tendency of the RWIS puck sensor was to report these situations as chemical wet.

Wet conditions were reported more accurately using the RWIS puck sensor than the IceSight camera. The RWIS puck sensor seemed to identify a wet condition sooner and continue reporting the wet condition for a longer period of time after a precipitation event. This is evidenced when comparing context of moisture conditions with those from visual observations and IceSight readings. The sensor may be reporting low levels of moisture which do not exceed the dry threshold setting on the IceSight camera and may not be completely recognizable to an observer.

If the RWIS sensor is able to detect very low levels of moisture, it could explain the relatively low 51.3 percent correct dry reporting compared to visual observations. Observations often took place during morning hours coinciding with the warming of the roadway surface and evaporation of roadway moisture. The RWIS sensor may have continued to detect thin layers of water remaining after the surface appeared dry. Other weather conditions could have presented similar opportunities for the RWIS puck sensor to record in a similar fashion, leading to the low percentage of correct readings.

It is important to analyze readings from the IceSight not only to determine the overall accuracy of reading, but how the camera tends to report conditions. The camera should not be overly sensitive towards a certain condition which could cause unneeded expense from equipment and personnel deployment. Of particular concern are reports of snow or ice, as these would normally require response by transportation agency maintenance personnel.

Table 4-5 and Table 4-6 illustrate how the RWIS puck and the IceSight performed when reporting snow/ice conditions. Road conditions other than snow and ice – including slush, wet or dry pavement – are referred to as “Not snow/ice”. As was mentioned earlier, the RWIS puck did not successfully detect snow or ice conditions when present. The IceSight tended to be overly sensitive to snow and ice conditions. When it was inaccurate, it tended to be reporting snow or ice conditions when they were not present.

Table 4-5: Actual versus Predicted Conditions, RWIS Puck

Actual Condition	Predicted Condition		# of Observations
	Snow / Ice	Not Snow / Ice	
Snow / Ice	0	59	59
Not Snow / Ice	32	340	372
Total	**32**	**399**	**431**

Table 4-6: Actual versus Predicted Conditions, IceSight

Actual Condition	Predicted Condition		# of Observations
	Snow / Ice	Not Snow / Ice	
Snow / Ice	54	1	55
Not Snow / Ice	43	304	347
Total	**97**	**305**	**402**

With this liberal definition of accuracy, the accuracy of each technology is summarized in Table 4-7. The IR camera was more accurate than the RWIS puck. The RWIS puck showed a significant amount of false positives – reporting there is snow or ice when it's absent – and false positives – reporting there is no snow or ice when it is actually present, whereas the IR camera had very few false negatives.

Table 4-7: False Negatives and False Positives, RWIS Puck and IceSight

Reporting Statsitics	RWIS Puck	IR Camera
Total Accuracy	78.9%	89.1%
False Positives	7.4%	10.7%
False Negatives	13.7%	0.2%

4.4. IceSight Challenges and Limitations

The IceSight camera seemed to record a higher number of incorrect readings during the month of January. A potential cause of these problems was road grime being deposited on the lens of the unit during wet roadway conditions. The grime seems to return an unusually strong signal, indicating a dry condition to the processing software. After contacting the vendor, the lens was cleaned using an extendable pole affixed with a glass cleaner. This issue has also been discovered during IDI's testing of the IceSight. They have implemented a monthly cleaning program as well as the use of an extension to the lens shield which would help prevent any deposition on the lens.

Another potential problem with the IceSight is false data being recorded when the signal is reflected by a passing car or truck. Normally these are easily recognized as being false by looking at data points immediately preceding and following, as shown in **Error! Reference source not found.**. An abnormally high voltage is also returned indicating an obstruction over the roadway surface. However, if traffic becomes slow and confined to one lane, as expected during winter driving conditions, the IceSight could return a string of false returns. In such instances, operators would need to refer to the live images recorded by the IceSight to confirm conditions; however, this could be a problem during nighttime conditions.

Table 4-8: Example of Vehicle-Induced Error for IceSight Measurements

Result	Voltage 1	Voltage 2	Air temp	Surface Temp	TIMESTAMP
WATER	87	42	28	29	3/13/05 15:18
WATER	93	45	29	31	3/13/05 15:21
WATER	102	44	31	29	3/13/05 15:24
WATER	92	50	33	28	3/13/05 15:27
DRY	**4999**	**4999**	**34**	**31**	**3/13/05 15:30**
WATER	119	54	35	33	3/13/05 15:33
WATER	131	66	36	33	3/13/05 15:36
WATER	151	86	36	36	3/13/05 15:39

An IceSight software glitch prevented data from being stored during the month of February. Unfortunately, the problem and a solution went undiscovered until mid-month, at which point the system was not operational until new software could be installed. This problem did not affect the operation of the IceSight, only the storage of the data points produced by the unit.

5. CONCLUSIONS

5.1. Summary of Results

Results from the IceSight camera show an ability to detect the presence and phase of water on the roadway surface. The IceSight is highly accurate in detecting winter weather conditions. Detection of other weather conditions also shows strong promise with proper installation.

One aspect of the IceSight's performance that became evident would be an increased need for in routine maintenance performed by transportation department personnel. While RWIS puck sensors can be calibrated or cleaned seasonally to prepare for winter weather, the IceSight may need cleaning once or more each month during the winter season. The need for cleaning would depend on the type and frequency of winter weather and site conditions. This could pose a problem during periods of high road maintenance activity when time and personnel are stretched thin.

5.2. Recommendations

The investigation into the accuracy of the IceSight seems to show that the technology functions well enough to merit deployment. Users should understand that the IceSight should not initially serve as a replacement for puck sensors. It would be appropriate to phase such technology in alongside existing RWIS networks to further examine the functionality of the sensor, in terms of increased maintenance, installation cost, training of maintenance personnel, and accuracy in measuring local weather conditions. Weather conditions not common to Montana or experienced during the investigation may affect the accuracy of the IceSight.

Deployment of the IceSight would be recommended on roadways carrying low to medium volumes of traffic, as high volumes may have a significant impact on the accuracy of conditions reported (see Section 4.4). A possible solution to this problem may be a high angle of installation to minimize time which traffic could interrupt the IceSight signal. Proper familiarization with the operation of the IceSight will also allow the operator to interpret the accuracy of results based on the voltages being returned.

During this study, the IceSight was installed at an angle 53˚ from vertical facing an easterly direction. Although this direction faced away from prevailing winds and precipitation, it did allow for the lens to become obscured during precipitation events approaching from the east, or other conditions which carried moisture and roadway grime from westbound traffic. Again, installation of the IceSight at a high vertical angle will help to alleviate this problem. Another solution proposed by IDI is a tube-like extension to the IceSight's lens shield which helps prevent contaminates from depositing in the lens; however, this was not tested during this study.

Finally, the IceSight should be installed with the intention of routine maintenance being performed. While the IceSight will operate without maintenance, accuracy will not be maintained for the lens becomes dirty or otherwise obscured.

APPENDIX A: TECHNICAL INSTRUCTIONS ON ICESIGHT B CAMERA

A.1 Connecting to Data Collection Computer (DCC)

- Open the Wireless G icon.
- Click on *Site Survey* tab. Active LAN's should appear in the window.
- Double click on DCCWAP
- Scroll down to *Wep Key* type: F137689CE
- Scroll down to *connection* select: Shared
- Enter

A.2 Use of Toolset Software

The Toolset is the interface used for initial setup or adjustment of the IceSight settings. The following paragraphs describe procedures used to set up the IceSight at a new location.

The Toolset, accessed through the *gui.bat* icon, allows the user to interface with the IRID control panel. The toolset actually consists of three windows which will appear when the *gui.bat* icon is opened. The "communications" window indicates the status of the laser, a red beam used to aim the IceSight. The "road image" window is an actual photo of the pavement surface and allows for manual control of the laser. The "control panel" window allows for manipulation of settings needed for calibration. Toolset is used primarily as a calibration tool.

The IRID IceSight B does require calibration before the unit can accurately process road weather information. A procedure to simulate wet and ice conditions allows the user to set wet and ice thresholds which control the IceSight's sensitivity to weather conditions. This process is discussed in further detail in following paragraphs.

Set Baselines

After IRID is mounted in its permanent location, baselines will need to manually be reset. By resetting the baselines, the strength of the IR beam will be set to an optimum level according to the distance and angle to the target area. Through the control panel window, the following steps are used:

- Start by checking to see that dry threshold is set to 0.8 and ice threshold is set to 1.2.
- Click on *GET DATA* button and record the values reported for channels 1 and 2 to the right of the button. This process should be repeated twelve times. (If values of 4.999V or 0.000 V are returned, the TIAG can be lowered or raised respectively in order to get usable readings.)
- After the twelve values are recorded, disregard the high and low value for each channel and determine the mean of the remaining ten values.
- Input the mean in the corresponding *BASELINE E.U.* box for each channel. An exponential subscript should be added to match the value in the *TIAG* box.
- WRITE POINT SETUP TO FLASH in order to save settings

The baselines used for this project are shown in Table A-1.

Table A-1: IceSight Baseline Calibration Settings

Calibration Reading	Voltages Board #1	Voltages Board #2
1	0.4730	0.3620
2	0.4250	0.3280
3	0.4260	0.3230
4	0.4270	0.3220
5	0.4260	0.3250
6	0.4270	0.3230
7	0.5080	0.3710
8	0.5440	0.3810
9	0.3900	0.3190
10	0.4270	0.3200
11	0.4290	0.3270
12	0.4240	0.3260
Average	**0.4438 e-5**	**0.3356 e-5**

Set Dry Threshold

The dry threshold setting may need to be slightly changed in order to compensate for site-specific conditions.

- Pour water over the test area indicated by the laser pointer. Water should cover an area approximately 3 ft. ×3 ft.
- Click on the *GET DATA* button. A condition of WATER should be returned.
- If a condition other than WATER is returned adjust the dry threshold up or down until a correct result is returned.
- Click on WRITE POINT SETUP TO FLASH in order to save settings

Set Ice Threshold

The ice threshold setting may need to be slightly changed in order to compensate for site-specific conditions.

- Put the slab of dry ice directly on the location of the test area. Allow the surface to cool for approximately 15 minutes. When the surface has reached a freezing temperature, remove the dry ice and spray the area with a mist of water in order to produce an icy condition.
- Click on the *GET DATA* button. A condition of ICE should be returned.

- If a condition other than ICE is returned adjust the dry threshold up or down until a correct result is returned.
- Click on WRITE POINT SETUP TO FLASH in order to save settings.

The IceSight is now ready for operation. Settings should not need to be adjusted unless obvious misreadings are occurring or there are changes to the site conditions.

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