Blow Ice Signalized Warning System Design

Final Report

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Executive Summary

Ice on roadways is a significant concern for a state that experiences below-freezing temperatures for the better part of three months. Even the most experienced drivers can be caught off-guard when traveling over black ice, through freezing rain, and on snow-packed roadways.

Minnesota Department of Transportation (MnDOT) District 8 maintenance staff identified a small section of US Highway 12 near the City of Cokato as an area which commonly experiences a condition locally known as “blow ice”. Due to the rural nature and roadway elevation of the area, ice forms when snow blows across the highway, creating an unexpected sheet of ice for travelers. Over the years, this “blow ice” phenomenon has caused numerous accidents, many of which involve high school students traveling to and from nearby Dassel-Cokato High School. MnDOT had previously implemented other solutions including living and traditional snow fences with marginal success.

With the assistance of MnDOT’s Office of Traffic, Safety and Technology staff, a project was initiated to develop an innovative technology-based solution to this problem. SRF Consulting Group, Inc. was selected to develop a Concept of Operations and System Requirements document that reflected stakeholder input for the proposed Intelligent Transportation Systems (ITS) solution. Based on these documents, a system was designed with three in-pavement ice sensors, a camera, and warning signs with flashing beacons upstream of the area where the ice develops to warn travelers. SRF prepared the plans, special provisions and estimate, and performed construction administration, and system integration.

To address a stakeholder requirement, the system also sends an alert to district maintenance staff with a link to a closed-circuit television (CCTV) camera for visual verification that can be viewed from a computer or smartphone. This allows district maintenance staff to determine the proper course of action to address the icy condition without having to travel to the affected area.

The system was installed in the fall of 2014 and an evaluation of system performance and effectiveness was conducted during the winter of 2014 – 2015.

Several pavement sensor parameters for ice detection were considered and it was determined that the system should activate when any sensor both detects ice and 0.4 millimeters of water film thickness on the sensor. The system should deactivate when the water film thickness falls below 0.05 millimeters or ice is no longer detected. Other parameters, such as chemical concentration and temperature were not found to directly correlate to the presence of ice.
Introduction

This report contains high-level information about the ice detection and warning system installed in 2014 near Cokato, Minnesota. The report documents analysis conducted to determine system optimal activation thresholds and presents lessons learned that will help future system designers and users.

Background

The section of Trunk Highway 12 between Dassel-Cokato High School and the City of Cokato has a history of snow and sleet blowing across the road, freezing, and creating icy conditions. These conditions, referred to as “blow ice,” can develop in this relatively short section of TH 12 even when the rest of the highway may be clear and dry. Not only does this condition violate drivers’ expectations, increasing the risk of crashes and injuries, it also prevents MnDOT from attaining their goal of maintaining roadways clear of ice and snow during the winter months. Last, it is time consuming and costly for MnDOT to respond to this isolated condition without real-time information. Figure 1 shows the system’s coverage area near Dassel-Cokato High School.

Figure 1. Ice Warning System Coverage Area.

This project provided a design for an ice detection and advanced warning system that alerts drivers when the pavement becomes icy. Commercial off the shelf (COTS) products are used to provide active, real-time warnings that alert drivers of the icy roadway conditions. The installed system also informs MnDOT District 8 Maintenance when icy conditions exist so they may respond to the condition more quickly and efficiently.

The system is composed of COTS components that are non-experimental, designed for the roadside environment, cost effective, and use standard software. The system provides real-time detection, processing, communications, and displays a warning so drivers and MnDOT maintenance personnel
know of the icy conditions that exist on this section of roadway. The roadside warnings use standard flashing beacons in association with a warning sign with the legend ICE ON ROAD / WHEN FLASHING as shown in Figure 2.

Figure 2.  Active Signs Installed for the Project.
Sensor Evaluation

The system uses model IT-SENS pavement sensors sold by Boschung America. These sensors directly report several metrics about pavement condition. One parameter is related to pavement surface state, but MnDOT District 8 maintenance found that the sensor was more sensitive and triggered the ice warning more frequently than they wished. Additional steps were taken to analyze other parameters that the sensor reports to make the activations match the District’s expectations. This section provides examples and documents that effort.

Introduction

The sensors individually measure surface state condition, surface temperature, chemical quantity, and water height. These measurements were analyzed by comparing trends in the variable readings over select time periods. Time periods were selected by isolating occurrences of snowfall and ice formation on the roadway. Snowfall events increased the expectation of ice formation on the roadway.

The sensors were found to always report an “ice” reading any time ice was on the road. However, they were more sensitive than desired. Cold and wet pavement conditions were sometimes reported as “ice” perhaps due to ice crystals forming on the sensor. However, these were deemed false activations and additional analysis was performed to determine alternative methods for ice state determination.

The sensor measurements were assessed for their effectiveness in indicating ice. Seventeen intervals were analyzed during in the months of November, December, and January 2014 to 2015. This report shows example data for the 48-hour time interval on January 13 and 14, 2015. Weather conditions at the nearby Maple Lake Municipal Airport were reported to be periodic snow between 8:35 p.m. and 11:36 p.m. on the 13th. The ice warning system detected ice conditions between 7:45 p.m. on the 13th and 10:25 a.m. on the 14th. MnDOT’s Maintenance Decision Support System (MDSS) predicted a reduction in mobility and friction on the roadway between 9 p.m. on the 13th and 9 a.m. on the 14th.

Water Height Analysis

The water height reading measures the height of water content on top of the roadway, including ice and snow. The water height reading was analyzed and determined to be a good indicator of roadway ice because of the positive correlation between the two variables. The behavior of water height measurements during a 48-hour time interval is shown in Figure 3.
Figure 3. January 13 and 14, 2015 Water Height Readings

The water height readings correspond with snowfall condition events. The water height readings increased as snowfall begins. The water height readings support the expectations of the MDSS system by increasing water height corresponding to worse as road conditions and decreasing water height readings corresponding to improved road conditions. False-positive ice indications are possible because of compacted snow influencing the water height sensor readings, but can be largely avoided by applying a system activation threshold.

Chemical Quantity Analysis

The chemical quantity measurement quantifies the concentration of road salt on the roadway. This metric was a poor indicator of roadway ice presence because ice forms independently of the condition. For reference, 95% of all non-zero chemical quantity readings fell within the 1900 g/m² range during the months of November, December, and January. An average chemical quantity reading is 500 g/m² for all non-zero readings. The behavior of chemical quantity measurements during a 48-hour time interval is shown in Figure 4.
Ice formed and remained present even though chemical quantity increased to a normal level and decreased back to zero. The chemical quantity readings then increased with the decrease of roadway ice. Therefore, chemical quantity readings were not used to activate the warning system.

**Surface Temperature Analysis**

The surface temperature reading measures the temperature on the roadway. The surface temperature reading is a poor indicator of roadway ice presence because ice presence occurred independently from roadway surface temperature. Therefore, surface temperature was not directly utilized in the analysis to determine the presence of roadway ice. The behavior of surface temperature measurements during a 48-hour time interval is shown in Figure 5.

Ice formed and remained present with little change in behavior of the surface temperature readings. The surface temperature slightly increased with the decrease in roadway ice.
Recommendation

Based on analysis of the recorded data from the three sensors’ November, December, and January time periods, a water height value of 0.4 mm should be used as an activation threshold for the ice warning system and 0.05 mm be used as a deactivation threshold. An activation threshold value of 0.4 mm is generally out of the range of the noise presented by compacted snow and other random influencing factors while still in the range to reliably detect ice formation events.

The gap in the activation-deactivation thresholds reduces the possibility of repeated activation-deactivation sequences with short time intervals. Analysis was performed over the 17 chosen intervals by finding common trends in ice conditions and water height readings to support these specific threshold values.

Activation thresholds less than 0.4 mm tended to potentially falsely activate the system. Deactivation thresholds greater than 0.05 mm deactivated the system too early during ice events, while deactivation thresholds less than 0.05 mm kept the system activated too long after an ice event. In the time interval example provided in this document, the activation threshold would trigger at 7:55 p.m. on January 13th and the deactivation threshold would trigger at 9:00 a.m. on January 14th, matching the observed conditions well.
Lessons Learned

These lessons learned will aid future system designers and system users.

- **Allow adequate testing in “shadow mode”** (in shadow mode, the system is active, but is not visible to the public. For this project, it was originally envisioned that the system would be installed and the contractor would provide the signs but not install them. However, during the design process, it was found it was not allowed for the contractor to provide signs but not install them. The complete system was installed before the system could be tested.

- **Fully calibrate system before making it operational.** This calibration period varies depending on the users understanding of the system. Here, additional effort was needed to analyze system parameters to adjust the activation criteria.

- **Ice on road is difficult to quantify.** The first software version only checked whether the sensors’ pavement condition read “ice” or “snow”. District 8 Maintenance found this criteria to be overly sensitive because the sensors would register this condition even if the sensors had traces of ice. Additional analysis resulted in an alternative activation threshold.

- **Be prepared to make unanticipated changes.** A closed-circuit television camera was installed at the ice detection site. The original concept was that a link to this camera would be included in the emails any time an alert was sent. However, this link caused MnDOT’s spam filter to reject it, so the link was removed to make sure that the email alerts were received.

- **Visual images are valuable for understanding road conditions.** The CCTV was important for verifying ice conditions. This would not be necessary for all systems, but was invaluable for building confidence in the system’s performance.

- **Remote communication/monitoring is essential.** The ability to not only communicate with maintenance staff, but also monitor system performance is essential to system effectiveness.
Conclusion

The system described in this document was operated and monitored during the winter of 2014-2015. After adjustments were made to the activation triggering thresholds mid-winter, the system activated at the times when MnDOT District 8 Maintenance expected. Analysis found that monitoring and activating based on water height with the sensor surface state readings produced accurate activations. The system is planned to remain inplace and be operated with minimal maintenance.

This project proved the concept and effectiveness of the ice detection system. Future implementations of this system may modify the design by using a single sensor and/or wireless communications, lowering the cost of the system, making further deployments more cost effective.