Non-Invasive Sensor Deployment in Aurora Member States

working to advance road weather information systems technology

tech transfer summary

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RESEARCH PROJECT TITLE
Invasive and Non Invasive Sensing: Assessing Agreement between Measurement Systems

SPONSOR
Federal Highway Administration Aurora Program Transportation Pooled Fund (TPF-5(290); Aurora Project 2018-02)

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The Aurora program is a partnership of highway agencies that collaborate on research, development, and deployment of road weather information to improve the efficiency, safety, and reliability of surface transportation. The program is administered by the Center for Weather Impacts on Mobility and Safety (CWIMS), which is housed under the Institute for Transportation at Iowa State University. The mission of Aurora and its members is to seek to implement advanced road weather information systems (RWIS) that fully integrate state-of-the-art roadway and weather forecasting technologies with coordinated, multi-agency weather monitoring infrastructures.

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This study provided an opportunity for many agencies to utilize and evaluate different non-invasive sensors for the first time at their road weather information system stations and to evaluate them at the same locations as their existing invasive sensors.

Project Overview

This project provides a national scale implementation of non-invasive sensors as opposed to in-pavement sensors embedded in the roadway at existing road weather information system (RWIS) locations. Sixteen state transportation agencies participated and were provided with the means and support to deploy non-invasive sensors on co-located sites where invasive (in-pavement) sensors were in service, enabling comparison between the measurements of the two sensor types.

Problem Statement

Documentation comparing in-field non-invasive sensor and invasive pavement sensor temperature readings is limited, even among the agencies with experience deploying them. Several Aurora states that have deployed non-invasive sensors have done so in a limited number of locations, focused primarily on the practical high points and logistics, with sensors from only one manufacturer and not generally co-located sensors. Therefore, only a few combined sites (where both sensor types are deployed) were available, producing very limited comparative data.

Background

Collecting, analyzing, and sharing weather information is critical for the safety, mobility, and vitality of surface transportation in the US. In terms of surface transportation, nearly 5,000 people are killed and more than 418,000 people are injured on average from weather-related crashes each year. This is according to 10-year averages from 2007 to 2016 analyzed by Booz Allen Hamilton based on National Highway Traffic Safety Administration (NHTSA) data (FHWA 2020).

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Non-invasive sensor installation in Pennsylvania

TPF-5(290) and Federal SPR Part II, CFDA 20.205

In the transportation industry, both public and private agencies use RWIS data to understand, analyze, and forecast weather-related impacts to traffic safety, roadway and supply chain operations, maintenance, and a variety of related decision support. Traditionally, RWIS locations relied on in-pavement sensors physically connected back to the roadside equipment for pavement temperature and other variables. Unfortunately, this style of in-pavement sensing is vulnerable to damage as road surfaces are replaced or maintained over time.

The recent market availability of non-invasive sensors has added a new element for consideration as agency personnel contemplate the use and integration of non-invasive sensing. Given this, agency staff are interested in understanding how non-invasive sensing serves their needs and matches up with their legacy invasive sensing data since pavement temperature readings are critical for winter weather treatment decisions.

The lack of comparative data, as well as comparative cost, has potentially slowed technology adoption of non-invasive sensing by some state departments of transportation (DOTs). Meanwhile, some small-scale studies comparing remote and in-pavement sensors have provided promising results confirming that the pavement temperature measurements from non-invasive sensors were comparable to the data obtained from in-pavement sensors (Feng and Fu 2008, Tilley 2010).

Research Description

This project pursued a large-scale effort to deploy non-invasive sensors adjacent to invasive sensors located at existing RWIS stations and to consider agency suitability between the different sensors. While some RWIS stations may have multiple invasive sensors measuring pavement temperature at various locations (e.g., bridge deck and approach), this deployment was unique in that both the invasive and non-invasive sensors were measuring the same, proximate physical locations.

Within this effort, the project team was responsible for identifying the non-invasive sensors on the market, purchasing and distributing the compatible devices and necessary auxiliary equipment to participating Aurora member states and, once installed, assimilating agency experiences and establishing access, if possible, to the sensor data for comparison and visual presentation. The participating Aurora agencies were responsible for site selection, sensor calibration, installation, and maintenance.

Prior to identifying specific needs and practices of Aurora member states, the project team investigated the non-invasive sensors available on the market and solicited feedback from others, such as Aurora members, Friends of Aurora, and vendors.

A market availability list was used as the basis for the procurement plan, which shortlisted equipment based on procurement guidelines, bid results, and selection of final equipment to meet the needs of each state. The procurement plan defined the equipment and quantities per member agency. The procurement budget also included auxiliary components/equipment for the sensors, such as wiring, poles, mounting hardware, and data loggers Not all agencies required auxiliary components.

The existing RWIS configuration in some states dictated non-invasive equipment choice due to compatibility.

A total of 65 non-invasive sensors, representing 51 potential sites, were purchased from four different vendors and distributed to the 16 participating states. The selected sensors were of different makes and models (six total) and based on market availability at the time the project was initiated, along with agency preferences. In general, one non-invasive sensor would be deployed per RWIS site, with the exception of Vaisala sensors, which are deployed in pairs—one for measuring surface temperature and one for determining surface state.

Given the existing RWIS configuration in several participating states, as well as their preference with respect to integration of the non-invasive sensors, a firmware update was also solicited. This firmware update facilitated communication with an existing system instead of requiring integration of a new datalogger. The required changes primarily involved a minor update to the configuration of the data acquisition software to connect to the remote sensors and download data.

Non-invasive sensor installation at bridge approach in Minnesota

While the project team had limited access to data, either due to installation status or data sharing issues, comparisons were conducted on the available data. The objective of the comparisons was not to assess the absolute accuracy of either the non-invasive sensor (or type of sensor) or invasive sensor. The simple relative comparison per site was intended to support agency assessment of non-invasive sensor operation, performance, and possible impacts, if any, on decision making in consideration of legacy data.

A straightforward point-to-point comparison method was used to present the measurements obtained from the two sensor types. The measurements obtained from each non-invasive sensor were plotted against the adjacent invasive sensor, or sensors, and assessed by linear regression for convergence.

Data were available and compared for six sites—four in three midwestern states and two in a western state. For each site, data were compared over multiple months, representing a variety of seasonal conditions and a wide range of surface temperatures.

Pavement surface temperature (in °F) was the measure of interest in the comparisons, because it was the common data item of all sensors at all locations. The results were plotted in the Tableau environment and combined in a Tableau dashboard to enable a side-by-side comparison of different sensors and locations.

Key Findings/Results

Prior to equipment selection, participating states provided input on their expectations for the non-invasive sensors with respect to performance and overall specifications. Many state DOT staff members envision a low-maintenance RWIS network and are developing agency roadmaps with this objective in mind.

Calibration and maintenance requirements were a primary concern regarding sensor deployment and performance. Even if all other aspects of performance were satisfactory, sensor maintenance and calibration were still a concern.

Another critical sensor specification was measurement distance, which could dictate where the non-invasive sensors could be installed. Because non-invasive sensors are mounted on a pole or overhead, a site's characteristics may only allow a pole to be installed at certain distances from the road surface (which can be greater than the sensor's range).

A significant challenge to the project was the COVID-19 pandemic, which impacted the project's flow and progress. Under pandemic conditions, the normal day-to-day routine of all involved institutions and supporting agencies was disrupted. Priorities also shifted and changed. In some cases, agency turn-over in personnel and their experience significantly impacted the ability to get the equipment installed prior to the project end date. Lastly, accessing the data from both sensor types, i.e., non-invasive and invasive, was a challenge that limited the project team's ability to compare data sets within permissible time constraints.

In general, many participating states provided positive feedback with respect to non-invasive sensors and their reported data. Some of the challenges that were shared included identifying a suitable installation location due to sensor specifications, initial sensor operation, and integration and data retrieval.

Implementation Readiness

The sensors at the co-located sites are anticipated to continue collecting data, which may supply a huge data set to investigate how the two sensor types, i.e., invasive and non-invasive, and the equipment from different manufacturers compare. Many sites with different service conditions and installation practices share the same non-invasive equipment, providing data to assess these sensors' performance—relative to invasive sensors—in different settings.

Image capture September 2021, ©2022 Google

Non-invasive sensor installation in Alaska

Ten of the 16 states had deployed and were operating at least some of the non-invasive sensors. As of the time of this report, the status of the states with respect to non-invasive sensor deployment can be broadly categorized as one of the following.

- Deployed all of the non-invasive sensors at co-located sites, i.e., RWIS with an invasive sensor
- Deployed some of the delivered non-invasive sensors at co-located sites
- Deployed non-invasive sensors at independent site(s), i.e., RWIS with no invasive sensor
- Not deployed the non-invasive sensors but plan to do so
- Not deployed the non-invasive sensors, and deployment status undetermined or not anticipated

Of the agencies that had deployed non-invasive sensors, some have provided data (or access to the data) for comparison. Other agencies had provided data (or access), but an element was currently missing for comparison, or data access was planned, pending, or yet to be determined.

Regarding data availability, a number of participating states have agreements in place to make all of their RWIS data available on the Federal Highway Administration (FHWA) Weather Data Environment portal at **https://wxde.fhwa.dot.gov/?org.apache.catalina.filters.CSRF_NONCE=CE9A194D4D12C00983C4710C50368FA6**. At this point, limited non-invasive data for the new installations were available; however, this may improve in the future. Some available data sets simply were missing pieces of information, in which case, the problem may potentially be solved with minimal correspondence.

A potential next step is to continue communication with the participating agencies to track non-invasive sensor installations and to obtain additional data for comparison. Final confirmation of installation status and participating agency plans would be beneficial. And, the current Tableau sensor comparison dashboard could be expanded into a comprehensive comparative presentation for the sites.

Implementation Benefits

Despite the considerable challenges caused by the COVID-19 pandemic and other external factors, the project enjoyed a good degree of cooperation from the state agencies and will continue to see the remaining installations completed as agencies add staff and work through their backlogs of critical projects. Although not all of the sensors were installed, many lessons were learned, and a considerable amount of data was collected by the agencies for internal use and on-going assessment.

This project involved a wide variety of agency practices, service conditions, and equipment models, giving promise to the possibility of using the experiences and results to develop a guideline for non-invasive sensor deployment. The feedback from the states regarding the long-term application of non-invasive sensors may be a valuable source for this endeavor.

If the future shows that this project has verifiably contributed to an upward trend in non-invasive sensor technology adoption by state DOTs, this framework can be modeled to promote the adoption of other useful technologies.

As a result of this experience, some participating state departments of transportation (DOTs) have decided to adopt non-invasive sensors, expand their deployment of them, or even consider applications beyond those planned with this project. While this project initially targeted pavement surface temperature, one participating agency with limited non-invasive sensor experience is planning on statewide deployment for real-time friction measurements for use in agency decision making.

The project allowed participating agencies to work with new vendors, creating an opportunity to evaluate the different products, encounter potential issues, and identify possible solutions through a low-risk environment. This effort will support future research on both pavement temperatures and friction across the US and based on data from the same make and model of non-invasive equipment.

References

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