Roadway Friction Modeling: Improving the Use of Friction Measurements in State DOTs

Aurora

working to advance road weather information systems technology

tech transfer summary

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RESEARCH PROJECT TITLE
Roadway Friction Modeling

SPONSOR
Federal Highway Administration Aurora Program Transportation Pooled Fund (TPF-5(435); Aurora Project 2020-04)

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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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Modeling roadway friction using routinely collected weather condition data can help predict friction at sites where direct friction measurements are not available.

Background and Problem Statement

States often use road friction measurement devices as guidance for snow removal activities. Given that the devices are costly, direct friction measurements are typically only available at certain key locations.

In addition, states sometimes use both stationary and mobile friction sensors from different manufacturers. Analogous readings from the different sensors typically disagree, leading to uncertainty as to how to interpret the measurements.

To help improve winter road maintenance and safety, methodologies are needed that model roadway surface friction based on commonly collected weather condition data and that standardize friction measurements from multiple sensor types.

Research Objectives

- Determine the relationship between weather conditions and roadway friction measurements as observed in the laboratory
- Determine whether friction measurements from different friction sensors for identical weather conditions and pavement types can be standardized
- Determine whether the relationship between weather and pavement friction found in the laboratory is analogous to the relationship between weather and pavement friction found in practice on highways
- Model roadway friction using weather condition data to predict friction at sites where friction measurements may not be available

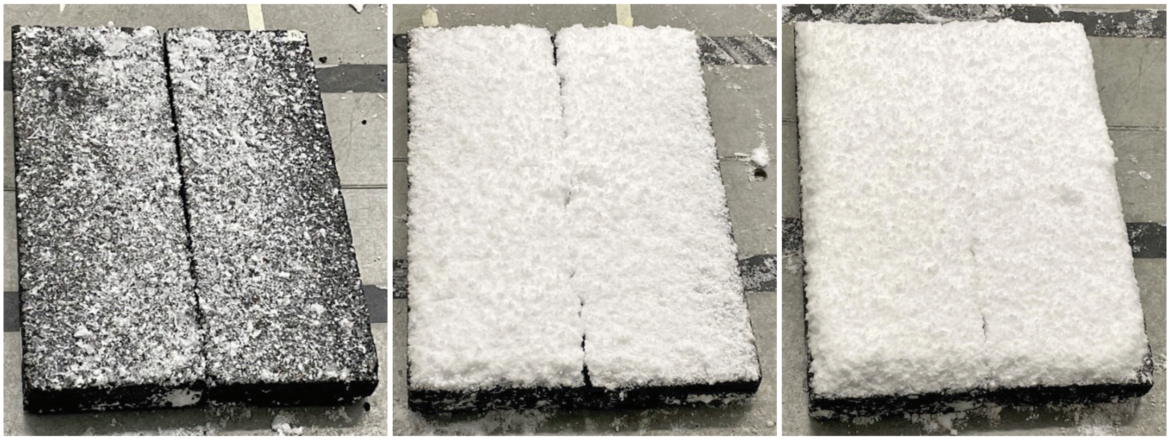
Research Description

The tasks described below were undertaken to address the research objectives.

Cold Laboratory Testing of Stationary Friction Sensors

The project team installed stationary friction sensors from Vaisala and High Sierra in the National Center for Atmospheric Research (NCAR) Cold Laboratory and spent one week simulating the sensors' response to different meteorological and road conditions. The High Sierra sensor did not produce adequate friction measurements during the test, so all reported data were from the Vaisala sensor.

TPF-5(435) and Federal SPR Part II, CFDA 20.205



Laboratory asphalt pavement samples showing light (left), moderate (middle), and heavy (right) snow

The project team analyzed the friction data and determined how the sensors responded to the simulated weather and road conditions. The team then modeled friction based on predictors such as air temperature, surface temperature, dew point temperature, relative humidity, water thickness, snow thickness, and ice thickness.

Key Findings

- The Vaisala sensor signaled a response to the different weather conditions but was not able to differentiate light, moderate, and heavy snow conditions
- The team was able to obtain an accurate prediction of surface friction based on the mean absolute error (MAE) using all of the measurements and a decent prediction when water, snow, and ice thickness were excluded

Standardizing Friction Measurements from Multiple Friction Sensors

The project team attempted to standardize collocated meteorological and friction measurements using data from two previous studies:

- Mobile friction sensor and associated meteorological data from a Clear Roads study performed in 2018 in Minnesota (Minge et al. 2019)
- Stationary friction and road weather information system (RWIS) data collected at a site in Etna, Maine, in 2021 by the Maine Department of Transportation (Hans et al. 2022)

Key Findings

- The different sensors were generally in close agreement at higher friction values
- During lower friction events, both the mobile and stationary sensors typically sensed the event in tandem but differed on the event's magnitude, sometimes significantly

Stationary friction sensors mounted at an RWIS site in Etna, Maine

Using Meteorological Measurements to Infer Road Friction Conditions

The team collected data from four different environments to model roadway friction based on meteorological conditions:

- Colorado Department of Transportation RWIS and optical friction data
- Cold laboratory RWIS and optical friction data (collected by the research team at the NCAR Cold Laboratory)
- Minnesota mobile optical friction data collected in a Clear Roads study (Minge et al. 2019)
- Minneapolis-St. Paul International Airport (MSP) RWIS and friction wheel data

The project team collected the Colorado RWIS and optical friction data over a 1.5-year period to target Colorado surface friction conditions using machine learning (ML). The team also used models based on the MSP and cold laboratory data to target Colorado surface friction.

Key Findings

- The model using the Colorado RWIS and optical friction data best predicted the Colorado friction magnitudes, illustrating that ML models focused on the data of a particular environment typically outperform models based on data obtained in other environments
- Including roadway state, water thickness, or snow thickness as predictor variables significantly improved the performance of the Colorado ML friction model, which indicates that these variables are significantly correlated with road friction measurement
- It is extremely important to perform ML training using a balanced set of friction values

Friction Wheel Measurement Analysis

The project team analyzed friction wheel measurements and collocated RWIS data from Trafikverket, the Swedish Transportation Administration, to determine the benefit of incorporating friction wheel data to either standardize or predict friction measurements.

Key Findings

- The researchers found a correlation between precipitation events and road friction as measured by the friction wheel
- The friction wheel measurements were not necessarily taken close to the RWIS sites, so data characterizing the relationship between RWIS and nearby friction wheel measurements were lacking

Conclusions and Recommendations

- ML models can be created using data from friction sensors in the cold laboratory that exhibit a good MAE when predicting the friction response to meteorological conditions in the laboratory. However, these models have a sizable MAE when applied to data from the field, so the research team does not recommend that the laboratory-developed models be used on field data.

Snyder 2019

Friction wheel

- Collocated RWIS and stationary friction sensor data can be used to develop state-specific friction models using ML techniques. These models can then be used to provide a synthetic friction estimate at RWIS sites that are not equipped with stationary friction sensors. The accuracy of the predictions can be determined at sites where friction sensors are available and can be improved when water thickness and/or snow thickness are also available.
- RWIS measurements, including air temperature, surface temperature, dew point temperature, relative humidity, and road condition (including roadway state, water thickness, and snow thickness), can be used to derive an accurate friction model that targets observed friction values.
- Friction values from multiple sensor types are close in magnitude when friction is high, but agreement among sensors varies for lower friction values. To standardize the measurements from multiple friction sensors, friction values can either be averaged or associated with a set of friction categories.

Implementation Readiness and Benefits

State agencies can develop robust models for estimating roadway friction based on weather conditions using RWIS data and corresponding friction measurements from at least one to two winter seasons that feature a variety of winter storm events. With these models, states can estimate roadway friction at locations where direct friction measurements are not typically available.

The final report for this project provides more detailed information on the results of this research based on the equipment and methods that were used and the specific measurements and data thresholds that were obtained.

References

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