Demonstration and Inter-Comparison of Seasonal Weight Restriction Models – Phase II

working to advance road weather information systems technology

tech transfer summary

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RESEARCH PROJECT TITLE
Demonstration and Inter-Comparison of Seasonal Weight Restriction Models – Phase II

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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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Precisely scheduling spring load restrictions and winter weight premiums will improve road use management during freezing and thawing cycles, ultimately enhancing roadway lifetime and usability.

Research Objectives

The overall objective of this research was to investigate the reliability, benefits, costs, and risks of various models that use atmospheric weather data to schedule spring load restrictions (SLRs) and winter weight premiums (WWPs).

The objective of this phase (Phase II) was to implement several models recommended in Phase I at demonstration sites, calibrate the models if needed, and validate the models using subsurface temperature data and, in limited cases, deflection data from falling weight deflectometer (FWD) testing.

Problem Statement

SLRs can impose economic hardships and introduce sustainability concerns when heavy vehicles are prohibited from using key roadways or are forced to take long detours, make more trips with reduced load sizes, and consume more fuel. The need to protect infrastructure must be balanced with the need to allow roadway use during high-stress periods such as freeze-thaw cycles.

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Some DOTs take advantage of the period of higher pavement strength in mid-winter by applying winter weight premiums to increase the allowable weight that trucks can haul

To prevent excessive roadway damage during spring thaws, DOTs apply spring load restrictions

Background

In seasonal frost areas, some state departments of transportation (DOTs) apply WWPs in mid-winter, when pavement strengths are highest, to increase the allowable weight that trucks can haul. During the spring thaw, many DOTs apply SLRs to limit loads on low-volume roadways that are weakened due to freeze-thaw processes and especially vulnerable to damage.

Many transportation agencies have traditionally applied WWPs and SLRs based on set dates and/or subjective visual inspection procedures. More recently, agencies have turned to quantitative approaches, applying WWPs and SLRs based on pavement deflection data from FWD testing or subsurface temperature and moisture profiles gathered from sensors installed in the pavement.

However, FWD testing and analysis is time consuming and expensive, as is instrumenting pavements to collect data. Atmospheric weather data are more readily available and much less expensive to obtain, with 7- and 10-day air temperature forecasts publicly available. Many agencies are therefore considering the use of weather-based indices and/or frost-thaw depth prediction models coupled with atmospheric forecasts to estimate dates when WWPs or SLRs should be applied and lifted.

Research Description

In Phase I of this research, available models for applying WWPs and SLRs based on atmospheric weather data were reviewed, and a subset of these models was recommended for demonstration in Phase II.

Two types of models were evaluated in this study: degree-day threshold protocols based primarily on air temperature data and models for predicting subsoil frost and thaw depth profiles based on atmospheric weather data and, in some cases, other details of the pavement structure.

The models selected during the Phase I study were evaluated at five sites, one each in Alaska, Michigan, North Dakota, Wisconsin, and Ontario, Canada. Each site had a road weather information system (RWIS) station to provide atmospheric weather data and a thermistor string to measure subsurface temperatures to a depth of about 6 feet. Pavement layer thickness and material type data were also collected.

The models' predictions and recommendations were validated against observed subsurface temperature profiles and, for the North Dakota site, pavement deflection data from FWD testing.

In addition to the Phase I models, FrezTrax, proprietary software developed by Meridian Environmental Technology, Inc. based on a degree-day threshold model, was evaluated at several sites using atmospheric weather data from 2014–2015, 2015–2016, and 2019–2020.

The following summarizes the degree-day threshold models evaluated:

- **Minnesota Department of Transportation (MnDOT) Protocol.** Evaluated using 2014¬–2015 and 2015–2016 winter season data at all five original sites; evaluated via a graphical user interface (GUI) developed by the Northeast Regional Climate Center (NRCC) at Cornell University at 22 sites in North Dakota for the 2020 spring thaw season.

- **Lakehead University and Ministry of Transportation Ontario (MTO) Model.** Evaluated using 2014¬–2015 and 2015–2016 data at the Ontario site; evaluated at the four other original sites for the 2015–2016 winter season using 2014¬–2015 data for calibration.

- **Pavement Surface-Temperature Prediction Model for SLR Application.** Evaluated using 2014¬–2015 and 2015–2016 data at the original sites in Alaska, Michigan, North Dakota, and Wisconsin.

- **Berg/U.S. Forest Service (USFS) Method.** Evaluated at the Alaska site for the 2019¬–2020 winter season data using data from 2010¬–2011 through 2013¬–2014 for calibration.

- **FrezTrax Model.** Evaluated using 2014–2015 and 2015–2016 data at the Alaska, Michigan, North Dakota, and Wisconsin sites; evaluated using 2020 thaw season data at the Alaska, Michigan, and North Dakota sites and five additional sites in North Dakota.

The following summarizes the frost and thaw depth prediction models evaluated:

- **Freeze-Thaw Index Model: Linear Regression.** Evaluated at all five original sites for the 2015–2016 winter season using 2014¬–2015 data for calibration.

- **Freeze-Thaw Index Model: Polynomial Regression.** Evaluated using 2014¬–2015 and 2015–2016 data at the Ontario site; evaluated at the four other original sites for the 2015–2016 winter season using 2014¬–2015 data for calibration.

- **U.S. Army Corps of Engineers Model 158.** Evaluated using 2014¬–2015 and 2015–2016 data at all five original sites.

- **Enhanced Integrated Climatic Model (EICM).** Evaluated via AASHTOWare Pavement ME software using 2014¬–2015 and 2015–2016 data at all five original sites; evaluated via vRWIS software using 2020 spring thaw season data at the Alaska, Michigan, North Dakota, and Wisconsin sites.

Key Findings

Degree-Day Threshold Models

- The MnDOT protocol was deemed a more reasonable approach for setting WWP start dates than the Lakehead University model due to the site-specific calibration required for the latter and the scatter observed in the calibration data.

- The MnDOT protocol provided the most conservative recommendations for SLR start dates, i.e., it recommended the earliest SLR start dates and ones that generally fell slightly before pavement thawing was observed, followed by the FrezTrax and Lakehead University models. The latter two models recommended SLR start dates after thawing was observed.

- The Berg/USFS method shows promise as a tool for estimating SLR start dates in higher latitude regions such as Alaska, where the MnDOT protocol does not work as well.

- For SLR removal dates, the FrezTrax model performed better than the other protocols at most of the six North Dakota sites in 2020, but it was not conservative enough at the original North Dakota site during the 2014–2015 and 2015–2016 winter seasons. The MnDOT model worked well at the original North Dakota site during spring 2015 and 2016, but it was not conservative enough at several of the North Dakota sites in 2020.

Frost-Thaw Depth Prediction Models

- The freeze-thaw index models and Modified Model 158 generally performed very well in tracking the onset of freezing and thawing and could be useful in deciding when to apply WWPs and SLRs. In contrast, the EICM in many cases predicted temperatures significantly colder than the measured temperatures, which could result in non-conservative SLR posting.

- Most of the frost and thaw depth prediction models evaluated in this study tended to estimate end-of-thaw dates later than those actually observed. Additionally, since these models do not provide information regarding the rate of stiffness recovery after thawing is complete, they do not appear to provide any significant advantage in determining SLR end dates.

Recommendations

Degree-Day Threshold Protocols

- In the absence of extensive subsurface temperature monitoring instrumentation, the MnDOT protocol is recommended for setting WWP start dates.

- The MnDOT protocol is highly recommended for setting SLR start dates, even when subsurface temperature data are available, for locations at a similar latitude to Minnesota. Anticipating the onset of spring thawing can allow for the three to five days of advance notice for posting required in most states.

- For regions at higher latitudes such as Canada and Alaska, the Berg/USFS method shows more promise than the MnDOT protocol for setting SLR start dates.

- To err on the side of caution when removing SLRs, the FrezTrax model may be preferred because its recommendations tend to be more conservative than the MnDOT protocol's 56-day duration limit. The MnDOT protocol might be modified to recommend the latter of 56 days or the date when the protocol's thaw index reaches a certain value.

- The MnDOT protocol may be the safest choice if an agency wants to use a single protocol for both SLR application and removal decisions because it is far more effective to place restrictions early than to delay their removal.

Frost-Thaw Depth Prediction Models

- Modified Model 158 was found to found to perform very well in terms of tracking the onset of freezing and thawing and could be useful in deciding when to apply WWPs and SLRs.

- While Modified Model 158 may be preferred over the degree-day threshold models because it does not require site-specific calibration, some skill is required to implement the model in a spreadsheet and/or to write computer code to run it.

- The EICM is not recommended for use as an SLR timing tool at this point. In many cases, the results of the EICM predictions were not accurate and tended to estimate the onset of thawing after substantial thawing had actually occurred.

- Overall, the frost-thaw depth prediction models did not provide any significant advantages over the degree-day threshold protocols and require input data that are not always available.

Implementation Readiness and Benefits

This study resulted in recommendations on the most useful and readily implemented methods for using air temperature data to determine WWP and SLRs application dates. Transportation agencies can use these recommendations to understand the reliability, benefits, costs, and risks of these methods.

Scheduling WWP and SLRs application dates as precisely as possible will improve the management of road usage during high-stress periods such as thaw cycles, which will ultimately improve roadway lifetime and usability, benefitting both agencies and roadway users.