Research Need Literature Review

**Topic:** NS #572 – Have Minnesota’s Warmer Winters Increased the Number of Freeze/Thaw Cycles?

**Date:** 26 June 2019

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**Resources searched:** TRID, RiP, Internet, Library Catalog

**Summary:** Although theoretically of interest to a broader number of localities, impacts of climate change on freeze-thaw cycles appear to have received less study than impacts on permafrost. Studies that have examined freeze-thaw cycles appear to be in broad consensus that such cycles will increase with detrimental impacts on pavement. Two opportunities seem to present for usefully extending work in this area. One would be a targeted study focused specifically on local impacts in the Minnesota context. The second would be an analysis bringing increased maintenance costs from freeze-thaw activity into the larger perspective of other maintenance impacts of climate change. Existing studies are ambivalent and/or contradictory as to whether net impacts of climate change on transportation maintenance in norther climates will increase or decrease expenses in total. It merits to be noted also that many of the most ambitious studies on freeze-thaw impacts are now approaching five years old. Depending on the extent to which data sets have been improved or consensus reshaped on the general climate science involved during that period, there may be a general benefit from updating those studies with more current data inputs.

**Results**

*(in order of relevance)*

**Title**
Minnesota Climate Trends

**Source**
Minnesota Department of Natural Resources

**URL**
https://arcgis.dnr.state.mn.us/ewr/climatetrends/

**Abstract**
The DNR has made a wealth of longitudinal climate data available on its website, particularly through this interactive mapping tool which affords opportunities to see trends in average temperature since 1895, with granularities by month and by watershed region within the state.

**Date**
2019

**Title**
Fourth National Climate Assessment
Two sections of this extensive report are particularly applicable to the proposed topic. Chapter 12 (https://nca2018.globalchange.gov/chapter/12/) focuses specifically on transportation impacts of climate change, noting that “warming winters… will likely extend the construction season, reduce winter road maintenance demand, and reduce vehicle accident risk”, but that “warming winters will also change the timing and location of freeze and thaw events, potentially increasing pavement cracking and pothole conditions in northern states.” Chapter 21 (https://nca2018.globalchange.gov/chapter/21/#key-message-5) specifically examines the Midwest region, where it observes that “[m]ilder winter temperatures, however, may … reduc[e] the amount of rutting caused by the freeze-thaw cycle.”

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**Title**  
Climate change: potential impacts on frost-thaw conditions and seasonal load restriction timing for low-volume roadways

**Source**  
Road Materials and Pavement Design 5

**URL**  
https://doi.org/10.1080/14680629.2017.1302355

**Abstract**  
Low-volume roads constitute a major percentage of roadways around the world. Many of these are located in seasonal frost areas where agencies increase and decrease the allowable weight limits based on seasonal fluctuations in the load carrying capacity of the roadway due to freeze–thaw conditions. As temperatures shift due to changing climate, the timing and duration of winter freeze and spring thaw periods are likely to change, potentially causing significant impacts to local industry and economies. In this study, an ensemble of 19 climate models were used to project future temperature changes and the impact of these changes on the frost depth and timing of seasonal load changes across five instrumented pavement sites in New England. The study shows that shifts of up to 2 weeks are projected at the end of the century and that moderate variability was observed across the study region, indicating that local conditions are important for future assessments depending on the desired level of accuracy. From 1970 to 1999, the average freezing season lasted between 9 and 13 weeks in the study region. By 2000–2029, the frozen period shortens by approximately 10 days over baseline duration (10–20% reduction). By the end of the century under RCP 4.5, frozen periods are typically shorter by 4 weeks or a 30–40% reduction. However, RCP 8.5 results indicate that four out of the five sites would have no frozen period during at least six winters from 2060 to 2089.

**Date**  
2018

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**Title**  
Assessment of climate change adaptation costs for the U.S. road network

**Source**  
Global Environmental Change 23(4), pp. 764-73

**URL**  
https://doi.org/10.1016/j.gloenvcha.2013.03.004
Abstract: The U.S. road network is one of the nation's most important capital assets and is vital to the functioning of the U.S. economy. Maintaining this asset involves approximately $134 billion of government funds annually from Federal, State, and local agencies. Climate change may represent a risk or an opportunity to this network, as changes in climate stress will affect the resources necessary for both road maintenance and construction projects. This paper develops an approach for estimating climate-related changes in road maintenance and construction costs such that the current level of service provided by roads is maintained over time. We estimate these costs under a baseline scenario in which annual mean global temperature increases by 1.5 °C in 2050 relative to the historical average and a mitigation scenario under which this increase in mean temperature is limited to 1.0 °C. Depending on the nature of the changes in climate that occur in a given area, our analysis suggests that climate change may lead to a reduction in road maintenance and/or construction costs or an increase in costs. Overall, however, our analysis shows that climate change, if unchecked, will increase the annual costs of keeping paved and unpaved roads in service by $785 million in present value terms by 2050. When not discounted, this figure increases to $2.8 billion. Policies to reduce greenhouse gas emissions are estimated to reduce these costs by approximately $280 million in present value terms and by $885 million when not discounted. These costs vary substantially by region and time period, information that should be important for transportation planners at the national, state, and local levels.

Date: 2013

Title: Transportation corridor resiliency in the face of a changing climate

Source: Pacific Northwest Transportation Consortium, Alaska University Transportation Center

URL: http://hdl.handle.net/1773/43584

Abstract: The effects of a changing climate on transportation corridor slopes are poorly understood, but several recent studies have suggested that landslide activity, especially rockfall, is likely to increase as a consequence of the increased occurrence of intense precipitation events. Effects from climate change such as extreme temperature fluctuations, freeze-thaw cycles, and increased rainfall quantity and intensity weaken geologic materials, exacerbating slope failures. In order to understand slope rockfall activity and its linkages to weather and climate, the authors acquired additional high-resolution lidar data and unmanned aircraft systems structure data from motion surveys of rock slopes in Alaska. Over several projects they have successively developed a rich data set spanning 5 years to quantitatively evaluate rockfall activity (the magnitude-frequency of rockfall events), which proved useful for examining correlations with historic weather patterns and future climate forecasts. As part of this research, the authors further developed the Rockfall Activity Index (RAI) and began to evaluate how the RAI can be linked to increasing temperature swings and freeze-thaw cycles. This quantitative approach for rockfall activity forecasting is an important step in providing tools to state departments of transportation to assess transportation corridor risks, sustainability, and resiliency, especially for Alaska in the face of a changing climate. This research is a first step in providing the analysis tools needed to meet a recent presidential directive and help improve
our fundamental understanding of the potential impacts of climate change on the safety of and mobility within transportation networks in landslide-prone regions such as the Pacific Northwest in the U.S.

Date 2017

Title The importance of asphalt mixture air voids on the damage evolution during freeze-thaw cycles

Source Canadian Technical Asphalt Association

URL https://trid.trb.org/Results?q=&serial=%22Proceedings%20of%20the%20Sixth-First%20Annual%20Conference%20of%20the%20Canadian%20Technical%20Asphalt%20Association%20(CTAA)%22

Abstract In Canada, like in many other northern countries, freeze-thaw cycles are a common phenomenon. Also, it is believed the number of freeze-thaw cycles is increasing with the influence of the climate change. Because of that, the actual methods to predict the pavement distresses may overestimate the pavement life. Environmental conditions, rate of loading and mixture properties are the most important factors that affect the complex modulus (|E*|) values. The effect of environmental freeze-thaw cycles on mechanical distresses of asphalt mixes have not yet been properly investigated. The main objective of this study was to compare the damage evolution created during freeze-thaw cycles of partially saturated samples with varying air void content. Three different percentages of air voids was used in this project. The samples were subjected to complex modulus test carried out using the Direct Tension-Compression (DTC) test on cylindrical samples. The rheological model 2S2P1D was used to simulate the behaviour of the mixes according to various states. The results indicate that the air voids content do affect the complex modulus value, and freeze-thaw cycles do decrease the value of the modulus.

Date 2016

Title Vulnerabilities and design considerations for pavement infrastructure in light of climate change

Source Transportation Association of Canada


Abstract Although climate is directly linked to infrastructure deterioration, there is little research on potential impacts of climate change. Canadian estimates suggest increases in temperature of 2oC to 5oC and up to 10% precipitation over the next 45 years. Relatively little research has been completed to investigate the potential engineering impacts of climate change on infrastructure, and particularly roads and bridges. Potential impacts need to be addressed given the importance of road and bridge infrastructure on economic and social activity. More specifically, climate change can impact: thermal cracking, frost heave and thaw weakening, permafrost melting, permanent deformation associated with warm and cold temperatures, to name a few. Current and past engineering designs generally assume a static climate whose variability can be adequately determined from records of weather conditions, which normally span less than 30 years and often
less than 10 years. The notion of anthropogenic climate change challenges this assumption and raises the possibility that the frequency, duration or severity of thermal cracking, rutting, frost heave and thaw weakening may be altered leading to premature deterioration. General methods for assessing the potential impacts of climate change on various aspects of society, economy and environment have been developed over the past two decades, largely based on approaches rooted in applied climatology or the hazards and risk assessment literature. The leading international source of guidance on climate change impact assessment is the Intergovernmental Panel on Climate Change (IPCC). It is an organization that is responsible for periodic reviews of the scientific literature on aspects of climate change science, impacts and adaptation assessment, and emissions mitigation. Generally, maintenance, rehabilitation or reconstruction will be required earlier.

The paper provides a brief introduction and background on climate change in general and the related predicted impacts on road infrastructure and associated structures, with primary focus on bridges. A summary of findings provides some more specific details and has been prepared using available public agency documents that were located from public sources.

Title 2015

| Date | 2015 |
| Title | Potential impact of climate change on porous asphalt with a focus on winter damage |
| Source | Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux |
| URL | https://trid.trb.org/Results?q=&serial=%22Transport%20Research%20Arena%20(TRA)%205th%20Conference%20-%20Transport%20Solutions%20from%20Research%20to%20Deployment%22 |
| Abstract | This paper investigates the impact and adaptation options of climate change on porous asphalt roads, specifically for the case of winter weather (freeze-thaw cycles) and road damage in the Netherlands. Changes in weather patterns pose a threat to the serviceability and long-term performance of roads, as up to half of road maintenance costs are attributable to weather stresses. Porous asphalt (PA) is of particular concern in the Netherlands, where its use has become mandatory, primarily for environmental (noise-reduction) concerns. In recent winters, ravelling and pothole damage have increased the discussion about cold weather performance of porous asphalt and the potential challenges of changing winter weather patterns. Current climate change impact research often produces results on a systemic, macro scale, and less is known about the regional impact to specific road types. To address this, we examine the correlation between historic winter weather and PA pavement performance, which is particularly sensitive to the freezing / thawing phenomena. That relationship is combined with Dutch regional climate models and used to analyse the potential physical and economic impacts of adapting to future climate. This has implications on maintenance, design, and long-term planning of the Netherlands' road network. |

Date 2014

Title Climatic effects on pavement and geotechnical infrastructure
This collection contains 22 peer-reviewed papers that address the impact of various climatic factors such as freeze and thaw, wet and dry cycle, rainfall, and flooding on designing, building, preserving, and maintaining transportation infrastructure. Topics include: international perspectives on climatic effects; preservation, maintenance, and operations; infrastructure materials and performance; and analysis and evaluation methods. This proceedings will be invaluable to professionals in pavement and geotechnical engineering including professors, students, design engineers, and contractors.

Title: Ground freeze-thaw, snow and roads in northern Sweden
Source: Uppsala Universitet

In this thesis freeze-thaw along roads in northern Sweden is examined. The examinations are put in a context of changing climate and its amplification towards the Arctic region on earth. The research focuses on the impact of a warmer climate on ground freeze-thaw and in extension road maintenance in the region. The investigation is presented through two scientific papers, where the first examines how ground temperatures are developed during a single frost season experiment, where a natural accumulation of snow cover and a continual removal of snow cover occur respectively. In the second paper, ground temperature data from sub-Arctic Sweden that has been logged by the Swedish Transport Administration, has been collected and freeze-thaw cycles have been calculated and analysed. The results are related to regional landscape factors and are in the context of regional climate change discussed to reach understanding of challenges for road maintenance in the region and opportunities to reach resilience. The results in Paper 1 show that also a thin cover of snow has impact on the freeze-thaw frequency, duration and intensity that occur in and on the surface of the ground. Furthermore the results show that the ground temperatures rise in due to an increase in snow cover amounts and that this process occurs in several steps. Paper 2 shows that the occurrence of ground freeze-thaw is affected by the proximity to open waters. Warmer temperatures in the air may cause later ice freeze-up and earlier ice break-up on lakes, rivers and on the Gulf of Bothnia and roads in northern Sweden are in general situated on the coast or near rivers. Ground temperatures around 0 °C has a high negative impact on road stability and a warmer and wetter climate in northern Sweden may thus increase road deterioration. The economic development in Sweden stays dependent on extraction of natural resources in sub-Arctic Sweden and thus it is of major concern to maintain and improve road infrastructure in the region.

Date: 2014