



Addressing Resilience in Project Development

Temperature and Precipitation Impacts on Cold Region Pavement

This study focused on the vulnerability of cold region pavement to changes in temperature and precipitation.¹

Site Context and Facility Overview

State Route (SR)-6/SR-15/SR-16 in Guilford, Maine is representative of many roads in New England. It is a rural two-lane highway that is exposed to long, cold winters. This study analyzed how changing temperature and precipitation patterns will alter freezing and thawing patterns, which could affect the performance of pavements in cold climates (e.g., frost heaving and thaw weakening).

The study also covered how the timing and duration of winter weight premiums (WWPs) and spring load restrictions (SLRs) may vary with changes in temperature. WWPs permit above-normal truck weight limits when the road bed is frozen and the hardened pavement can handle heavier traffic weights without damage. SLRs require below-average truck weight limits when thawing weakens the pavement system.



Figure 1: Map of project location (blue star).

Environmental Stressors and Scenarios

This study focused on the projected changes in the following environmental stressors:

- Temperature
 - Mean daily temperature
 - Annual average maximum temperature
 - Annual average minimum temperature
 - Degree days greater than 50-degrees Fahrenheit
 - Low pavement temperature
 - Cumulative freezing index²
 - Number of freezing days³
- Annual total precipitation
- Derived from temperature and precipitation
 - Depth of frost penetration
 - Thornthwaite Moisture Index (TMI), which is indicative of soil moisture

Future projections of temperature and precipitation data were taken from the U.S. Bureau of Reclamation (2013) which provides peer-reviewed statistically downscaled Coupled Model Intercomparison Project 5 data.

¹ This snapshot summarizes one of nine engineering-informed adaptation studies conducted under the Transportation Engineering Approaches to Climate Resiliency (TEACR) Project. See <https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/> for more about this study (including full citations) and Synthesis of Approaches for Addressing Resilience in Project Development.

² The cumulative number of degree-days when the air temperature is below 32-degrees Fahrenheit.

³ The number of days with mean temperatures less than 32-degrees Fahrenheit (i.e. a non-zero daily freezing index).

Temperature and precipitation projections obtained for this location show a clear upward trend in temperature (Figure 2), and on average, a slight increase in total annual precipitation (although some individual models project a decrease; see Figure 3).

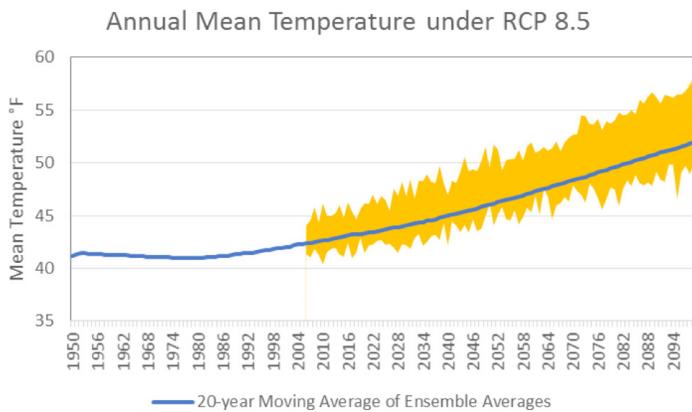


Figure 2: Annual mean temperature projections for Guilford, ME.

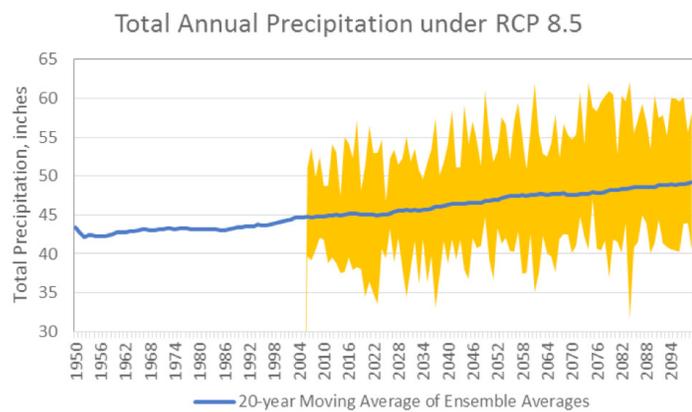


Figure 3: Annual total precipitation projections for Guilford, ME.

Analytical Approach

Flexible Pavement Design

SR-6 is currently constructed with a flexible pavement system that consists of an asphalt concrete layer over a granular or bituminous base and subbase. Several analyses were conducted to determine the impacts of temperature and precipitation change on flexible pavement.

- **Subgrade support conditions:** The research team used the TMI-Matric Suction⁴ models, developed by Arizona State University (ASU) for the National Cooperative Highway Research Program (NCHRP) Project 1-40D and adopted in the Mechanistic-Empirical Pavement Design Guide (MEPDG), to evaluate the impacts of TMI change on subgrade resilient modulus.⁵
- **Asphalt binder requirements:** The research team used the Long Term Pavement Performance Program Bind (LTPPBIND) 3.1 software to evaluate how future temperature projections would influence the selection of asphalt binder grade.
- **Load-related fatigue cracking and subgrade rutting:** The research team used Asphalt Institute methodology to determine structural distress.⁶
- **Asphalt concrete (AC) rutting:** The research team used the AC rutting model from the MEPDG for the analysis.
- **Serviceability loss due to frost heave:** The research team used the frost heave model from the 1993 AASHTO Guide for Design of Pavement Structures for the analysis.⁷

Seasonal Load Restrictions

MaineDOT uses a methodology developed by Minnesota DOT for determining when to allow WWPs.⁸ To determine a trend in when future WWPs could be posted, the research team calculated when the projected annual cumulative freezing index exceeds 280 degree Fahrenheit days through 2099.⁹ To determine trends in when WWPs may be removed, the research team tracked when the first thaw is projected to occur (i.e., the first day above 32-degrees Fahrenheit).

Additionally, per the Minnesota approach, the research team tracked when the projected three-day cumulative thawing index¹⁰ indicates a warming trend to determine when future SLRs may be put in-place.¹¹

⁴ Matric suction is the pressure exerted by soils in drier state on the surrounding soils in wetter state to equalize the differences in moisture content between two soil masses.

⁵ Witczak et al, 2006.

⁶ Huang, 2003.

⁷ MaineDOT Highway Design Manual, 2007.

⁸ Mechanistic Approach to Determine Spring Load Restrictions in Maine, Ovik et al, 2000.

⁹ Degree days are the accumulated total of the positive or negative differences between daily temperatures and a base temperature (in the case of the freezing index, 32-degrees Fahrenheit).

¹⁰ Index that considers three-day forecasted high and low temperatures and long-term temperature trends.

¹¹ Mechanistic Approach to Determine Spring Load Restrictions in Maine, Ovik et al, 2000.



Results

Future temperature and precipitation trends will have both beneficial and detrimental effects on the continued use of flexible pavements in areas prone to freeze-thaw effects (Table 1). The benefits to flexible pavements come from reduced frequency of frost heave and thus reduced pavement smoothness loss. The potential risks to pavement performance, which can be attributed to softening of bituminous pavement layers due to warming trends, include:

- Increase in load related fatigue damage or interlaced cracking.
- Increase in subgrade rutting.
- Increase in AC rutting.

Shorter freezing seasons will also result in fewer opportunities for WWPs and earlier posting of SLRs. The study projects that the time period available for winter premiums will decrease at an approximate rate of one week per two decades.

Adaptation Options

Table 1 provides a summary of the various expected temperature and precipitation change impacts and the recommended adaptation strategies. Strengthening the pavement gradually over time by increasing the pavement thickness can address many of the impacts.

Topic	Expected Impact by 2099	Recommended Adaptation Strategy
Load Related Fatigue Cracking	Fatigue cracking will increase by 34 percent	Strengthen by increasing pavement thickness gradually over time
Subgrade Rutting	Subgrade rutting will increase by 40 percent	Strengthen by increasing pavement thickness gradually over time
AC Rutting	AC rutting will increase by 42 percent	Use polymer modified asphalt binders starting in the 2060s
Serviceability Loss due to Frost Heave	Serviceability will improve by 10 percent	None
Winter Weight Premium	No opportunities for winter weight premiums by the early 2080s	Strengthen by increasing pavement thickness gradually over time
Spring Load Restrictions	Early posting of load restrictions by at least 4 weeks	None

Table 1: Summary of climate impacts and adaptation strategies.

Towards the end of the existing pavement's service life, it is expected that MaineDOT will rehabilitate the pavement to restore the functional and/or structural condition. During rehabilitation, the research team proposes an incremental change in the thickness of AC overlay to compensate for the softening of AC layers due to warming trends. Table 2 summarizes the implementation timeframe and the estimated costs of the adaptation actions.

Design Case	Increase in AC Overlay Thickness	2020 Dollars	Cost Difference	
			Cost Increase	Percent Increase
Typical Overlay	No action	\$4,142,000	N.A.	0.0%
2020-39	0.25 inches	\$4,420,000	\$278,000	+6.7%
2040-79	0.5 inches	\$4,697,900	\$555,900	+13.4%
2060-79	0.5 inches	\$5,038,500	\$896,500	+21.6%
2080-99	1.0 inch	\$5,594,300	\$1,452,300	+35.1%

Table 2: Estimated cost of recommended increases in AC overlay thickness.

While the cost premium for upgrading pavement thickness is fairly low at this site, the effects of temperature and precipitation changes will be systemic and statewide. The budgetary implications of adopting enhancements at the agency level should be investigated.

Recommended Course of Action

The study results recommend that MaineDOT use phased implementation of the adaptation measures as outlined in Tables 1 and 2. The phased approach will allow MaineDOT to track the effectiveness of the measures over time and to only implement the next measure when it is necessary.

Additional recommendations include:

- Stabilizing the subbase and subgrade, and installing subsurface drainage to expedite the removal of water from the pavement system.
- Proactively preserving the existing pavement with the use of seal coats and crack sealing.
- Exploring ways to mitigate impacts of weight restrictions on commerce, such as redrawing freight corridors and implementing specialized or dedicated truck corridors for local industries.

Lessons Learned

- In this location, temperature and precipitation projections indicate some systematic and long-term adverse consequences on the performance of pavements that warrant corrective action.
- In this location, the projected increases in temperature and changes in precipitation will result in shorter freezing seasons, which could lead to a modest increase in flexible pavement distresses including fatigue damage and rutting. However, due to lower depths of frost penetration, there may be some benefits from lower serviceability loss due to frost heave. The increase in predicted pavement distresses can be handled using increases in pavement thicknesses and improvements to material selection and mix design criteria, construction practices, and specification requirements.
- While the cost to adapt this one roadway segment are relatively low, the cost to upgrade all roadways in the state that experience similar impacts could have significant budgetary repercussions for the state.

- Shorter freezing seasons will lead to shorter and lighter allowances in WWP. Similarly, early on-set of spring thaw will require early postings of spring load restrictions. There is a need to evaluate the economic impacts of changing seasonal load restrictions on the trucking industry in terms of repurposing freight networks, truck user fees, and pavement strengthening measures.
- DOTs in cold regions need to monitor changes in temperature and precipitation trends and periodically re-evaluate pavement design decisions and seasonal load restriction policies. DOTs should move away from the sole dependence on historical climate records such as the "State of Maine Design Freezing Index."

For More Information

Resources:

Transportation Engineering Approaches to Climate Resiliency (TEACR) project website

<https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/>

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