Use of Climate-change Informed Life Cycle Assessment in Pavement Rehabilitation and Maintenance Decision Process

Katie E. Haslett, Eshan V. Dave*, Weiwei Mo

*Department of Civil and Environmental Engineering, University of New Hampshire, Durham, NH, USA

Introduction

Pavement life cycle assessment (LCA) and life cycle cost assessment (LCCA) are common techniques used to evaluate both economic and environmental impacts associated with different maintenance and rehabilitation (M&R) techniques for short- and long-term pavement management. Typically, pavement LCAs are conducted using historical climate data to evaluate pavement performance and provide recommendations for budgeting and planning purposes of M&R strategies to be implemented in the future. However, due to climate change this assumption may not be appropriate as flexible pavement performance can be severely influenced by climatic stressors. This study explores the impact of using historical versus future climate data to evaluate pavement M&R techniques using a life cycle assessment framework.

The motivation behind this study is driven primarily by two factors. First, the shift in how pavement engineers design and maintain roadway infrastructure has changed from solely an empirical approach to a mechanistic-empirical approach. Second, by the advancement in data collection and knowledge surrounding climate change and its impacts on asphalt pavements, including ability for future climate projections.

The United States interstate highway system dates back to the Federal-Aid Highway Act of 1956, signed by President Dwight D. Eisenhower (FHWA, 2017). The US interstate highway system has since grown to become part of the world’s largest road network with over 7 million miles of road length, consisting of both paved and unpaved roads in the U.S. (FHWA, 2018). As one of the U.S. largest infrastructure systems, impacts from climate change on the
safety, reliability and efficiency of transporting people and goods are of a major concern for agencies and users. By the year 2045, the U.S. population is expected to increase by 70 million to 390 million people (USDOT, 2017). As the population grows, the demand for travel also increases. On average, the U.S. population spends over 42 hours stuck in traffic each year per person, with the annual cost of congestion in delays and lost fuel to be $160 billion. Moreover, the annual cost of truck congestion is $28 billion (USDOT, 2017). Therefore, as efforts are made to maintain and improve the mobility of people and goods via the interstate system, it is critical to consider the short and long term impacts of climate change on pavement structures. One of the most common pavement design methods utilizes the 1993 American Association of State Highway and Transportation Officials (AASHTO) pavement design guide based on the American Association of State Highway Officials AASHO Road Test. However, with the advancement in pavement performance testing, a shift from purely empirical design approaches to a mechanistic-empirical design approach (e.g. AASHTOWare Pavement ME Design software) is being adopted by agencies. A major reason for this shift is the due to the fact that material sources and properties are constantly changing along with the environmental conditions they are expected to perform under. Just as engineers do not want to rely only on historical material properties to design roads of the present and future, historical climate information should not be solely relied on to inform the design and maintenance of pavement in the future.

Efforts by several organizations such as, the Intergovernmental Panel on Climate change (IPCC), the United States Environmental Protection Agency (US EPA), the United Nation Environment Programme (UNEP) and World Meteorological Organization (WMO), have led the charge in educating the public and also researching the impacts of climate change on infrastructure systems. Several researchers have explored the impacts of climate change on transportation systems such as asphalt pavements. For example, changes in freeze thaw cycles
and season durations, extreme heat frequency and intensity in different regions which can reduce asphalt modulus leading to an increase in fatigue cracking and permanent deformation in asphalt pavements (Knott et al., 2019; Jacobs et al., 2018; Stoner et al., 2019). Using a pavement LCA framework with the inclusion of future climate projections, a more resilient pavement management practices can be incorporated that includes mechanistic pavement performance predictions with inclusion of climate change.

While there has been substantial research on the development of LCA frameworks for pavements (Pavement Life Cycle Assessment Workshop, 2010; Ventura, A. and Roche, C.D.L, 2012; International Symposium on Pavement LCA, 2014; Al-Qadi, I., Ozer, H., Harvey, J., 2017; Gu, F., and Tran, N., 2019), there has been limited studies focused on pavement LCA that incorporate both realistic traffic conditions and future climate data in analysis. In 2015, a tech brief was released by the Federal Highway Administration (FHWA), which admits that detailed pavement implications for climate change are scarce (Muench, S., Van Dam, T., 2015). Efforts to integrate climate change into pavement design is growing based on work from Mills et al., 2009; White et al., 2010; Wistuba M.P. and Walther, A., 2013. Similarly, Bilodeau et al., 2013, investigated the ability to predict pavement performance based on future climate scenarios. A study by Knott et al. in 2019, focused on the seasonal and long-term changes to pavement life caused by rising temperatures from climate change. Results from this study that evaluated a site in coastal New Hampshire (NH) suggest that, “A 7% to 32% increase in the asphalt-layer thickness is recommended to protect the base and subgrade with rising temperatures from early century to late-mid-century”. However, while the majority of these studies provide general advice or predictions they fall short of recommending immediate changes in practice or a framework which may be used to incorporate future climate data into the pavement management process using a LCA and LCCA approach.
Pavement LCA Framework

The following basic steps are recommended when conducting a pavement LCA. First, the project location, analysis period and system boundaries must be identified. Next, an inventory is constructed to collect information such as material properties, traffic volumes and characteristics, pavement structures and climatic information, to evaluate pavement performance and various M&R strategies. A technique called climate downscaling, which is a general name for a procedure to take information known at large scales and make predictions at local scales, is used to integrate future climate data into AASHTO PavementME. The Coupled Model Intercomparison Project Phase 5 (CMIP5) is one of many climate model databases that can be used to obtain future climate predictions. Variables such as daily precipitation, maximum and minimum temperatures are available from the year 1950 to 2099.

Next, AASHTO PavementME design software is used to simulate different cross sections with varying materials characteristics, future climate prediction data and varying maintenance scenarios to quantify pavement distresses in terms of International Roughness Index (IRI). Meanwhile, fuel consumption and carbon emission factors for different vehicle classes under various IRI and speeds are calculated using a combination of Google Maps®, the U.S. EPA’s Motor Vehicle Emission Simulator (MOVES), the SHRP2 Naturalistic Driving Study, and MassDOT’s Transportation Data Management System. Lastly, a life cycles impact assessment is performed to quantify all impacts from both a user and agency perspective in terms of LCC in net present value (NPV), GWP and CED.

An example focusing on the incorporation of realistic traffic conditions and future climate data (temperature, precipitation, wind speed, percent sunshine and relative humidity) within pavement LCA framework for M&R decision process is used for demonstration. Climate data from 21 global circulation models assuming representative concentration pathway 8.5 (highest emissions scenario) is incorporated into AASHTO’s PavementME Design
software to evaluate pavement performance in terms of IRI. Recent work by Haslett et al., 2019, provides a case study example for a 26-km stretch of interstate highway and how the proposed LCA framework may be adapted to include realistic traffic conditions. Using the proposed LCA framework, future climate data projections may be implemented into the LCA framework through climate inputs in AASHTO PavementME software.

**Preliminary Results**

Preliminary findings from the present study show that incorporating future climate data into pavement LCA framework decreases the service life of pavement structures, causing an increase in frequency and timing of M&R activities. Figure 1 provides an example for a given pavement cross section the pavement performance curves with respect to time using historical climate data and future climate data for the following two M&R scenarios; DNR: do nothing reconstruct, MO: mill and overlay.

![Historical Climate Data](image1)

![Future Climate Data](image2)

Figure 1: Example of incorporating future climate data versus historical climate data on pavement performance and maintenance and rehabilitation frequency.
It can be observed that for the MO maintenance scenario (blue line) over the same analysis period from 9/1/2020 to 10/1/2129, when using future climate data, the frequency of maintenance activity increases. MO is performed 6 times due to the shorten service life (steeper pavement performance curve) compared to when historical climate data it is only performed 4 times. A threshold IRI value was selected as 172 in/mile to trigger M&R treatment. It should be noted that researchers used a sufficiently long enough analysis period to make comparisons of M&R treatment types that may have different structural contributions.

Figure 1 also demonstrates that using future climate data has varying implications for agencies depending on the type on M&R treatment. Examining the DNR (red line) versus the MO (blue line) scenarios, the timing of M&R is different when considering the analysis performed using historical or future climate data. Due to the concept of time value of money (TVM), money available at the present time is worth more than the identical sum in the future due to its potential earning capacity. This can lead to insufficient planning and funding availability to maintain let alone to try and improve the current state of the road network system if decisions makers are not provided with the most accurate estimate of pavement performance curves using future climate projection data.

There are direct implications for agencies to be able to accurately predict when maintenance will be required and when funding for those projects should be allocated. Majority of State Departments of Transportations (DOT’s) develop a 10-year and or a 20-year plan for maintenance and investments. The current study has immediate implications to help agencies improve the planning and budgeting process by using the proposed LCA framework with the real time traffic data and the inclusion of future climate data.
References


AASHTOWare. Pavement ME Design; Version 2.3; AASHTOWare: Washington, DC, USA, 17 July 2015.


Google. Google maps. Available online: https://www.google.com/maps/dir/42.603823,-71.3501962/42.7392095,-71.1416834/@42.7452328,-71.134279,14.71z/data=!4m2!4m1!3e0 (accessed on 8 January 2018).


