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Impact of climate change on pavement structural performance in the United States

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ABSTRACT

This study uses climate projections from multiple models and for different climate regions to investigate how climate change may impact the transportation infrastructure in the United States. Climate data from both an ensemble of 19 different climate models at both RCP8.5 and RCP4.5 as well as three individual prediction models at the same Representative Concentration Pathways (RCP) levels is used. These models are integrated into the AASHTOWare Pavement ME software to predict the pavement performance. Comparisons are made between the predicted performance with respect to typical pavement distresses using both historical climate data as well as climate projection data. Though there is substantial variation for different prediction models in terms of the magnitude of the impact, the consistency in results suggest that projected climate changes are highly likely to result in greater distresses and/or earlier failure of the pavement. This finding is consistent across all the climate zones studied, but varies in magnitude of 2–9% for fatigue cracking and 9–40% for AC rutting at the end of 20 years depending on the climate region of the pavement section and prediction model used. This study also compares the impacts incorporating temperature only projections with temperature and precipitation projections. In this respect, the sections considered in this study do not show any substantial difference in the pavement performance when the precipitation data from the climate predictions are also considered in the climate inputs into AASHTOWare Pavement ME software.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC, 2014) indicates that climate change poses a major risk to human life, nature, and the built environment. One component of the built environment that may be particularly prone to these impacts is the physical network of roads, bridges, railroad, and hydraulic structures that ensure efficient, safe, and reliable movement of people, goods, and services, i.e., transportation infrastructure. The components of this system are particularly prone to climate since they are constantly exposed to the natural environment. When these components fail they may cause substantial loss of user productivity as repairs can often take days to months depending on the magnitude of the disruption. Even when full closures are not needed for repairs, the losses can be substantial with work zones contributing to nearly 17% of non-weather related congestion in the US (Chin et al., 2004). Considering that roads and highways allowed Americans to travel more than 3 trillion vehicle trip in the year 2015 (USDOT, 2015), the nation's roadway infrastructure is clearly a major contributor to the development of the US economy.

In 2008, the National Cooperative Highway Research Program (NCHRP) evaluated how climate change might introduce hazards

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to transportation infrastructure. These hazards were described in broad terms across all transportation modes, but encompassed a range of potential impacts from increased shipping seasons in cold weather ports to operational challenges due increased coastal and inland flooding events (Humphrey, 2008). With respect to pavements this report suggested that future increases in very hot days and heat waves may lead to concerns with pavement integrity. They also recognized that changes in subgrade moisture levels (either by changes to the water table depth or through precipitation) could alter the bearing capacity and thus performance of this infrastructure, and conclude that the typical design scope for pavements (10–20 years), may help to mitigate these impacts.

While the findings from the NCHRP are enlightening, they do not quantify the potential impacts from moisture and temperature changes on pavement performance. Reviews of other studies on climate change impacts reveals some gaps in accurately quantifying the impacts using distresses directly. For example, Anderson et al. (2015) quantify the potential impact to Arizona transportation infrastructure using the number of projected days above 38 °C. This approach is not addressing the fact that pavements are designed with materials specific to the location in which they are placed and thus the number of days above a single fixed temperature does not indicate the impacts fairly across areas that are already climatologically diverse. In addition, Anderson et al. (2015) do not account for the interactive impacts of soil conditions, traffic, and structure. In another study involving the state of Texas, researchers recognized the difference in materials across regions, but did not project how an increase in temperature might affect performance with respect to the continuation of historical trends (Cambridge Systematics, 2015).

Chinowsky and Arndt (2012) developed an economic dynamic-stressor model based on empirical performance impacts from precipitation and temperature). These models reflect, but do not predict the precise impact of climate change on materials. This approach has been codified into a planning system and used extensively to assess the economic impacts of climate change on pavement infrastructure (Schweikert et al., 2014). A limitation in these network level analyses is that they ignore the actual engineering details of the infrastructure. They essentially overlay climate variables in terms of changes in temperature and/or precipitation on top of the existing infrastructure and identify where the two (infrastructure and climate change) intersect. Such an approach does not account for the fact that the pavement performance is a cumulation of many interactive factors (materials, structures traffic, and climate).

An engineering analysis was completed by Daniel et al. (2014) to evaluate the impact of climate change on the performance of New England pavements. Climate prediction data was incorporated into the pavement design process and results were compared with design/analysis completed using the historical data. The study concluded that climate change predictions may have a substantial effect on pavement distresses, specifically that pavement life may decrease from between 16 years to 4 years and maintenance cost may also increase by 100%. Meagher et al. (2012) used climate change projections from the North American Regional Climate Change Assessment Program to evaluate designs of flexible pavements in New England. In this study the authors used only temperature data and found that changes in alligator cracking for secondary and interstate pavements was negligible but for the increase ranged from 4% to 16% depending on the precise location. Other studies have concluded that rutting and pavement failure occurs much earlier than anticipated leading to the frequent new construction and maintenance of roadway infrastructure (Harvey et al., 2004; Mills et al., 2009; Mndawe et al., 2013).

Most of these studies mentioned above focus on temperature data alone from the climate prediction models to study the impact of climate change on the pavement performance. However, two recent studies used changes in precipitation levels along with temperature data from climate prediction models and reported that climate change shows significant impact on the pavement life (Heitzman et al., 2011; Mndawe et al., 2015). These studies integrate both temperature and precipitation data, but do not indicate whether one or the other factors has a greater impact. Very little data is found isolating the impact of precipitation. Many of the studies that exist echo that of Gaspard et al. (2007), which studied pavements performance after Hurricane Katrina and found that pavements submerged during the hurricane were weaker than the ones that were not. In case of flexible pavements, the damage observed is more than the damage observed for rigid pavements.

Overall, existing evidence suggests that climate change will impact the performance and maintenance of the pavement infrastructure. However, there are some limitations in the existing literature:

1. Most of the existing studies are limited to one pavement structure, location, and/or one climate region. Even taken collectively the literature uses dissimilar models and other underlying assumptions making it impossible to gain a comprehensive view of impacts,
2. Most current studies focus on one or maybe two climate models and do not include different potential emission scenarios in the analysis, thus it becomes very difficult to infer or ascertain the certainty/uncertainty in the predicted outcome, and
3. Current studies do not identify the relative significance of projected temperature versus precipitation on predicted pavement performance.

The primary objective of the research is to predict the performance of freeway sections in different climate regions across the United States and for different climate models and in so doing address the gaps in the literature. Then, using these results in conjunction with performance predicted using historical climate data, quantify the impact of incorporating projected climate data.

2. Methodology

The overall approach followed in this study is shown in Fig. 1. As seen in this figure the methodology involves conducting multiple pavement performance predictions using the, AASHTOWare Pavement ME software, to predict and compare the long-term behaviors of pavements under either historical or projected climate scenarios. Simulations using the historical database are referred to as the baseline cases, while those using the climate model data are referred to as the future cases. As detailed below, these future