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Evaluating the effects of climate change on road maintenance intervention strategies and Life-Cycle Costs

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ABSTRACT

Climate change has the potential to impact long-term road pavement performance. Consequently, to maintain pavements within the same ranges of serviceability as before, current pavement maintenance strategies need to be re-assessed and, if necessary, changed. Changes in maintenance may lead to different agency costs and user costs as a consequence. This paper commences by defining an assessment procedure, showing how maintenance intervention strategies and Life-Cycle Costs (LCC) may be affected by future climate. A typical Virginia flexible pavement structure and anticipated climate change was used as an example. This example is believed to be representative for a great number of localities in the United States. A method using historical climatic data and climate change projections to predict pavement performance using Mechanistic-Empirical Pavement Design Guide (MEPDG) under current or future climate was introduced. Based on pavement performance prediction, maintenance interventions were planned and optimized. The maintenance effects of three treatments (thin overlay, thin overlay with an intermediate layer, and mill & fill) were considered. A Life-Cycle Cost analysis is reported that used binary non-linear programming to minimize the costs (either agency costs or total costs) by optimizing intervention strategies in terms of type and application time. By these means, the differences in maintenance planning and LCC under current and future climate can be derived. It was found, that for this simplified case study, pavement maintenance and LCC may be affected by climate change Optimized maintenance may improve resilience to climate change in terms of intervention strategy and LCC, compared to responsive maintenance.

Introduction

Global average surface temperature has increased 1.3 °F (0.74 °C) since 1850. Moreover, the warming rate has been increasing, with global average surface temperature increasing in the last 50 years twice as fast as in the last 100 years (IPCC, 2007). This presents many challenges for conventional infrastructures, which are usually designed and managed on the basis of historical climate data. Thus there is a need to rethink the design of infrastructures for future climate (Austroads, 2004; Meyer, 2006; TRB, 2008; Willway et al., 2008).

Assuming that local changes mirror global changes, researchers found by pavement performance modeling that rutting of flexible pavements may be aggravated by climate change, due to temperature increasing or seasonal hot/cold extreme

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temperatures (Qiao et al., 2013b; Tighe et al., 2008). Pavement cracking may be affected by climate change, including longitudinal and fatigue cracking (Kim et al., 2005). Pavement roughness was found to be affected by climate change (Graves and Mahboub, 2006), although the impact may sometimes be negligible (Kim et al., 2005; Qiao et al., 2013b).

If pavement performance will be affected by climate change, it is important to know how pavement maintenance and Life-Cycle Costs (LCC) may change as a consequence. Australian researchers (Austroads, 2004) estimated that a small budget decrease between 0% and −3% would be necessary to maintain the same level of performance based solely on climate factors because a predicted generally drier climate leads to a slower pavement deterioration rate nationally (Cechet, 2007). However, this budget reduction may not be applicable elsewhere with different climate conditions. This paper proposes a method for assessing the necessary changes to pavement maintenance procedure(s) and the LCC consequent of climate change and to illustrate this with a case study.

Overall methodology and assumptions

A methodological framework to compute the LCC for a particular pavement & climate is presented in Fig. 1. This section of the paper considers each part of the methodology (each box in Fig. 1) in turn. By using this framework twice, once with historic climate and current optimized maintenance interventions and once with an anticipated climate, the effects of climate change may be assessed and maintenance can be adjusted in the second use to minimize the LCC.

The impact of climate change on flexible pavements can be direct and indirect (Austroads, 2004). Direct impacts are due to environmental effects e.g. temperature, precipitation, solar radiation, wind speed and groundwater level. Indirect impacts refer to changes in traffic loading caused by demographic changes due to climate change (Koetse and Rietveld, 2009). Due to the significant uncertainties in likely demographic changes, the indirect impact of climate change is excluded in this study. When traffic demand prediction is available, the methodology of this study should be updated by integrating this indirect impact.

Pavement maintenance intervention strategies can be classified into several categories according to the frequency of maintenance, maintenance intensity, costs, and time for maintenance. In this paper, the mentioned maintenance treatments are categorized as follows:

- Crack sealing and filling: routine maintenance.
- Chip seal, slurry seal, microsurfacing, and thin overlays: preventive maintenance.
- Thin overlay with intermediate layer, and mill & fill (inlays): corrective maintenance.

Routine maintenance is applied periodically and is less determined by pavement performance, compared to preventive and corrective maintenance. Preventive maintenance is most cost-beneficially applied before a pavement starts to exhibit visible deterioration (Hicks et al., 2000) and is usually used to improve the functional condition of the road without substantial improvement in structural capacity. It has also been observed that some preventive maintenance will deliver reduction in pavement roughness and rutting (ISOHDM, 1995; Odoki and Kerali, 1999). Corrective maintenance is planned according to the pavement performance level. For instance, many road authorities initiate a certain intervention when a performance threshold is triggered. Triggers may occur when one of the pavement performance indices reaches a critical level or when a combination of conditions is reached. Early application of corrective maintenance can often be applied to achieve greater cost-benefit, becoming, in effect, a form of preventive maintenance. Major corrective maintenance removes the pavement surface distress, and has the greatest maintenance effect. Pavement performance prediction aids decision making concerning the time and type of preventive maintenance or early corrective maintenance.

The effects of maintenance may include two parts in general, which are:

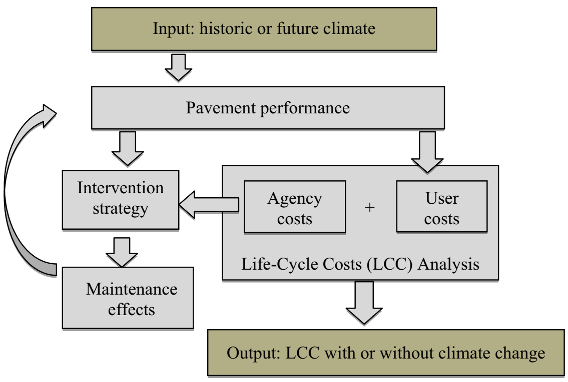

Fig. 1. Methodological sequence (Qiao, 2015).