Transportation Research Part A 69 (2014) 367–378

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

A stochastic optimization approach for the selection of reflective cracking mitigation techniques

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ARTICLE INFO

Article history:
Received 21 March 2014
Received in revised form 11 July 2014
Accepted 16 September 2014

Keywords:
Hot Mix Asphalt
Reflective cracking mitigation method
Life cycle cost
Exploratory Modeling and Analysis
Multi Criteria Decision Making

ABSTRACT

Purpose: In Hot Mix Asphalt (HMA) overlays, the existing cracks in the underlying pavements can propagate upward to the new added overlay and may cause Reflective Cracks (RC). These cracks allow water infiltration to the underlying layers and causes further moisture damage as well as weakening the unbound layers. Over the years, several methods have been developed for mitigating the RCs. This study aims to investigate the current reflective cracking mitigation methods and develop a methodology for the selection of appropriate mitigation technique. The developed model is then applied to a case study in the state of Florida.
Method: To accomplish this goal, a nationwide literature review was conducted to better understand the current in practice methods in the United States. Moreover, a life cycle cost analysis (LCCA) in five different road types was performed to find the annuity of roadway rehabilitation for each of the mitigation methods. The uncertainty in the LCCA results is represented using Exploratory Modeling and Analysis (EMA) method. Then through a Multi Criteria Decision Making (MCDM) model, a stochastic optimization model was developed to find the appropriate reflective cracking mitigation solution under Florida's climate and road conditions, based on different cost and performance weights.
Results: Based on the available data for the state of Florida, the LCCA results indicate that the annuity of maintaining the roadway with Fabrics and ISAC are lower compared to other methods. However, the results of stochastic optimization model reveal that while looking at the performance and cost at the same time, different methods would be more feasible. For instance, while the cost of the used method does not matter at all and only performance matters, STRATA® is more probable to be the appropriate mitigation technique. The findings of this research are critical for decision makers to better understand the most cost-effective mitigation technique in different conditions.

1. Introduction

The United States road system is one of the largest networks in the world by more than 4 million miles public roads and more than three million Vehicle Miles Travelled (VMT) per year, as of 2010 (FHWA, 2010). However, more than half of the nation's roads were in poor, mediocre or fair condition as of 2008, while almost a quarter of the nation's urban roads are in poor condition, which makes the motorists to drive on a rough surface and increases the vehicle maintenance and operating

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http://dx.doi.org/10.1016/j.tra.2014.09.006
0965-8564/

costs (FHWA, 2009). American Society of Civil Engineers estimates the vehicles repairs and operating costs to be $67 billion a year-an average of $333 per motorist- due to poor conditioned roads (ASCE, 2013). The most common method to provide a smoother riding surface and extend the pavement life is to overlay the existing pavement with Hot Mix Asphalt (HMA). However, the existing cracks in the underlying pavements can propagate upward to a new overlay and cause Reflective Cracks (RC). These cracks allow water infiltration to the underlying layers and causes further moisture damage as well as weakening the unbound layers. An old rule of thumb says these cracks propagate one inch per year towards upward overlay (Bischoff, 2007). However, experiences have shown different propagation rates under different conditions. RCs cause a rough pavement surface and poor ride quality for vehicles as well as more operating and maintenance costs for roadway agencies.

Reflective Cracking in asphalt pavement overlays occurs over the joints of existing underlying concrete pavement or structural cracks in HMA pavements. It can also be caused by traffic load or more generally, by differential settlement at joints of jointed concrete pavements. The RC can also be caused by the pavement expansion, causing contraction and bending from thermally induced movement of the layers. Moreover, material aging in the overlay may accelerate the deterioration. RC reduces the service life of the pavements by introducing premature deterioration of the pavement structure or other distresses that might be caused by water infiltration in the overlay (e.g., weakening the load bearing capacity of the base layer and losing bonds between aggregates and asphalt binder).

To prevent or retard RC, different mitigation methods have been developed based on reviewing mechanisms or experimental experiences. The performance and cost of these methods are reported differently in the literature and there is a considerable amount of uncertainty in these parameters. Therefore, the aim of this study is first to conduct a nationwide literature review on the existing practical mitigation techniques. Second, a performance measure is defined based on the available data and the life cycle cost of each method is then calculated. Third, uncertainty in the life cycle cash flow of roadway maintenance is molded using Exploratory Modeling and Analysis (EMA). Then, a stochastic Multi Criteria Decision Making (MCDM) analysis is performed to find the optimal reflective cracking mitigation technique considering Florida's climate and road conditions, based on different cost and performance weights. In Florida, approximately 98% of the pavements are HMA and a major pavement distress is cracking not rutting, particularly top-down cracking. In case of severe top-down cracks or full-depth cracks, milling may not remove all the existing cracks; thus partial top-down cracks can remain. Therefore, the study was focused on reflective cracking mitigation techniques for the HMA overlays over old asphalt pavements. There are a handful of reflecting cracking mitigation techniques for the overlays over Portland cement concrete (PCC) pavements (such as saw-cut sealant) which are not in the scope of this study.

2. Literature review

2.1. Selected RC mitigation methods

Over the last two decades, many RC mitigation methods have been introduced and they are generally categorized as four types of treatments (Quintus et al., 2009): Modifying/Strengthening Existing Pavement Surface, Treatment of Existing Pavement, Interlayer Systems, and Reinforcement of HMA Overlay. Table 1 indicates the most practical RC mitigation methods for each category.

There are not adequate performance and cost data for all of these methods in the literature. Therefore, in this study, only Stress and Strain Relieving Interlayer methods as well as Mill and Inlay, HIR, and CIR are studied in detail.

2.2. Cost-benefit studies on RC mitigation methods

There are a considerable amount of studies on the reflective cracking mitigation methods that have analyzed their performance, constructability and cost effectiveness. Tighe et al. studied the LCCA of RC mitigation techniques and mainly focused on the economic asset of reducing the reflective cracking before using HMA as an overlay (Tighe et al., 2007). In their results they indicated that a reduction in transverse crack spacing from 5 to 20 m, will result in 5-year extension of service life and will save the maintenance costs by the amount of $25,000 (2002 U.S. dollars) per two-lane kilometer. Al-Qadi et al. used a LCCA tool in order to evaluate the cost-benefit and retarding ability of interlayer systems. This LCCA also was able to develop a decision-making procedure for the decision makers to choose different systems that satisfy their requirements (Al-Qadi et al., 2009).

Moreover, due to their serviceability, Fabrics have been used and studied widely for RC mitigation purposes (Buttlar et al., 1999; Engle, 2001; Holtz et al., 1998; Maurer and Malasheskie, 1989). The second largest application of the geotextile in the North America is in the area of mitigating the reflective cracking (Holtz et al., 1998). Barksdale defined a rule of thumb to evaluate the reflective cracking mitigation costs based on using geosynthetics. In his results he concluded that the cost of 0.5–0.6 in of asphalt concrete is almost equivalent to the cost of a full-width paving fabric (Barksdale, 1991).

Although there have been extensive efforts in the literature to estimate the rehabilitation costs of different reflective cracking mitigation techniques, they have not considered the cost of entire life cycle of rehabilitation. To make long term appropriate and successful policies, pavement rehabilitation assessment from a life cycle perspective is crucial to have a general understanding and awareness about the whole picture (Santero et al., 2011). Therefore, in this study a life cycle cost model is developed to estimate and compare the rehabilitation costs of different mitigation techniques.