A HYBRID MODELLING APPROACH FOR MAINTENANCE AND REHABILITATION TREATMENT EFFECTIVENESS OF ASPHALT PAVEMENTS IN TEXAS

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Abstract

Analysis tools in pavement management systems are critical to assist transportation agencies in developing the most adequate maintenance and rehabilitation program. The significant elements are not only the type of treatment selected and its cost, but also the quantification of its short-term and long-term effectiveness and the timing of intervention. Methodologies with complex statistical approaches and performance model theories have been previously implemented in their derivation, but they may not be suitable or accurate. Therefore, it is imperative to factor in engineering experience in their assessment. In this thesis, a hybrid modelling approach was presented to systematically introduce expert knowledge in the statistical processes for quantifying the maintenance and rehabilitation short-term and long-term effectiveness, performance models, and optimal treatment times. The approach was applied to asphalt pavements using historical performance information from the Texas Department of Transportation (TxDOT) located in the Pavement Management Information System (PMIS). Furthermore, the hybrid approach was validated in the quantification of the short-term effectiveness of different construction treatments, under changing pavement characteristics, through extensive state-wide field performance monitoring. The presented hybrid model better reflected the treatment's effectiveness measures observed in the field when compared to the previous recommendations.

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Chapter 1: Introduction

Today's transportation agencies are facing severe challenges to preserve the existing roadway infrastructure at a satisfactory level (Tasai et al.). The U.S. Department of Transportation estimates that $85 billion would need to be invested in the nation's highways in the next 15 years. Budget shortfalls and growing traffic has forced the agencies to maximize the allocation of available resources when developing their maintenance and rehabilitation (M&R) programs. To assist decision-makers in selecting the most effective treatments, agencies have implemented pavement management systems (PMS). The PMS implements pavement performance prediction models, cost analysis, optimization algorithms, decision trees and impact analysis for network-level planning, programming, and budget optimization. The most critical elements that aid this process are the type of treatment selected, their short- and long- term effectiveness, the cost and, the timing of the intervention.

In Texas' 190,570 lane mile network, of which 90% are asphalt pavements, the annual maintenance and rehabilitation (M&R) budget reached $2.7 billion annually (Persad et al. 2010). To aid in the management of the large pavement network, the Texas Department of Transportation (TxDOT) uses the Pavement Management Information System (PMIS) created in 1993. The PMIS is used for storing, retrieving, analyzing and reporting pavement related information at the network level (Zhang and Machemehl 2004). The analysis tool is used in the process of "providing, evaluating, and maintaining pavements in a serviceable condition according to the most cost-effective strategy" (Zhang and Machemehl 2004). The current system was established over 20 years ago. During this time, there have been many new treatment types, improvements to construction practices and implementation of new specifications that have resulted in changes to the short- and long-term M&R improvements. Therefore, extensive research has been performed in this thesis to develop a methodology to quantify the treatment effectiveness.

1.1 Treatment Effectiveness

An integral part of the treatment selection process is to determine the effectiveness of M&R treatments. Treatment effectiveness should be measured in the short- and long-term. Short-term effectiveness measures include condition improvement jump (CIJ), deterioration reduction level (DRL), "holding" the condition, and deterioration rate reduction (DRR) (Zaghloud et al., 2006; Dong and Huang, 2012; Labi and Sinha, 2012; Haider and Dwaikat, 2011; Peng and Ouyang, 2011; Ong et al., 2010). On the other hand, the long-term effectiveness measures include extending the service life and area bounded by the treatment performance curve or "benefit" (Zaghloud et al., 2006; Dong and Huang, 2012; Chou et al., 2008; Haider and Dwaikat, 2011; Peng and Ouyang, 2011; Ong et al., 2010; Peshkin et al., 2004). Besides the dependency on short-term effectiveness, an important consideration of the long-term effects is the requirement of pavement performance models which vary from simple deterministic regression models to complex probabilistic Markovian or Bayesian Models (Hamdi, 2012; Flintsch, 1997; Wolters and Zimmerman, 2010). These models can be empirical, mechanistic or a combination of the two (Hajek et al. 1985).

The treatment performance is greatly dependent on the condition of the pavement at the time of the application, meaning different M&R strategies will be most effective at certain times in a pavement's life (Peshkin et al., 2004). This translates into an optimal timing for applying the treatment. Under a "Needs Estimate" where the budget constraints are ignored, the optimal time is based on the ability of the treatment to address the functional and structural condition of the pavement (California DOT, 2007).When the budget constraints are introduced, feasible projects must be prioritized and the optimal timing becomes closely related to cost-effectiveness. At the end, the optimal timing information aids to establish M&R strategy evaluation and prioritizing the funding allocation over the planning horizon.

The accuracy of the effectiveness modelling relies heavily on the quality and quantity of pavement data available (Hajek et al. 1985). Furthermore, it relies on the accuracy of the predicted future condition by the deterioration models. There are many sources of error in

performance models, which affect their reliability; for example the introduction of bias and the absence of key information such as unobserved heterogeneity and pavement construction dates. The effectiveness calculation and optimal timing of treatments is also affected by the difficulty in combining static, new to failed, deterioration models with the observed incremental condition changes in maintenance-effectiveness models.

1.2 Thesis Objective and Scope

The objective of this thesis is to provide a reliable method in the quantification of effectiveness and the optimum treatment timing. This process will provide pavement managers with more robust and reliable support in the preservation of the roadway infrastructure. A hybrid modelling approach is developed to systematically merge expert judgment with historical data to quantify the short-term effectiveness. This hybrid approach can be applied to any transportation agency's M&R program. The hybrid approach presented in this thesis was validated for the short-term effectiveness in the State of Texas. Furthermore, the method was expanded to adopt the hybrid techniques for the calculations of long-term effectiveness and the optimum treatment timing under budget and non-budget constraints.

1.3 Thesis Organization

The thesis will present the results and conclusions of this research in the following Chapters.

- Chapter 1 will introduce the importance of identifying the treatment effectiveness and its optimal timing application, in addition to the measures that are used in their quantification. The objective and scope of this thesis is also provided herein.
- Chapter 2 presents an extensive literature review of the relevant effectiveness measures, the performance models that compliment them and the techniques available to implement expert knowledge.
- Chapter 3 will demonstrate the hybrid methodology implemented in the short-term effectiveness calculations in the state of Texas and its expansion to include long-term effectiveness and optimal treatment timing.

- Chapter 4 describes an overview of the database PMIS and the process to link it to other Texas perpetual databases.
- Chapter 5 will show the steps taken in updating and establishing the PMIS treatment levels that include Preventive Maintenance (PM), Light Rehabilitation (LRhb), Medium Rehabilitation (MRhb) and Heavy Rehabilitation (HRhb).
- Chapter 6 demonstrates the statistical process to derive final short-term treatment effectiveness recommendations from historical, field data and expert knowledge, as well as the impact caused by climate, traffic and pavement types,.
- Chapter 7 describes the steps taken in the creation of pre- and post-treatment performance models and their usage to quantify long-term effectiveness.
- In Chapter 8, the optimal times for treatment application based on benefit and cost-effectiveness can be found.
- Chapter 9 summarizes the research, provides concluding remarks and offers recommendations.

Chapter 2: Literature Review

2.1 Introduction

There is an extensive body of work related to the different measures used to quantify short- and long-term effectiveness, as well as the derivation of the optimal treatment timing. The measures have been implemented across transportation agencies using different condition indices, mathematical approaches and performance model theories. In addition, there is a wide variety of techniques used to implement expert knowledge. For this reason, a comprehensive literature review was performed to identify the best techniques for quantifying treatment effectiveness and the implementation of expert knowledge.

2.2 Short-Term Effectiveness

Past research efforts on treatment effectiveness have been predominantly focused on certain preventive maintenance treatments. The focus of this measure lies in the immediate impact due to the treatment. This might be taken as the condition improvement jump (CIJ), the deterioration reduction level (DRL), and the deterioration reduction rate (DRR). The CIJ is the difference between two condition points, one pre-treatment and one post-treatment. The CIJ is illustrated in figure 1 as the ΔC_4 or the change between D and F. The smaller the time interval between the pre- and post-condition measurements and the construction activity, the higher the accuracy of the performance jump (Ong et al., 2010). The deterioration reduction level (DRL) entails the estimation of condition increase over a 1-year period (Labi and Sinha, 2012). To derive this measurement a condition reading is needed one year before treatment and another measurement right after or vice versa and their respective deterioration is calculated. This is illustrated as the deterioration difference along ΔC_1 and ΔC_2 in figure 1. The calculation can also be accomplished with three readings, one taken one year before the project begins, another right before the project begins and the third taken after the project has been completed. It has been widely stated that deriving this measurement is problematic because of the timing between the condition monitoring and the application of the treatment. The deterioration reduction rate

(DRR) refers to the change of the pavement deterioration before and after the M&R project. The deterioration of the pavement is observed to be

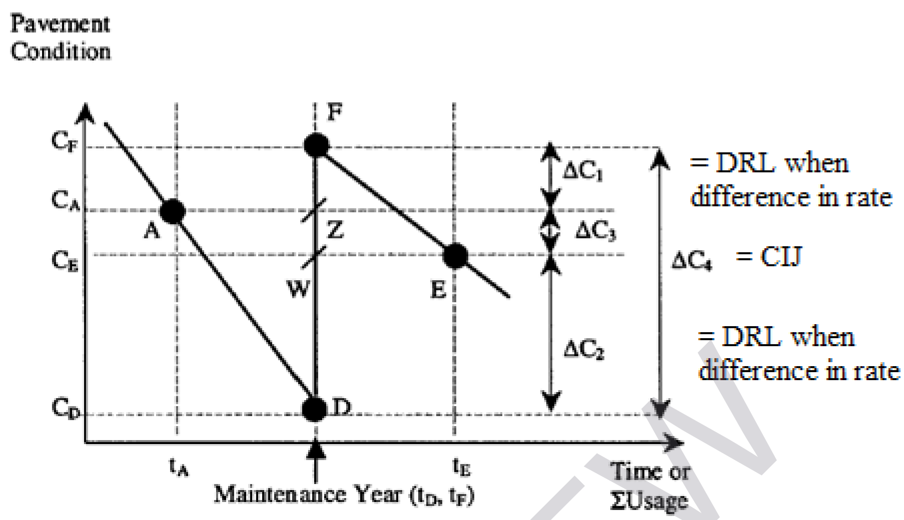

Figure 1: Concept of Deterioration Reduction Level in Short-Term Effectiveness (Modified from Ong et al., 2010).

reduced once a treatment has been applied, meaning a steep deterioration in condition over time will slope more gently. A major construction activity will have a greater impact on the deterioration making the slope more positive as is illustrated in figure 2. The figure shows the expected deterioration before the treatment is applied according to the condition of the pavement and the expected deterioration slope after the treatment is applied depending on the treatment intensity. The slope is assumed to linear because the effectiveness is viewed over a short time and at least 3 data points are needed.

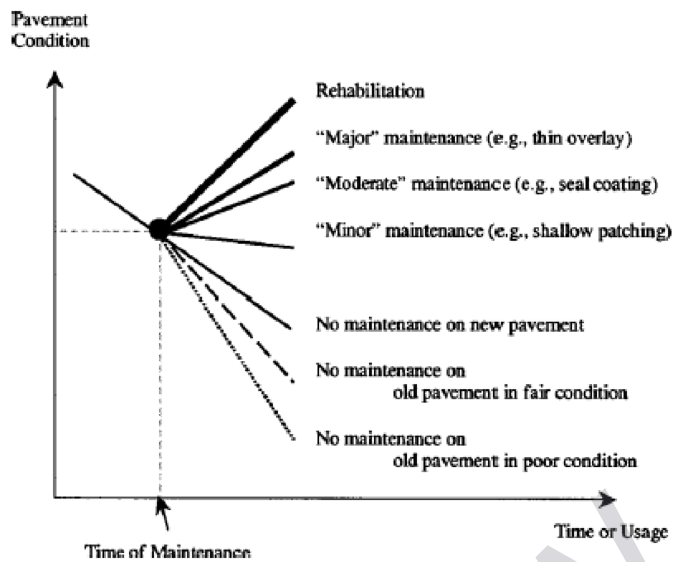

Figure 2: Concept of Deterioration Reduction Rate in Short-Term Effectiveness (Ong et al., 2010).

Labi and Sinha (2012) conducted testing on various linear and non-linear functional forms using annual Seal Coating condition data starting from year 1995 and 1966. The paper focused on the measures of CIJ and deterioration rate reduction in terms of the International Roughness Index (IRI) converted to Pavement Serviceability Index (PSI). In addition, the models developed were validated with sections treated with seal coating in both lane directions. Labi and Sinha (2012) concluded that for performance jump models, the initial condition as opposed to pavement family (traffic level, subgrade properties and pavement layers), was the most important factor. Pavements in poor initial condition reflected higher performance improvement jumps than pavement in good condition. In the case of DRR, Labi and Sinha concluded that the initial condition index, traffic level and subgrade properties had the most impact on the models. On the contrary to performance jump, pavements in good condition showed a greater deterioration reduction rate than when poor pavements were treated. In Ong et al. (2010), short-term effectiveness models for thin overlay, microsurfacing, crack seal and patching were created based on the condition index before the treatment was applied. The condition indices used in the study included the IRI, the pavement condition index (PCI) and the rut depth. It was conclude,

that in the cases of crack sealing and patching there was no discernable performance jump, but a deterioration reduction rate was introduced in its place. Furthermore, both of those treatments had no effect on rut depth. For the thin overlay and microsurfacing, the paper proposed performance jumps and performance resets for the three condition indices.

The Arizona DOT Pavement Management System recommends the lighter construction treatments which are the general and localized maintenance activities, to have a small immediate CIJ (Zaghloud et al., 2006). The improvement is followed by holding the condition constant for a period of time. The rehabilitation and construction activities are to reset to a newly construction condition.

In the state of Texas for the Texas Department of Transportation, Stampley et al. (1993) provided CIJ based on engineering judgment since there was not enough available historical data. The condition indices used are the ride score (RS) and the distress score (DS). Table 1 provides the recommended increase based on the severity of the construction activity. The medium and high rehabilitation treatments show a score reset instead of a finite CIJ for RS. Also, all treatment levels show a DS reset.

Table 1: Current Gain of Rating Values for TxDOT PMIS Treatment Level Categories (Stampley et al., 1993).

Treatment Type	Gain in Distress Score	Gain in Ride Score
Preventive Maintenance	Distresses reset to 95	Ride Score increases 0.5
Light Rehabilitation	Distresses reset to 100	Ride Score increases 1.5
Medium Rehabilitation	Distresses reset to 100	Ride Score resets to 4.8
Heavy Rehabilitation	Distresses reset to 100	Ride Score resets to 4.8

2.3 Performance Models

The importance of performance models in the long-term effectiveness has led to the development of extensive methodologies for their creation. The models vary from deterministic to stochastic. Furthermore they can be empirical (site-specific), where the dependent variable (condition) is related to one or more independent variables (age, cumulative traffic, environment and pavement structure characteristics); mechanistic, where the response parameter is dependent