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A methodology for evaluating micro-surfacing treatment on asphalt pavement based on grey system models and grey rational degree theory

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HIGHLIGHTS

- Evaluating micro-surfacing using grey system model and grey relational degree theory.
- Grey models are established for predicting types of indicators' long-term performances.
- New PQI models were developed with the application of grey rational degree theory.
- Service life of micro-surfacing treatment are determined using the new PQI model.
- The average service life for micro-surface treated pavement was predicted to be 4.5 years.

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ABSTRACT

This paper presents and demonstrates a methodology for evaluating a micro-surfacing treatment on asphalt pavement based on the grey system model and grey relational degree theory. Firstly, over 5,375,000 data points from the Guangdong Province are collected and processed using the Pauta criterion and short-term trends of selected performance indicators including pavement surface condition index (PCI), riding quality index (RQI), rut depth index (RDI), and skid resistance index (SRI) are analysed. Grey models of different types of indicators are then established for predicting long-term performance. A new PQI model was developed using the optimum predicted long-term performance with the application of the grey rational degree theory. Finally, the service life of the micro-surfacing treatment was determined using the new PQI model. Results demonstrate a representative service life over 4.5 years for the micro-surfacing treatment with a critical PQI value of 80. The proposed methodology validated the micro-surfacing treatment as a valuable assessment system that can be successfully applied with or without other pavement maintenance treatments.

1. Introduction

1.1. Background

Micro-surfacing refers to the application of a mixture of polymer-modified asphalt emulsion, crushed mineral aggregate, mineral filler, water, and a hardening-controlling additive [1].

Micro-surfacing has been successfully applied to pavement industries around the world owing to its short curing time before traffic opening and its flexibility to address slight distresses, correct ruts, improve surface texture, enhance ride quality, and ultimately extend pavement life [2,3]. In particular, micro-surfacing treatment has been used in China for many years. In 2005, the Technical Guidelines for Micro-Surfacing and Slurry Seal was first issued to encourage the broad adoption of this new technology in China [4]. Initial research on micro-surfacing was mainly focused on the mix gradation design and performance assessment, rarely involving decision making concepts [5], etc. However, micro-surfacing is actually a relatively complicated technology requiring pavement management knowledge of items such as raw materials, pavement condition evaluation, short- and long-term performance prediction, and determining the optimal time for treatment [6].

Long-term performance prediction of special preservation treatments is a basic yet important component of pavement managements practice strategy and decision making [7]. Researchers have expressed a strong interest in this issue and have proposed some pavement management models for long-term performance prediction including major stochastic prediction models, which are mainly statistical regressions, artificial neural networks, and Markov models. For example, Labi, Lamptey quantified the

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long-term performance of micro-surfacing treatments with regard to accumulated traffic loading and climatic severity with an exponential model [8]. However, this exponential model (statistical regression) might be not feasible for all pavement performance metrics due to the grey nature of pavement systems. Abaza established a discrete-time Markov model to predict pavement deterioration that includes pavement improvement resulting from maintenance and rehabilitation actions [9]. Although these models have been applied widely in special regions, they require large data sets. This is problematic as sample data is usually lacking in pavement system management.

The grey system theory was initially proposed by Deng [10]. Grey system theory is a mathematical methodology for modelling problems lacking sufficient information or sample data. The grey model adopts the essential part of the grey system theory and has been successfully used in finance, physical control, engineering, and economics [11]. Pavement performance prediction has similar characteristic with grey system theory. Both are uncertain systems with limited known sample data and unknown data. The application of grey models for pavement performance prediction based on grey system theory is consistent with the actual engineering. Bezuglov and Comert developed a pavement permanent deformation prediction model based on grey system theory for investigating the grey pavement system naturally [11]. The grey model was considered as a valid method of predicting pavement performance and followed the characteristics of pavement systems, but the studies just focused on permanent deformation prediction that could not fully account for the effectiveness of micro-surfacing.

A grey system model based on the grey system theory was utilized in this paper for long-term performance prediction of micro-surfacing treatment. Seven selected pavement sections with a total length of over 320 km were surveyed. Four typical performance indicators, pavement surface condition index (PCI), riding quality index (RQI), rut depth index (RDI), and skid resistance index (SRI), were modelled and predicted using a grey model for each pavement section. Three sub-indicators of PCI (longitudinal cracks, transverse cracks, and potholes) were predicted as well for further understanding the micro-surfacing treatment. The above indicators fully reflect the pavement condition and may be helpful in making maintenance decisions.

Single indicators, such as PCI, represent one aspect of the pavement surface condition. In order to have an integrated and comprehensive understanding of pavement condition, a composite performance index must be applied. According to the Highway Performance Assessment Standards, pavement quality index (PQI) has been used for assessing the pavement condition and determining the service life for maintenance. Pavement quality index is a composite of PCI, RQI, RDI, and SRI. The weights of the four typical indicators are constants determined by engineering experience across all of China [12]. The PQI may not be feasible and reliable for all pavement maintenance treatments without also considering any special conditions such as pavement structure, traffic, humidity, and temperature. In order to tackle this problem, the grey relational degree analysis methodology was applied in this research. Grey relational degree analysis is a measurement method in grey system theory that analyses uncertain relations between one main factor and all the other subordinate factors in a given system [13,14]. When experiments are ambiguous or when the experimental method cannot be carried out exactly, grey relational degree analysis helps to compensate for the shortcomings in statistical regression. Service life of micro-surfacing treatment was determined with the grey weights based on the extensive short-term performance data and a critical PQI level for distinguishing good or poor pavement condition was obtained for practical engineering application.

The remainder of this paper is organized as follows:

(1) Section 1.2 describes the objective and scope of this study.
(2) Section 2.1 describes the pavement sections with micro-surfacing treatment and the interesting performance indicators tracking.
(3) In Section 2.2, details of analyses of short-term pavement performances based on the annual data of each pavement sections are described.
(4) Section 3 describes the prediction and assessment of long-term pavement performances according to grey system model of each pavement sections.
(5) Section 4 describes the modelling process of pavement quality index based on grey relational degree analysis. Section 4 describes the service life analysis of micro-surfacing treatment as well.
(6) Conclusions and future work.
(7) Acknowledgements.

1.2. Objective and scope

The objective of this study is to assess the short-term pavement performance in different pavement sections with micro-surfacing treatment and to propose a mathematical method to predict and analyse the long-term pavement performance using a grey system predicted model.

This study aims to put forward a new PQI model for evaluating the comprehensive condition of pavement treated with micro-surfacing using deterministic weights from grey relational degree theory based on measured performance data. Consequently, a service life of micro-surfacing treatment using the PQI model is determined.

Combined with previous engineering application experience, this research aims to validate the PQI model and the proposed assessing method for determining the service life of pavement micro-surfacing treatments.

2. Material and methods

2.1. Pavement sections and pavement performances tracking

2.1.1. Pavement sections with micro-surfacing treatment

Seven representative pavement sections applied with micro-surfacing with a total length of over 320 km were selected from throughout Guangdong Province, which depends on pavement structural, traffic and environmental impact, for performance tracking over a minimum of 3 years. Details about the seven represented pavement sections are listed in Table 1.

Guangdong province belongs to tropical, subtropical monsoon climate, which presents the characteristics of high temperature and rainy typhoon, dry and wet significant changing. The annual average temperature ranges from 18 °C to 24 °C. The average annual rainfall varies between 1350 mm and 2600 mm. The social-economic status of Guangdong province results in heavy

Table 1
Pavement sections with micro-surfacing treatment.

Pavement Sections	Terminal treatment	Length (km)
CH11	November 2011	23.75
MZ12	October 2012	40.44
SF11	December 2011	29.76
XT11	December 2011	33.46
YM11	December 2011	79.76
YZ12	April 2012	56.90
YG10	December 2010	55.98