DESIGN OF PERFORMANCE EVALUATION MODEL FOR WARM MIX RECYCLED ASPHALT PAVEMENT BASED ON FUZZY DECISION ALGORITHM

by

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In order to improve the accuracy and comprehensiveness of asphalt pavement performance evaluation, a performance evaluation model based on warm mixed recycled asphalt pavement was proposed. Based on the evaluation indexes such as pavement quality, pavement damage, pavement structure bearing capacity, pavement skid resistance, pavement rutting and pavement comprehensive performance, the performance evaluation system of warm mixed recycled asphalt pavement was established. According to the standard numerical characteristics of asphalt pavement performance evaluation index, the subjection function of asphalt pavement performance is constructed. The trapezoidal and semi-trapezoidal distribution functions are obtained, and the membership functions of each distribution section are established. Considering the comprehensiveness, fuzziness and complexity of the evaluation, the fuzzy decision algorithm is introduced to determine the interval weight of each index, and the structure is quantified according to the evaluation index. The membership function and fuzzy subset are established. The evaluation standard and evaluation level are determined based on fuzzy relation matrix, and the pavement performance is evaluated. The experimental results show that the evaluation results of this model are accurate and reliable, and it has obvious advantages in application.

Key words*: fuzzy decision algorithm, warm mix recycled asphalt pavement, performance evaluation, interval weight, fuzzy subset, membership function, fuzzy evaluation, numerical characteristics*

Introduction

Road is an important part of urban infrastructure and the fundamental condition of urban development. The basic functions of the city and people's life are inseparable from a sound urban road system. However, with the increasing development of economy and the acceleration of urbanization process, the vehicle load and the number of private cars on the road have increased dramatically. In addition, due to the unreasonable design and inadequate construction quality control of some urban pavements, the damage of the pavement structure has gradually increased. The early built pavement has been unable to meet the current urban traffic demand, and close to its service life [1, 2]. In addition, some of the newly-built urban

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roads cannot meet the rapid growth of traffic demand due to the traffic capacity, coupled with the heavy load and overload phenomenon, leading to some roads into the overhaul and reconstruction stage in advance. In the process of asphalt pavement reconstruction, the relevant departments need to take scientific reconstruction plan, fast maintenance, so as to keep the asphalt pavement in good use.

The warm mix asphalt mixture can make the asphalt cover the aggregate surface well at a relatively low temperature by adding additives and other measures. Because of its good adhesion and lubrication, the asphalt can be mixed and constructed at a relatively low temperature, while maintaining the service performance of the mixture not lower than that of the hot mix asphalt mixture. Compared with the traditional hot mix asphalt mixture, the mixing and compaction temperature of the warm mix asphalt mixture is relatively low, which reduces the energy consumption and exhaust gas emissions. It is a new type of energy-saving and environmental protection road material, and has a very broad application prospect [3, 4]. With the use of warm mix asphalt mixture, the evaluation and test of its road performance have become an urgent problem, which has also attracted extensive attention of researchers in this field.

In [5], the application status of warm mix at home and abroad is systematically investigated, to determine the main classification of warm mix modification technology and the types of commonly used warm mix at present, and comprehensively evaluate the influence of Sasobit, Aspha-min, Evotherm, and EC120 on the high temperature performance, low temperature performance and water stability of asphalt mixture. In [6], different dosage of self-developed warm mixing additive is added into asphalt mixture, and its influence on asphalt performance is analyzed from the aspect of temperature sensitivity. Under the optimum content of warm mix additive, the road performance of asphalt mixture is verified, and compared with hot mix asphalt mixture. In [7], different amount of Leadcap is added into SBS modified asphalt according to certain test method, detect penetration, softening point, ductility, Brinell viscosity, and rheological property of asphalt, and discuss the influence of Leadcap on SBS modified asphalt.

Traditional pavement renovation and expansion, will directly to the old pavement milling planer, and adoption of new asphalt paving asphalt pavement with xinji materials again, this will not only create the non-renewable resources such as oil resources and the aggregate amounts of waste, and will produce large amounts of waste, causing serious pollution of environment, based on a large number of old pavement materials waste, in recent years, the study of regeneration of pavement is more and more widely, and got a lot of attention. As we all know, the energy-saving and emission reduction performance of warm mix asphalt mixture is far better than that of hot mix asphalt mixture, but the performance of different mixtures is different compared with hot mix asphalt mixture. However, the unilateral evaluation is lack of systematicness and comprehensiveness, so it cannot make a correct and reasonable evaluation on the road performance of warm mix recycled asphalt pavement. Therefore, a road performance evaluation model based on fuzzy decision algorithm is designed.

Performance evaluation of warm mix recycled asphalt pavement

Performance evaluation index content and system of warm mix recycled asphalt pavement

In the current Technical Code for the Maintenance of Highway Asphalt Pavement in China (Hereinafter referred to as *Maintenance specification*), the pavement condition is divided into the following single indexes: RQI for the evaluation of pavement smoothness, PCI for the evaluation of disease damage, SSI for the evaluation of bearing capacity, SFC for the evaluation of skid resistance, and a comprehensive index (pavement quality index, PQI) are used to represent the overall performance of all aspects of the pavement. The evaluation system structure is shown in fig. 1.

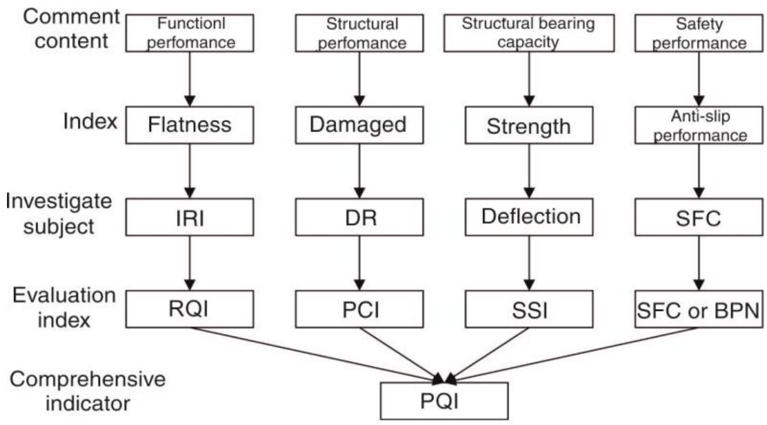

Figure 1. Evaluation system of pavement performance

In the current Highway Technology Evaluation Standard (Hereinafter referred to as *Evaluation standard*), the evaluation of highway technology includes four parts: pavement, subgrade, bridge, and tunnel construction and facilities along the highway. The performance evaluation of asphalt pavement includes pavement damage, flatness, rutting, skid resistance and structural strength. The evaluation system is shown in fig. 2, and each index range is 0-100.

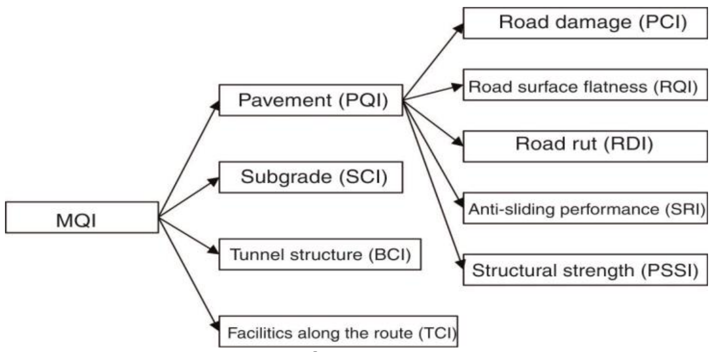

Figure 2. Evaluation system of highway technical conditions in *Evaluation standard*

Riding quality evaluation

When evaluating the riding quality of the road, RQI is used as the evaluation index, and it is calculated by the IRI.

According to the *Maintenance specification*, IRI can be measured by reaction equipment, and the measurement results need to be calibrated by test. The calibration relationship between IRI and other equipment is generally:

$$IRI = a + b \times BI \tag{1}$$

where BI is the test results of flatness test equipment, a and b – the calibration coefficient, and IRI – the international flatness index.

The relationship between RQI and IRI is:

$$RQI = 11.5 - 0.75 \times IRI \tag{2}$$

where RQI represents the riding quality index, and the value range is 0-10. If there is a negative value, RQI is taken as 0 and if the calculation result is greater than 10, RQI is taken as 10.

The classification standard is shown in tab. 1.

Table 1. Evaluation standard of riding quality in *Maintenance specification*

Rating/evaluation index	Excellent	Good	Medium	Secondary	Poor
Driving quality index RQI	≥8.5	7.0-8.5	5.5-7.0	4.0-5.5	<4.0
Corresponding flatness index IRI	≥4.0	4.0-6.0	6.0-8.0	8.0-10.0	<10

In the *Evaluation standard*, the riding quality index RQI is calculated:

$$RQI = \frac{100}{1 + a_0 e^{a_1 IRI}} \tag{3}$$

where a_0 and a_1 represent the calibration coefficient.

The evaluation criteria are shown in tab. 2.

Table 2. Evaluation standard of riding quality in *Evaluation standard*

Rating/evaluation index	Excellent	Good	Medium	Secondary	Poor
Driving Quality Index RQI	≥ri	80-90	70-80	60-70	<60
Corresponding flatness index IRI	≤orr	2.3-3.5	3.5-4.3	4.3-5.0	>5.0

Pavement damage evaluation

The damage condition of pavement structure reflects the degree that the pavement structure remains intact or intact, which directly affects the service level of the road [8 ,9]. Generally speaking, the so-called pavement damage generally refers to the visible damage phenomenon on the road surface. When evaluating the damage of the pavement structure, it must be described from three aspects: the type of damage, the severity of the damage, and the scope and density of the damage.

The PCI is used to evaluate the pavement damage condition in the *Maintenance specification*, and PCI is calculated by the comprehensive damage rate (DR) of asphalt pavement.

Comprehensive DR:

$$DR = \frac{D}{A}100 = \sum\sum D_{ij} \times K_{ij} / A \times 100 \tag{4}$$

where D is the equivalent damaged area in the investigated road section, A – the total pavement area of the investigated road section, D_{ij} – the actual damaged area of class i damage and class j severity, and K_{ij} – the conversion coefficient of class i damage and class j severity.

Pavement condition index (PCI):

$$PCI = 100 - a_0 DR^{a_1} \tag{5}$$

The evaluation criteria of pavement damage in the *Maintenance specification* are shown in tab. 3.

Table 3. Evaluation standard of pavement damage in *Maintenance specification*

Rating/evaluation index	Excellent	Good	Medium	Secondary	Poor
Pavement condition index	≥85	70-85	55-70	40-55	<40

In the *Evaluation standard*, the pavement damage is also evaluated by PCI, but the specific type and severity of pavement damage and the conversion coefficient of pavement damage are different from those in the maintenance specification. The PCI expression is shown in eq. (5), where DR is:

$$DR = 100\frac{\sum_{i=1}^{i_0} w_i A_i}{A} \tag{6}$$

where w_i is the weight of the type i pavement damage.

Bearing capacity evaluation of pavement structure

In the performance evaluation system of asphalt pavement in the current code, the pavement representative deflection is used to represent the structural strength of asphalt pavement. In the code for maintenance, the structural strength of pavement is evaluated by structural strength index (SSI). The SSI is calculated:

$$SSI = \frac{l_d}{l_0} \tag{7}$$

where SSI is the structural strength index, l_d – the design deflection of the pavement, and l_0 – the deflection value of the road section.

In the *Evaluation standard*, the pavement structure strength is evaluated by the structure strength index (PSSI). The calculation equation of PSSI is:

$$PSSI = \frac{100}{1 + a_0 e^{a_1 SSI}} \tag{8}$$

Evaluation of anti-sliding of pavement

In the maintenance specification, the anti-sliding coefficient is used as the evaluation index for the anti-sliding performance of the pavement, and the anti-sliding coefficient is expressed by the side-way force coefficient (SFC) or the pendulum value (BPN) of the pendulum instrument.

In the *Evaluation standard*, SRI is used to evaluate the anti-sliding performance of pavement and calculated:

$$SRI = \frac{100 - SRI_{\min}}{1 + a_0 \mathrm{e}^{a_1 SFC}} + SRI_{\min} \tag{9}$$

where $SRI_{\min}$ represents the calibration parameter, using 35.0.

Pavement rut evaluation

The *Evaluation standard* standardizes the road rut detection method of expressway, takes the road rut depth (RD) as an independent detection index, and calculates the road rut depth index (RDI) accordingly. The RDI is calculated:

$$RDI = \begin{cases} 100 - a_0 RD, \left(RD \le RD_a \right) \\ 60 - a_1 \left(RD - RD_a \right), \left(RD_a < RD \le RD_b \right) \\ 0, \left(RD > RD_b \right) \end{cases} \tag{10}$$

where RD is rut depth, RD_a – the parameter of rut depth, and RD_b – the limit of rut depth.

Comprehensive evaluation of pavement performance

In the *Maintenance specification*, the pavement quality index (PQI) is used as the evaluation index for the comprehensive evaluation of the pavement, and the PQI is calculated by weighting the sub-indexes. The value range of PQI is 0-100. The higher the value is, the better the road condition is.

The PQI is calculated:

$$PQI = PCI' \times P_1 + RQI' \times P_2 + SSI' \times P_3 + SFC' \times P_4 \tag{11}$$

where P_1, P_2, P_3, and P_4 represent the weight of corresponding indexes.

Performance evaluation of warm mix recycled asphalt pavement

Based on the previous evaluation index content and system, fuzzy decision algorithm is introduced to realize the evaluation of road performance.

Determination of fuzzy subsets

Supposing that $U = \{u_1, \ldots, u_n\}$ represents the set of n indexes, $V = \{v_1, \ldots, v_m\}$ represents the set of m evaluation grades in each evaluation factor, and the set of evaluation grades is: {excellent, good, medium, secondary, poor}.

Selection of membership function

The idea of subordination degree is the basic idea of fuzzy mathematics evaluation process. The main problem of fuzzy mathematics evaluation method is to establish a membership function which meets the needs of practical problems. At present, there is still no good solution to the selection of membership function [10-14]. In the method of determining the membership function of practical problems, the approximate method is often used to establish the membership function of practical problems.

According to the standard numerical characteristics of the performance evaluation indexes of asphalt pavement [15], the membership function of the performance of asphalt pavement is constructed, and the trapezoid and semi-trapezoid distribution functions are adopted to establish the membership function of each grading section:

$$\text{When } j = 1: \ r_{i1} = \begin{cases} 1, x_i \ge C_{i,1} \\ \dfrac{x_i - C_{i,2}}{C_{i,1} - C_{i,2}}, C_{i,2} \le x_i < C_{i,1} \\ 0, x_i < C_{i,1} \end{cases} \tag{12}$$

$$\text{When } j=2:\ r_{i2}=\begin{cases}\dfrac{C_{i,1}-x_i}{C_{i,0}-C_{i,1}}, C_{i,1}\le x_i<C_{i,0}\\ 1, C_{i,2}\le x_i<C_{i,1}\\ \dfrac{x_i-C_{i,3}}{C_{i,2}-C_{i,3}}, C_{i,3}\le x_i<C_{i,2}\\ 0, x_i<C_{i,3} \text{ or } x_i\ge C_{i,0}\end{cases} \tag{13}$$

$$\text{When } j=3:\ r_{i3}=\begin{cases}\dfrac{C_{i,1}-x_i}{C_{i,1}-C_{i,2}}, C_{i,2}\le x_i<C_{i,1}\\ 1, C_{i,3}\le x_i<C_{i,2}\\ \dfrac{x_i-C_{i,4}}{C_{i,3}-C_{i,4}}, C_{i,4}\le x_i<C_{i,3}\\ 0, x_i<C_{i,4} \text{ or } x_i\ge C_{i,1}\end{cases} \tag{14}$$

$$\text{When } j=4:\ r_{i4}=\begin{cases}\dfrac{C_{i,2}-x_i}{C_{i,2}-C_{i,3}}, C_{i,3}\le x_i<C_{i,2}\\ 1, C_{i,4}\le x_i<C_{i,3}\\ \dfrac{x_i-C_{i,5}}{C_{i,4}-C_{i,5}}, C_{i,5}\le x_i<C_{i,4}\\ 0, x_i<C_{i,5} \text{ or } x_i\ge C_{i,3}\end{cases} \tag{15}$$

$$\text{When } j=5:\ r_{i5}=\begin{cases}\dfrac{C_{i,3}-x_i}{C_{i,3}-C_{i,4}}, C_{i,3}\le x_i<C_{i,4}\\ 1, C_{i,5}\le x_i<C_{i,4}\\ \dfrac{C_{i,4}-x_i}{C_{i,4}-C_{i,5}}, x_i<C_{i,5}\\ 0, x_i\ge C_{i,3}\end{cases} \tag{16}$$

Results

In order to verify the effectiveness of the performance evaluation model of warm mixed reclaimed asphalt pavement based on fuzzy decision algorithm, the following experimental tests were carried out.

The experimental platform is built on MATLAB, and a test section is paved on ramp a of expressway interchange area in a province. The total length of the section is about 220 m, and the structure of asphalt concrete pavement is designed as 7cm lower layer + 5cm upper layer.

The experiment verified the effectiveness of the evaluation results of the established model from the following six perspectives: pavement driving quality, pavement damage, bearing capacity of pavement structure, skid resistance of pavement, pavement rutting, and comprehensive performance of pavement.

In the experiment, the fitting index CFI is taken as the verification index. If the value is greater than 0.9, it indicates a good fitting degree with the actual data. The better the accuracy of the model, the stronger the feasibility.

Conclusions

Pavement performance evaluation is the research project with the largest scale, the longest time and the largest consumption of funds and resources in current road engineering. According to the actual needs, a performance evaluation model of warm mix recycled asphalt pavement based on fuzzy decision algorithm is proposed. According to the construction of evaluation index system, its innovation lies in the use of fuzzy decision algorithm to realize the comprehensive evaluation of asphalt pavement performance. The experimental results show that the CFI of this model is large, which can provide a basis for the research in this field. In the future research stage, the proposed model will be further optimized, the application range of the model will be expanded, and the performance of other things in road engineering will be evaluated.

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