

Investigation of cost-effectiveness of highway asphalt pavement maintenance treatments based on rutting development analysis

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Abstract: To investigate the cost-effectiveness of different maintenance treatments of highways in Jiangsu Province, the historical pavement maintenance records, traffic load information and pavement performance data in the pavement management system (PMS) are recorded and analyzed. Compared with the growth model, the linear model, the logarithm model and the exponential model, the cubic model has higher regression accuracy R^2 and it can capture the sigmoid shape of the deterioration curve. So it is selected to simulate the pavement rutting development. The benefit over cost ratio is calculated to quantify the treatment cost-effectiveness. The analysis results show that thin hot mix asphalt (HMA) overlays and micro surfacing are more cost-effective than the other two treatments on light and moderate traffic roads. Hot in-place recycling and thick HMA overlays have much longer service lives and greater cost-effectiveness under heavy or extra heavy traffic.

Key words: asphalt pavement; maintenance treatment; cumulative equivalent single axle loads; cubic model; cost-effectiveness

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Asphalt pavements cover more than 85% of the highways built in China. Most of the highways in Jiangsu Province are semi-rigid base asphalt pavements and the pavement surface thickness varies from 16 to 20 cm. The pavement performance of highways deteriorates year by year under traffic loads^[1]. Most of the highways in Jiangsu Province were built more than 10 years ago and stresses of various types and severity levels have affected the pavements.

The fundamental purpose of maintenance is to delay deterioration and major repairs. The cost-effectiveness of a pavement treatment can be defined as the relationship between the long-term cost of a pavement maintenance treatment over a given evaluation period and improvement in the serviceability of the pavement^[2]. Several studies

have been done to evaluate and define various methods for determining the cost-effectiveness of maintenance treatments^[3-4].

Due to the lack of pavement conditions and traffic related data and analysis methods, limited findings of the pavement performance in China were attained in previous studies. Now detailed information of pavement structure, weather, environment, traffic, axle loads, performance detection and historical maintenance activities are recorded in the developed pavement management system (PMS) of Jiangsu Province. Moreover, various pavement maintenance treatments have been employed for a sufficient number of years. The actual performance and effects of those treatments can be observed. Therefore, it is urgent and of great importance that a thorough investigation is taken into the effectiveness of those maintenance treatments to provide effective and economic maintenance strategies.

1 Pavement Maintenance Information

1.1 Pavement maintenance treatments

Three widely used asphalt pavement treatments in Jiangsu Province are micro surfacing, hot mix asphalt (HMA) overlay, and hot in-place recycling (HIPR). Micro surfacing is a mixture of polymer-modified asphalt emulsion, fine aggregate, mineral filler, and water, uniformly spread over the pavement surface in one or two thin layers. The HMA overlay consists of 2 to 6 cm thick heated and mixed asphalt placed over the existing pavement surface. In this study, two typical thicknesses, 2.5 and 4 cm, are evaluated. Hot in-place recycling consists of heating, scarifying, mixing, placing, and compacting the upper layer of an existing asphalt pavement. Normally, 70% to 100% of the material in a mix is recycled in-place. Virgin aggregate, new asphalt binders, recycling agents, and/or new hot mix asphalt may be added as needed.

1.2 Traffic and loads

Due to the large variance of traffic and axle loads, the cumulative equivalent single axle loads (ESALs) is usually calculated to characterize traffic level based on measured traffic flow^[5]. According to the Chinese specifications for design of highway asphalt pavement^[6], asphalt pavements with different traffic levels can be classified

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based on cumulative ESAL repetitions of one lane in the design service life. Although the design life of highways in China is between 15 and 20 years, all the highways in Jiangsu Province have not reached their design lives yet. Using axle load data from weigh-in-motion (WIM) sta-

tions since the opening of different highways till 2012, cumulative ESALs were calculated. Tab. 1 summarizes calculated cumulative ESALs until 2012 on highways included in the study, based on which the traffic levels of each highway can be identified.

Tab. 1 Cumulative ESALs till 2012 and traffic levels of investigated highways

Road name	Road code	Direction	Pavement age/a	Lane number	Cumulative ESALs/ ($10^6 \text{ times} \cdot \text{lane}^{-1}$)	Traffic level
Yan Jing	S29	North Bound	10	2	2.66	Light
		South Bound	10	2	2.82	Light
Ning Xu	S49	North Bound	11	2	4.72	Light
		South Bound	11	2	11.88	Moderate
Lian Xu	G3	West Bound	11	2	23.04	Heavy
		East Bound	11	2	17.07	Heavy
Xi Guang	G2	North Bound	13	3	28.63	Heavy
		South Bound	13	3	33.31	Extra heavy
Jing Hu	G2	North Bound	12	2	37.07	Extra heavy
		South Bound	12	2	76.47	Extra heavy

1.3 Selection of performance indicators and thresholds

To evaluate treatment effectiveness, two pavement performance indicators including the international roughness index (IRI) and the rutting depth were selected^[7]. Both IRI and rutting depth increase with time and usually upper performance thresholds are required to trigger pavement maintenance treatment. In this study, 15 mm rutting depth and 3 m/km IRI value were selected as the upper benefit cutoff values^[8].

Accumulative ESALs is an important factor influencing

pavement performance. Fig.1 shows relationships between pavement performance and accumulative ESALs in the initial six years for new constructed or rehabilitated highways with different traffic levels. It is noted that when rutting reaches the threshold value (15 mm) for heavy and extra heavy highway sections as shown in Figs. 1 (c) and (d), the IRI values generally remain much lower than the treatment triggering threshold (3 m/km). Thus, the rutting depth is a more critical performance indicator and will be adopted as a performance indicator in the following study.

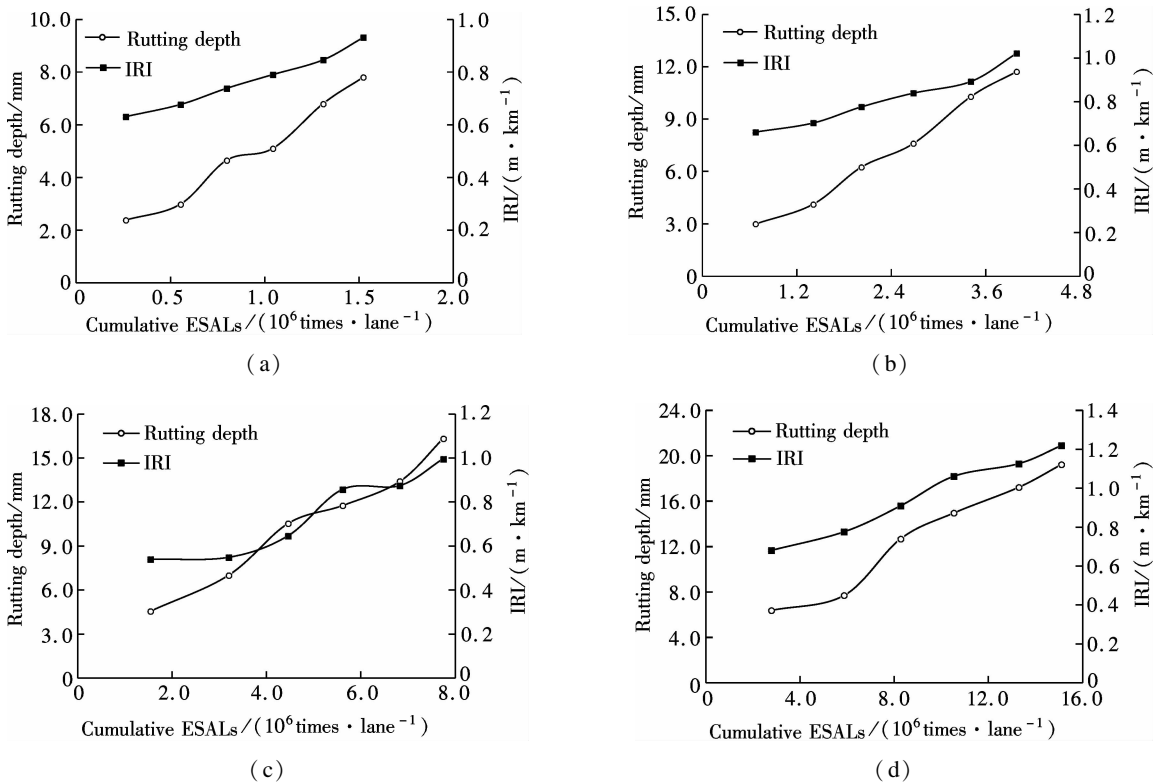


Fig. 1 Relationship between the performance indices and cumulative ESALs. (a) Light traffic; (b) Moderate traffic; (c) Heavy traffic; (d) Extra heavy traffic

2 Rutting Performance Models

Regression analysis can be used to predict future pavement deterioration based on abundant condition measurements data from the past. This method is simple and efficient when a large volume of data is available, and, thus, has been widely used in PMS. The traffic index of cumulative ESALs and pavement service time can both be used as influence factors for the regression model of the rutting depth. From the perspective of cost-effectiveness analysis of maintenance treatments, time has been selected as the independent variable to set the regression model of the rutting depth. By referring to previous research results^[9], the linear model, the logarithm model, the cubic model, the exponential model and the growth model have been adopted for the regression analysis.

The do-nothing relationship defines the pavement performance over time that will be expected if no or only minor routine maintenance is conducted. The post-treatment relationship defines the pavement performance over time that will be expected if a treatment is applied. Fig. 2 shows different regression model curves of the rutting depth of thick HMA overlays (4 cm) at the heavy traffic level. From the statistical analysis of abundant maintenance projects, for the model accuracy, the cubic model has the highest regression accuracy R^2 , followed by the growth model, the linear model, the logarithm model and the exponential model. In terms of regression accuracy and significance levels, the linear model, the growth model and the cubic model are all suitable for different pavement sections. Since the cubic model has the highest R^2 and is capable of capturing the sigmoid shape of the deterioration curve, it is selected to simulate the rutting development.

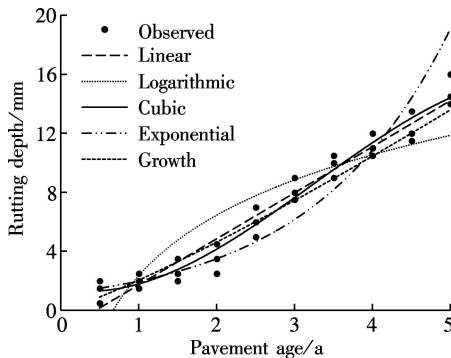


Fig. 2 Pavement rutting depths under heavy traffic after the thick HMA overlays

3 Cost-Effectiveness Analysis

Typically, cost-effectiveness is expressed as a ratio of costs and benefits^[2,10]. The costs are in terms of unit costs. Maintenance projects at different pavement sections are usually carried out in different years. In order to com-

pare their costs, the present value is calculated to account for the effects of inflation.

$$C = F \frac{1}{(1+i)^n} \quad (1)$$

where C is the present value; F is the future cost or current cost; i is the discount rate and the value can be adopted as 6% in China; n is the age of the maintenance project.

The benefits associated with the application of a maintenance treatment is based on the improvement in performance compared with that for the “do-nothing” alternative^[2].

As shown in Fig. 3, for a specific condition indicator, the benefits are determined by the difference in computed areas associated with the post-treatment performance indicator curve and the do-nothing curve.

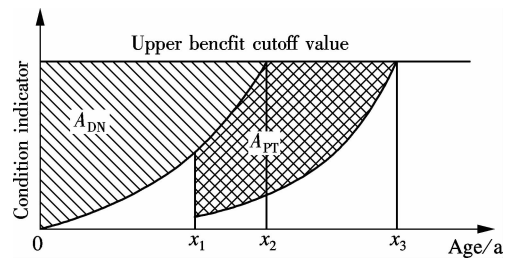


Fig. 3 Calculation of benefit area associated with increasing condition indicator

$$A_{DN} = \int_0^{x_3} (U - E_{DN}) dx \quad (2)$$

$$A_{PT} = \int_0^{x_3-x_1} (U - E_{PT}) dx - \int_{x_1}^{x_3} (U - E_{DN}) dx \quad (3)$$

$$B = \frac{A_{PT}}{A_{DN}} \quad (4)$$

where A_{DN} is the computed do-nothing area; A_{PT} is the computed post-treatment area; U is the upper benefit cutoff value; E_{DN} is the equation defining the do-nothing condition indicator relationship; E_{PT} is equation defining the post-treatment condition indicator relationship; x_1 is the pavement age at treatment application; x_2 is the pavement age at which the do-nothing curve intersects the upper benefit cutoff value; x_3 is the overall post-treatment analysis period (in terms of pavement age); B is the benefit.

4 Project Case Study

The historical maintenance projects conducted by the maintenance department of Jiangsu Province have been investigated. The do-nothing performance curve can be established by using the pavement condition data of the section adjacent to the maintenance section when the surface ages are available. Those adjacent pavement sections have

the same base and subgrade, traffic and environmental conditions. By setting a threshold value of 15 mm, the service life of treatment can be determined based on the rutting performance models. All the maintenance costs were converted to the present worth in 2004 in this study.

Tab. 2 and Fig. 4 show that the characteristics of the benefit over cost ratio are quite different under different

traffic levels. Due to the low cost, the benefit over cost ratios of thin HMA overlays and micro surfacing are higher than those by the other two treatments at light traffic level and moderate traffic level. Hot in-place recycling and thick HMA overlays have much longer service lives and greater cost-effectiveness under heavy or extra heavy traffic.

Tab. 2 Results of cost-effectiveness analysis of different maintenance treatments

Treatment method	Traffic level	Apply time	Cost/(yuan · m ⁻²)	Samples number	Service life/a	Benefit	Benefit over cost ratio
Micro surfacing	Light	2004	31.5	84	5.5	0.69	0.0219
	Moderate	2005	30.2	26	4.2	0.66	0.0218
	Heavy	2004	31.8	32	3.3	0.56	0.0176
	Extra heavy	2004	32.0	48	2.8	0.57	0.0178
Thin HMA overlay (2.5 cm)	Light	2007	31.7	16	6.0	0.74	0.0233
	Moderate	2007	32.0	20	5.5	0.81	0.0253
	Heavy	2005	35.6	20	3.6	0.60	0.0169
	Extra heavy	2005	36.0	50	3.1	0.61	0.0169
Thick HMA overlay (4 cm)	Light	2007	43.2	16	7.0	0.87	0.0201
	Moderate	2007	43.5	30	6.2	0.91	0.0209
	Heavy	2005	47.5	30	5.5	0.91	0.0192
	Extra heavy	2005	48.0	120	4.5	0.89	0.0185
Hot in-place recycling	Light	2007	38.9	28	6.5	0.81	0.0208
	Moderate	2005	43.2	30	5.6	0.82	0.0190
	Heavy	2005	43.6	30	5.0	0.83	0.0191
	Extra heavy	2006	41.5	30	4.2	0.84	0.0202

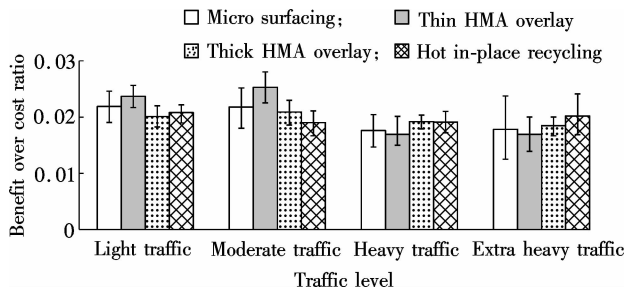


Fig. 4 Benefit over cost ratios of maintenance treatment at different traffic levels

5 Conclusion

Three widely used asphalt pavement treatments in Jiangsu Province are micro surfacing, hot mix asphalt overlay, and hot in-place recycling. The rutting depth is a more critical pavement performance indicator and is used to determine the effectiveness of treatment. The cubic rutting model not only has higher R^2 , but can also capture the sigmoid shape of the deterioration curve. The cubic model has been selected to simulate the pavement rutting development.

In the cost-effectiveness analysis, the benefit over cost ratio is used as an index to quantify treatment cost-effectiveness. Thin HMA overlays and micro surfacing are more cost-effective than the other two treatments on light and moderate traffic roads. Hot in-place recycling and thick HMA overlays with much longer service lives have greater cost-effectiveness under heavy traffic or extra

heavy traffic.

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基于车辙发展分析的高速公路沥青路面 养护措施的费用-效益研究

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摘要:为了调查江苏省各种路面养护措施的费用-效益,对路面管理系统的养护历史资料、交通轴载信息、路面性能的数据进行观察和分析. 与增长模型、线性模型、对数模型和指数模型相比,立方模型具有更高的回归精度,能够捕捉路面性能衰退曲线,因此采用立方模型来模拟路面车辙的发展. 计算效益费用比来定量评价路面养护措施的费用-效益. 研究结果表明,在中、低交通条件下,热拌沥青薄层罩面和微表处比其他养护措施的费用-效益更大;在重、特重交通高速公路上,热再生和厚热沥青罩面具有更长的使用寿命和更大的费用-效益.

关键词:沥青路面;养护措施;累计当量单轴荷载;立方模型;费用-效益

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