Construction of Highway Asphalt Pavement Maintenance Comprehensive Post-evaluation System

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ABSTRACT—This paper proposes a post-evaluation index system and index hierarchy for utility model technologies and processes for maintenance based on domestic and international road maintenance post-evaluation studies, mainly evaluating it from five aspects of engineering technology, management technology, economic benefits, social environment, and sustainable development. The engineering technology is evaluated according to the implementation stage, and the corresponding comprehensive evaluation formula is established according to the maintenance classification, which can comprehensively analyze the implementation quality and effect of the maintenance measures. By establishing the life-cycle cost model, the economic benefit of conservation is evaluated from the two aspects of the cost of the management department and the user. Using energy consumption and carbon emission intensity index to analyze the stage of the conservation process can effectively evaluate the impact of conservation measures on the social environment. This study can provide a reference for the evaluation of new maintenance technologies and new processes, which has very important practical significance.

1. Introduction

The post-evaluation method was first introduced in the United States. The post-evaluation was first carried out in the "New distribution" plan, and then gradually involved in various industries of the society.[1] Our country carried out pilot work of post-evaluation in the 1980s, analyzed the use of funds, management level and construction experience of construction projects, and gave the purpose, content and methods of post-evaluation.[2]In 1990, Ministry of Communications first proposed to carry on post-evaluation in highway construction, making our country's highway and other infrastructure aspects of post-evaluation into the program and standardization.[3]In recent years, domestic and foreign researchers have adopted different evaluation methods and indicators in the process of post-evaluation of highway construction projects, and their research contents also have different focuses.[4-5]However, there are few post-evaluation of highway maintenance projects at present. Jianbo Y et al.[6]Improved the post-evaluation system on the basis of referring to the content, indexes and methods of post-evaluation of highway construction projects at home and abroad, and the optimized evaluation system has a positive impact on project maintenance. Shah Y U et al.[7] Proposed two road maintenance evaluation methods based on subjective evaluation and economic evaluation by using indexes such as road condition index, traffic volume factor and dedicated factor. Setianingsih A I.[8]Established a regression model between IRI value, flexural value and traffic volume growth to evaluate the functional and structural condition of pavement and the availability of existing roads. Guo-xiang H et al.[9]Elaborated the significance of post-evaluation of pavement preventive maintenance in view of the status of no determined post-evaluation method for preventive maintenance projects, established the principles for establishing post-evaluation methods for pavement preventive maintenance, and proposed qualitative and quantitative evaluation methods from five aspects: engineering technology, management, economy, environment and society. Sun Bo et al.[10] built the evaluation index system of maintenance scheme from three aspects, including pavement performance, traffic impact and construction situation, and evaluated the feasibility of maintenance scheme in many aspects. Fan Shangning.[11]Evaluated the engineering effects of asphalt regenerative pre-curing and other maintenance technologies by evaluating the pavement damage, pavement structure and pavement anti-skid performance after maintenance. Many researchers have made a lot of contributions to the pavement performance evaluation, but the post-evaluation of utility model maintenance technology and process is almost blank. The evaluation of highway maintenance technology and process is an important means and necessary measure to improve and promote the progress of new technology and process, as well as a strong guarantee to promote the correct development and rapid improvement of new technology and process, which has very important practical significance.

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2. Engineering Technology Evaluation System

Engineering technology evaluation refers to the analysis of the advanced nature, reliability, and applicability of maintenance technology from the level of technology implementation. The evaluation should include three stages: early stage, middle stage, and late stage of project implementation. The evaluation indexes of each stage are proposed respectively and the post-evaluation system is established.

2.1 Implement the preliminary evaluation index system

In the early stage of the project implementation, the research object is divided into different elements according to the levels of elements through the analytic hierarchy process (AHP). Then, the scoring criteria are determined according to the levels of elements. The scoring results of each element are used to analyze and evaluate the engineering technology in the early stage of implementation. Among them, staffing reflects the maintenance technology for construction personnel and technical personnel configuration requirements, low staffing requirements, indicating that ordinary construction and technical personnel after simple training can quickly master the technology, harsh staffing said maintenance technology must be implemented by the professional construction team, technical personnel training needs a long time to master the technology to come; Material requirement is the technical index of maintenance technology extension evaluation. According to the implementation characteristics of maintenance engineering, maintenance engineering materials are divided into stone, asphalt, and admixture for evaluation respectively. Mechanical equipment configuration mainly reflects the requirements of maintenance technology for mechanical configuration. The actual requirements of equipment configuration required by maintenance technology are low, which indicates that the maintenance technology can meet the implementation requirements by using common equipment, which is conducive to the large-scale promotion of maintenance technology. The harsh equipment configuration means that the maintenance technology must be leased or purchased especially equipment to implement; The technical characteristics include the degree of technology popularization and completeness, which is to judge the characteristics and novelty degree of maintenance technology. The new technology indicates that the technology is formed through systematic innovation, has an independent technical system, and has not been applied on a large scale in China, while the mature technology indicates that the technology is not included in the project evaluation when it is implemented on a large scale. Technical standards for material index body, construction quality control standards, relevant test data and engineering experience and other information, complete technology, with perfect and operational implement ability, as shown in Table 1.

Table 1 Pre-data statistics table for engineering technology implementation

Construction configuration	**Classification**	**Scoring standard**	**Technical feature**	**Classification**	**Scoring standard**	**Material index**	**Classification**
Personnel allocation	Low	10-8	Degree of technology popularization	New type	10-8	Aggregate material	Ordinary
	In general	8-6		Derivative	8-6		Refining
	High	6-4		Improvement	6-4		Special
	Harshness	4-0		Maturity	4-0	Asphalt	Ordinary
		Refining					
Mechanical configuration	Low	10-8	Technical completeness	Complete	10-7		Special
	In general	8-6		More complete	7-3	Additive	Nothing
	High	6-4					Ordinary
	Harshness	4-0		Complete	3-0		Refining

2.2 Implement the mid-term evaluation index system

Mainly from construction quality control and construction process control two aspects of analysis and evaluation, the maintenance construction quality is mainly based on the comparison and analysis of the actual detection indicators and the previous technical indicators. The control indicators are scored according to the random inspection qualified rate. The random inspection qualified rate is the ratio of the qualified number reached by the index detection to the total quantity of the random inspection, which mainly includes the technical indicators such as the pavement thickness of the mixed material, smoothness, compaction degree, water seepage, and skid resistance. According to the characteristics of maintenance technology, the related technical indicators can be increased or decreased, and the construction quality control indicators proposed by the new maintenance technology can also be restricted. A horizontal comparison method is adopted to control the maintenance construction process. The engineering situation implemented on-site is compared and analyzed with other similar or expected situations. According to the actual implementation effect, the evaluation is divided into three levels, which are: superior, good, and poor.

2.3 Implement the late evaluation index system

In the later stage of project implementation, summative evaluation is mainly carried out on the implementation effect and technical applicability of the project, to judge the construction quality and effect of maintenance measures, and to test whether the adopted maintenance measures are reasonable, whether the timing is appropriate, and whether the selection of road sections is appropriate.

2.3.1 Establish the basic evaluation model

Based on the short-term benefit index and service life index, the basic evaluation model is established, and the weight coefficient is adjusted according to the actual situation, as shown in Table 2.

Table 2 Basic formula for post-conservation evaluation

Evaluation index	**Weight coefficient**	**Calculation method**
Short-term benefit index	a_1	Actual performance improvement/Expected performance improvement
Service life index	a_2	Actual service life/expected service life of measures
Basic model: M= $a_1\times$ short-term benefit index + $a_2\times$ service life index		

In the table, the short-term benefit index is the ratio of actual performance improvement to expected performance improvement. Different indexes (PCI, RQI, SRI, RDI, PSSI, etc.) are selected as performance values for calculation according to the characteristics of conservation measures, and the default expected performance value is increased to 100.

2.3.2 Implementation of late evaluation criteria

According to the results calculated by the evaluation formula of conservation measures, the comprehensive evaluation standard of conservation effect is evaluated. The larger the value is, the better the conservation effect is, and the higher the corresponding evaluation level is. To carry out the whole process evaluation of conservation engineering technology, it needs to be unified with the comprehensive scoring standard of the early and middle stages, so the evaluation level is scored and the later score is calculated. The comprehensive score of the post-implementation evaluation is shown in Table 3.

Table 3 Comprehensive evaluation standard for maintenance effect

Comprehensive aluation index	**>1**	**0.8-1**	**<0.8**
Evaluation level	Optimal	Fine	Poor
Scoring criteria	10-8.5	8.5-7	7-5.5

2.4 A comprehensive evaluation of engineering technology

A comprehensive evaluation was carried out on the early, middle, and late stages of engineering technology implementation, and the statistical scores of each implementation period were summarized in Table 5. Considering the influence degree of each implementation period in the whole period of engineering technology implementation, different influence coefficients are set respectively, comprehensive scoring formula is established, and comprehensive evaluation is carried out for each stage and the whole according to the comprehensive evaluation index, as shown in Table 4.

Table 4 Engineering technology implementation period score and comprehensive evaluation

Score	**Prophase**	**Middle phase**	**Late phase**
	Z_1	**Z_2**	**Z_3**
Composite score	W1= $z_1\times a_1$+ $z_2\times a_2$+ $z_3\times a_3$		
Comprehensive evaluation index	≥8.5	8.5~7	≤7
Comprehensive evaluation	Optimal	Fine	Poor

3. Management Technology Evaluation System

3.1 The evaluation of highway maintenance

Management is very important For the evaluation of highway management, the key to quality management is quality control. The given assessment items and scoring criteria are adopted to evaluate the quality control of maintenance engineering, that is, the degree of completion of the implementation process and the goals achieved are judged by the scoring method. The maintenance management technology was evaluated comprehensively through the quality control score of maintenance engineering. The evaluation is carried out from four aspects: preliminary process, technical scheme, road condition inspection and evaluation, and operation and maintenance. The evaluation standards are shown in Table 5 below.

Table 5 Quality Control Score Evaluation Table for Maintenance Engineering

Index	Type	Specific requirements	Score standard
Implementation process evaluation Scheme applicability evaluation Road inspection and evaluation	Strict compliance with requirements	The process of making a conservation plan is carried out in strict accordance with the specification;	10~7
	Partially as required	Part of the maintenance plan formulation process is carried out following the specification, and part of the content is missing.	7~4
	Basically as required	The process of making a conservation plan is following the specification or not under the specification.	4~0
Operation and maintenance evaluation Index Implementation process evaluation	Strict compliance with requirements	The type of maintenance scheme is matched with the maintenance requirements of the road conditions of the section, and factors such as technology, economy, safety, and environmental protection are comprehensively considered.	10~7
	Partially as required	The type of maintenance plan matches the maintenance requirements of the road conditions of the section, and some	7~4

Index	Type	Specific requirements	Score standard
		factors such as technology, economy, safety, and environmental protection are considered.	
	Basically as required	The type of maintenance plan does not match the maintenance requirements of the road conditions, and the factors such as technology, economy, safety, and environmental protection are not fully considered.	4~0
Scheme applicability evaluation Road inspection and evaluation	Strict compliance with requirements	The process of making a conservation plan is carried out in strict accordance with the specification;	10~7
	Partially as required	Part of the maintenance plan formulation process is carried out by the specification, and part of the content is missing.	7~4
	Basically as required	The process of making a conservation plan is basically by the specification or not by the specification.	4~0
Index	Excellent	Strip repair rate ≥80% and pavement effective repair rate ≥70%;	10~7
	General	80 > strip repair rate ≥50; and pavement effective repair rate ≥50;	7~4
	Disqualification	Strip repair rate < 50 or effective repair rate < 50	4~0

3.2 A comprehensive evaluation of conservation management technology

According to the scoring standard, the scores of the preliminary process score A, technical plan B, road condition inspection evaluation C, and operation and maintenance D were calculated respectively, and the comprehensive scores WA, WB, WC, and WD were calculated. Considering the influence degree of each work on the maintenance engineering, different influence coefficients were set respectively (A is 0.2, B is 0.2, C is 0.2, D is 0.4). The comprehensive scoring formula is put forward.

$$W_1 = Z_1 * 0.2 + Z_2 * 0.1 + Z_3 * 0.2 + Z_4 * 0.4 \qquad (1)$$

The evaluation standards are shown in Table 6 below.

Table 6 Comprehensive Evaluation Table of maintenance engineering management technology

Score	W_A	W_B	W_C	W_D
	Z_1	Z_2	Z_3	Z_4
Composite score	W_2			
Comprehensive evaluation index	＞80	80~60		＜60
Comprehensive evaluation	Optimal	Fine		Poor

4. The Economic Benefit Evaluation System

Economic benefit evaluation is an important part of highway construction feasibility study and project post-evaluation report. It demonstrates the technical feasibility and economic rationality of the project and provides the scientific basis for project decision-making. In this study, road life cycle cost (LCCA) was used to evaluate the economy of maintenance projects according to corresponding economic indicators.

4.1 Total life cycle cost composition

During the analysis period of the whole life cycle of the highway, the expenses involved shall include the custodial department expenses and the road user expenses, and the specific contents shall comply with the provisions of Table 7.

Table 7 Composition of Life Cycle Cost of Highway

Cost classification	**cost composition**	**cost description**
Custodial department expenses	Initial construction cost	The sum of all costs required to adopt the alternative conservation plan
	Daily maintenance cost	The cost of minor repairs and maintenance required to maintain the normal level of service
	Maintenance engineering cost	Cost of preventive maintenance and overhaul during the analysis period
	Pavement salvage cost	Analyze the value of pavement remaining at the end of the period
User expense	Vehicle operating expenses	The expenses incurred in the consumption of various resources during the running of the vehicle, such as fuel consumption, wheel consumption, warranty material consumption, and vehicle depreciation costs

Cost classification	cost composition	cost description
	Travel time expense	The equivalent cost of time spent traveling by passengers and cargo
	Traffic accident expense	Expenses incurred as a result of traffic accidents

4.2 Total cost present value calculation

The present value of the cost index (PVC) was used to evaluate the economic benefit of the conservation scheme. The calculation formula is as follows.

$$PVC_{xi,n} = IC_{xi,n} + \sum_{t=0}^{n} \left(RC_{xi,t} + MC_{xi,t} + UC_{xi,t} \right) \left(P/F, i, t \right) - SV_{xi,n} \left(P/F, i, n \right) \quad (2)$$

where PVCxi,n is the present value of the cost of plan xi; ICxi is the initial construction cost of Plan xi; RCxi,t is the reconstruction cost in year t of scheme xi; MCxi,t is the maintenance cost of scheme xi in year t; UCxi,t is the user expense in year t of scheme xi; SVxi,n is the residual value of scheme xi at the end of the analysis (n years); (P/F,i,t) is the present value coefficient of funds in year t, indicating the present value of one yuan at the end of t =(1+i0)-t; n is the analysis period (from the beginning of the investment to the end of the effective life); i0 is the discount rate.

4.3 Comprehensive evaluation

To evaluate the economic benefits of maintenance schemes, maintenance schemes with the same maintenance effect or type should be selected for comparison and analysis. For maintenance schemes with different highway lengths and number of lanes, to make the calculation results of the life-cycle cost of each scheme comparable, the input of maintenance cost should be converted into the maintenance cost per lane kilometer.

The present value A of the implementation conservation scheme and the present value B of the comparison scheme were calculated by the ratio of the present value A of the implementation conservation scheme to the present value B of the comparison scheme, and the change of economic benefits was used to evaluate the conservation scheme. With the smaller percentages, the maintenance cost of the implementation scheme was significantly lower than that of similar schemes in terms of new technology, new material, or new technology, and the economic improvement was more obvious with better benefits. The evaluation standards are shown in Table 8 below.

Table 8 Life Cycle Cost Analysis and Evaluation of Maintenance Scheme

Comparison	Scheme implementation scheme ratio (%)	The maximum	Evaluation standard	Evaluation grade	Comprehensive evaluation
B1	A/B1	C	＜ 60%	Optimal (8-10)	W_3
B2	A/B2		60~100%	Fine (7-5)	
…	…		＞ 100%	Poor (5-1)	

5. Social Environment Evaluation System

In this section, the life cycle evaluation method (LCA) is used to establish the evaluation system framework of the asphalt pavement construction period, define the research objectives and scope of the life cycle evaluation of the asphalt pavement construction period, and specifically divide it into three stages of material and chemical phase (including asphalt, aggregate, additives, asphalt mixture, etc.), and material transportation and construction. The boundary range of each stage in the construction period is divided, and the list of energy consumption and environmental emissions during the construction period of asphalt pavement is determined.

Evaluation contents and methods: The physical and chemical stage of materials includes the production process of pavement raw materials. The list of raw materials studied is as follows: cement production, road asphalt, modified asphalt and emulsified asphalt production, aggregate production and mining, used material recovery, and other processes; The transportation stage includes the transportation of raw materials to the mixing plant and the processing of materials in the mixing plant to the construction site, etc. The construction phase includes the processing, spreading, and rolling of asphalt pavement materials, as well as the heating and mixing of asphalt materials, as well as the energy consumption of mechanical equipment in the process of spreading and rolling of a mixture, as shown in Figure 1 and Figure 2 below.

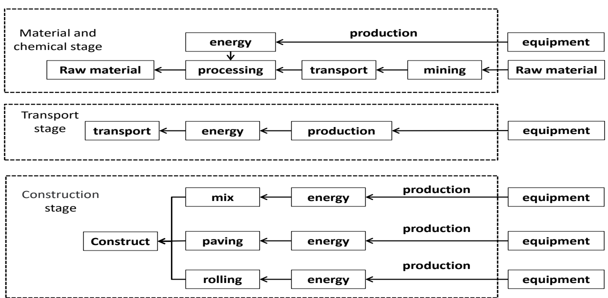

FIG. 1 Schematic diagram of social environment assessment method in construction Period

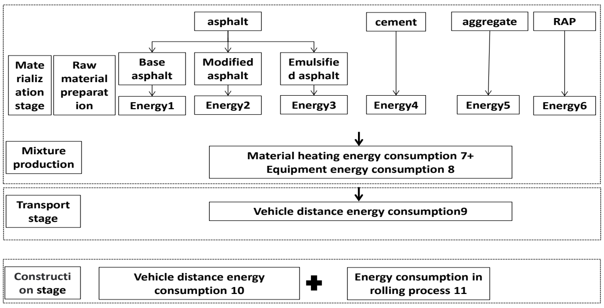

FIG. 2 Calculation flow chart

Scoring criteria: Due to the influence of paving thickness, ECI and EAI show inconsistency in some maintenance engineering technologies. Because the paving thickness of the upper layer is generally thinner than that of other parts, and the materials used are mostly different types of modified asphalt with higher energy consumption, the paving thickness will also change according to different engineering projects. The fact is that the energy consumption benefit is not as intuitive as the EAI index if the comparison is made by using the mix per unit mass, as shown in Table 9 below.

Table 9 Score criteria of social environment assessment

Evaluation classification	Index	Value range	Evaluation grade	Scoring standard
Upper layer	EAI	≤2.5	Optimal	10-8
		2.5-3.6	Fine	7-5
		≥3.6	Poor	4-0
Meso-lower layer	ECI	≤12	Optimal	10-8
		15-23	Fine	7-5
		≥25	Poor	4-0
Basic Layer		≤7	Optimal	10-8
		7-10	Fine	7-5
		≥10	Poor	4-0

6. The Sustainable Development Evaluation System

The sustainable development of highway construction projects emphasizes the sustainable development of the economy, environment, society, and technology of highway construction projects. Therefore, the establishment of a sustainable development evaluation system includes economic sustainable development evaluation, environmentally sustainable development evaluation, socially sustainable development evaluation, and technologically sustainable development evaluation, among which the economic sustainable development is mainly evaluated according to the pavement residual value index. The calculation formula is as follows:

$$SV = (\frac{L_E - L_A}{T_r})C_r \quad (3)$$

where SV is the cost of pavement salvage value; LE is the number of years from the year of last curing to the end of analysis; LA is the expected service life of the conservation measure; Cr is the cost of intermediate repair (major repair) measures; Tr is the design life of the medium repair (overhaul) measure.

According to the coordination between pavement maintenance and environmental resources, the evaluation of environmentally sustainable development mainly considers the utilization rate of resources and whether they are renewable resources. Through analysis and evaluation, the coordination degree of conservation engineering to environmental resources is divided into high, medium, and low levels according to the use of old resources. The evaluation of socially sustainable development mainly considered the continuous comfort and safety of the pavement after maintenance. The pavement running quality index RQI and the pavement anti-skid performance index SRI were used to record the service time when one of them reached 70 points (the lower limit of the middle grade), and the ratio between the service time and the service life of the maintenance measure was evaluated. The evaluation of the sustainable development of technology mainly considers the evaluation of the new materials, new processes, and new technologies applied in the maintenance, and analyzes its innovative and forward-looking application. The evaluation standards are shown in Table 10 below.

Table 10 Sustainable Development Indicators Rating Table

Index	Evaluation grade	Scoring standard	Scoring
Sustainable economic development	Optimal (sv＞0)	10-8	A
	Fine (sv=0)	7-5	
	Poor (sv＜0)	4-2	
Environmentally sustainable development	High (regeneration rate of more than 50%)	10-8	B
	Medium (regeneration rate up to 10%-50%)	7-5	
	Low (regeneration rate of less than 10%)	4-2	
Socially sustainable development	Medium(＞0.8)	10-8	C
	Middle(0.4~0.8)	7-5	
	Low(＜0.4)	4-2	
Technologically sustainable development	Novelty (with many applications)	10-8	D
	Relatively new (with application on one hand)	7-5	
	General (none applied	4-2	
Total value $w_5 = (a+b+c+d) / n$			
Comprehensive evaluation index	$W_5 \geq 8.5$	$8.5 > w_5 > 7$	$W_5 \leq 7$
Comprehensive evaluation	Optimal	Fine	Poor

7. Comprehensive Post-Evaluation System

A post-evaluation index system of utility model maintenance technology and process is established, with engineering technology evaluation, conservation management technology evaluation, economic benefit evaluation, social environment evaluation, and sustainable development comprehensive evaluation as the basic indexes. The evaluation results of each index are converted into corresponding scores, and the weight value of each index is distributed with the project objectives and benefits as the core. We conduct a comprehensive and systematic evaluation of the project.

The above evaluation scores are collected in Table 11. Considering the influence degree of each index on the maintenance project, the corresponding weight value is set and the comprehensive score W total is calculated. The comprehensive post-evaluation results of the maintenance project are determined according to the evaluation criteria.

Table 11 Scores and comprehensive evaluation of each indicator of the maintenance project

Index	**Engineering technology evaluation**	**Management technology evaluation**	**Economic benefit evaluation**	**Social environment evaluation**	**Sustainable development evaluation**
Score	W_1	W_2	W_3	W_4	W_5
Composite Score	$W_t = 0.5W_1 + 0.1W_2 + 0.3W_3 + 0.05W_4 + 0.05W_5$				
Evaluation Criteria	Optimal (＞8.5)		Fine (8.5~7)		Poor (＜7)
Comprehensive evaluation	Evaluation results				

8. Conclusion

(1) We put forward the index system of highway maintenance post-evaluation and its hierarchy, which includes five aspects: engineering technology evaluation, management technology evaluation, economic benefit evaluation, social environment evaluation, and sustainable development evaluation.

(2) The engineering technology is evaluated in stages, and the corresponding comprehensive evaluation formula is established according to the conservation classification, which can comprehensively analyze the quality and effect of the maintenance measures.

(3) The whole life cycle cost model was established to evaluate the economic benefits of conservation from the aspects of custodial department costs and user costs.

(4) Stage analysis of energy consumption and carbon emissions in the conservation process can effectively evaluate the impact of conservation measures on the social environment.

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