Analysis of Cost Benefit of Asphalt Pavement Maintenance and Reconstruction Project within the Whole Life Cycle

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Abstract: Based on problem of focusing on initial investment costs in current maintenance project, this paper made a comprehensive analysis of the cost in the life cycle of pavement maintenance program using LCCA and determined the components of LCCA and calculation model of each stage. Finally, an example was used to analysis and compare the economic impacts of different plan for road reconstruction schemes in the whole life-cycle. On the one hand, it was found that the application of LCCA was useful in engineering. On the other hand, it proved that rubber asphalt not only had outstanding performance, but also had good economic and environmental benefits. Through LCCA, the most economic and social benefits can be obtained, which will provide the necessary technical support for the upcoming large-scale maintenance projects.

1. Introduction

As one of the main way of modern transportation, the construction of highway reflects the overall development of economic and development level [1]. However, with the rapid increasing traffic volume and accumulation of load, the asphalt pavement is also under unprecedented pressure. The increasing diseases not only affect the service quality of the pavement and reduce the transportation efficiency, but also seriously affect the regional economic development. Therefore, it is necessary to solve the problem through maintenance and transformation methods to keep the service quality of pavement and efficiency of transportation.

The maintenance and construction have become the main content of current work. The cost of daily maintenance and repair of highway is not considered in the past, so it often occurs low initial construction cost and a high the final life-cycle cost, which caused an unreasonable scheme selection. Therefore, it is very important to analyze the life-cycle cost of highway project in the early stage. However, the determination of key factors is still a problem. This paper mainly referred to the existing achievements of the economic analysis and evaluation methods in China and pointed out a method for choosing the scheme by analyzing and comparing the economic impact of different highway reconstruction schemes in the whole life cycle of the project. As a result, the reasonable scheme could be chosen to obtain the maximum economic and social benefits.

As one efficient way of evaluating the benefits of different scheme, life-cycle cost analysis (LCCA) refers to the analysis of the total cost generated in the whole life cycle, including the cost of raw materials and products. The life-cycle cost of a construction project usually refers to the total cost incurred in the whole stage of the project including the stage of planning, construction, service and final abandonment[2]. LCCA is an effective tool for economic analysis of similar products because of its ultimate goal for maximizing the product benefit in the whole life cycle.

LCCA adopts the theory of comprehensive cost optimization in the comparison and selection of different schemes, instead of taking the scheme with the least initial investment, which can effectively optimize the whole life cycle investment benefit. Through LCCA analysis, the timing and proportion of cost demand in the life cycle can be effectively controlled, which has great help for reducing investment risk and maximizing benefit.

After AASHTO introduced it into pavement design firstly, it was widely used and became an important factor in the investment decision-making process of highway projects. According to the pavement construction procedure in China, the life-cycle can be divided into the following stages [3]: planning and design period, construction period, operation period and final abandonment period. The cost of planning, design and construction is generated around the project construction, which is called the cost of construction period. The cost generated by users and maintenance management in the operation process was called operational cost. At last, the residual value generated at the end of life is called abandonment cost.

Operation period cost is complex, according to the relevant researches[4], it includes the money spent on management and maintenance, the user cost of travel users, and the environmental cost caused by the impact on the environment. It was found that the user cost was composed of vehicle operation cost, traffic accident cost and time delay cost, which were mainly related to the pavement and external conditions, so it was difficult to calculate. In recent years, the environmental impact cost has gradually attracted great attention. However, as the uncertain related indicators and difficulty for quantifying cost value, this paper also did not take it into account.

To sum up, the main content of LCCA analysis in this paper included three parts: construction cost, operational cost and abandonment cost.

2. Calculation model of LCCA

2.1. Determination of functional units

Due to the different scale of pavement structures, the amount of materials and machinery using in construction is very different, resulting in a big difference in economic investment. In addition, the different service life of different pavement structures and different maintenance measures will have an impact on LCCA, so it is necessary to establish a standard of different pavement structures for comparison. The highways are mainly for six-lane two-way in China, so 1km of these highways for one direction was selected as a basic unit in this paper. At the same time, design service life (15 years) was adopted for LCCA to ensure the consistency and comparability between the evaluation results.

2.2. The method for LCCA

The method for LCCA was applied to pavement economic analysis in the 1970s, which was considered to be a more reasonable method [5]. According to the investigation of FHWA in 1997, there were 52 organizations using LCCA to determine the pavement type. This paper tried to use the method to decide the plan of pavement structure for highway reconstruction.

The method of LCCA was introduced in detail in AASHTO guide for the design of pavement structures in 2002. The analysis process mainly includes the following eight steps and the flow chart was shown in Figure 1.

(1) Formulating various pavement design schemes;
(2) Determining the service period and time limit for maintenance;
(3) Estimating management expenses;
(4) Estimating user costs;
(5) Drawing up expense flow chart;
(6) Calculating life-cycle cost;
(7) Analyzing results;
(8) Reevaluating the design schemes.

In the step 8, the pavement designer can determine the most economical design scheme for pavement.

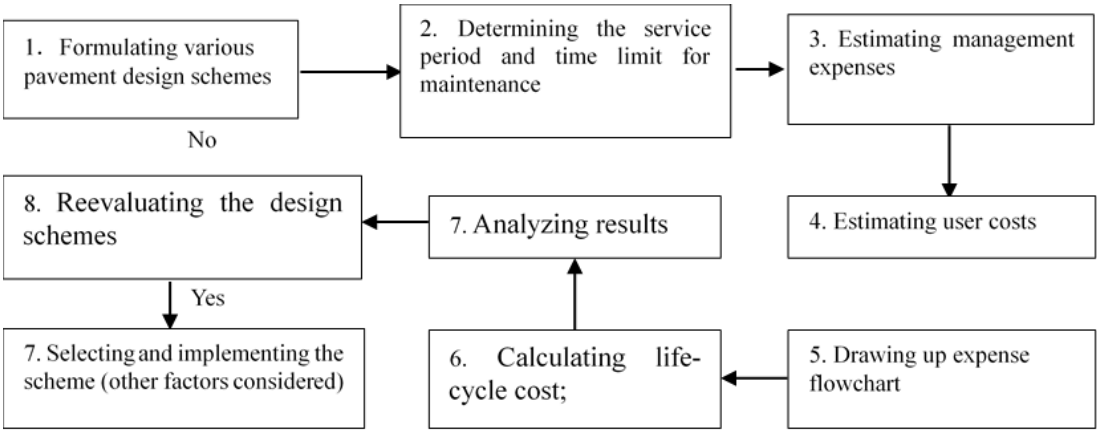

Figure 1. Analysis step of LCCA

The initial construction cost occurs at the early stage of the life-cycle of pavements and the maintenance cost occurs at the middle stage of the life-cycle, in addition, residual cost occurs at the last. The cost generated at different times cannot be simply added. It is a function of time and will increase in value with the passage of time. Therefore, in order to compare the total cost in life-cycle of each comparison scheme, the functional relationship between time and fund must be introduced to convert the cost generated at each time point into the cost incurred at the same time point.

Through the discount rate, the cost of different time expenditures in the analysis period was converted into present value [6]. The cost of each scheme could be compared by this method. In this paper, the net present value(NPV) method of cost was adopted and its expression was as follows:

$$PWC_{x_1,n} = IC_{x_1} + \sum_{i=0}^{n} pwf_{i,t}(RC_{x_1,t} + MC_{x_1,t} + UC_{x_1,t}) - pwf_{i,n} \bullet SV_{x_1,n} \quad (1)$$

where: $PWC_{x1,n}$ was the present value of the total cost of scheme X_1 within n years of the analysis period. IC_{x1} was the initial construction cost of scheme X_1, $RC_{x1,t}$, $MC_{x1,t}$. $UC_{x1,t}$ were reconstruction cost, maintenance cost and user cost of scheme X_1 (in t years) respectively. SV_{x1} was the residual value of scheme X_1 at the end of the analysis period (n years). $pwf_{i,t}$ was the present value coefficient of the discount rate in t year, which was calculated by $pwf_{i,t}=1/(1+i)^t$.

This paper mainly recommended a new method for the decision-making of highway management and reconstruction, so it only considered the cost of management and maintenance, not including the cost of fuel consumption, wheel cost and other user costs.

3. Case analysis

In recent years, rubber asphalt has been favored by engineers. It is not only unique in environmental protection, but also has excellent pavement performance. With the development of technology, it has been widely used. In order to quantitatively analyze the application prospect of rubber asphalt in maintenance and reconstruction, this paper analyzed the life-cycle cost of three mixtures of rubber asphalt AR-AC13, SMA-13 and AC-13[7-9].

3.1. The calculation of cost in construction period

In this paper, the life-cycle cost of SBS modified asphalt mixture AC-13, SBS modified asphalt SMA-13 and rubber asphalt mixture AR-AC13 were compared and analyzed. According to the project experience, the proposed pavement width was 11.5m, and the construction cost of three kinds of mixture pavement overlay schemes was determined based on the actual investigation, as shown in Table 1.

Table 1. The cost of different surface asphalt mixture

Scheme	Thickness（cm）	Unit cost（RMB/m^2）	Cost （RMB/m^3）
AR-AC13	4	70	805000
SMA-13	4	65	747500
AC-13	4	60	690000

3.2. The calculation of cost in service period

(1) Daily maintenance cost

Daily maintenance cost refers to the cost of preventive maintenance and repair of highway in daily use, which is one of the important daily expenses in the process of highway operation and management. According to the relevant literature research, the daily maintenance cost was mainly related to the pavement type, environmental conditions, traffic volume and other factors. This paper focused on the introduction of life-cycle cost analysis method and daily maintenance costs had less importance to it. Combined with the actual research, the annual daily maintenance cost was set as 10000 RMB/year per kilometer.

(2) The cost of heavy and intermediate maintenance

According to previous engineering experience, the service life of SBS modified AC-13 was calculated as 10 years while SMA pavement was assumed as 15 years. According to its excellent high temperature performance and low temperature crack resistance, rubber asphalt pavement was also estimated as 15 years. When considering the maintenance of heavy and intermediate maintenance, SBS modified asphalt AC-13 needed to be maintained 1 time in the 15 year, while SMA-13 and rubber asphalt pavement did not need the maintenance of heavy and intermediate maintenance in the life-cycle. The cost of heavy and intermediate maintenance calculated according to the new surface course, as shown in Table 2.

Table 2. The cost of heavy and intermediate maintenance in 2015

Scheme	Life（year）	Daily maintenance period (year)	Maintenance times	Costs (RMB)
AR-AC13	10	1~9,11~15	1	805000
SMA-13	15	1~15	0	0
AC-13	15	1~15	0	0

3.3. Residual value of abandonment period

The residual value in the abandonment period refers to the economic value of the pavement surface after losing the basic driving function. The residual value of pavement can be determined by the proportion of residual life to its expected service life. It means that the service life of a project exceeds its analysis period, and then the residual service value is estimated. The residual service life value is different, which should be considered in the LCCA process. The value of remaining service life of comparison scheme. The calculation formula is as follows:

$$SV = (1 - L_A/L_E)C_r \quad (2)$$

Where: LA is the number of years from the year of the last maintenance to the end of service life. LE is the expected service life of the maintenance measure. Cr is the construction cost of this maintenance measure. SV is the pavement residual value.

The residual values of several schemes were calculated by the formula and the results were shown in Table 3.

Table 3. Pavement residual value for different types (1 basic units)

Scheme	L_A（year）	L_E（year）	C_r（RMB）	SV（Ten thousand RMB）
AR-AC13	5	10	805000	40.25
SMA-13	15	15	747500	0
AC-13	15	15	690000	0

3.4. The analysis of life-cycle cost

When analyzing the life-cycle cost, the cost interest rate was taken as 8%. The result for the above three materials in the 15 year was calculated as shown in Table 4.

Table 4. The summary of total cost in life cycle (RMB)

Types	AC-13	SMA-13	AR-AC13
Initial construction cost	805000	747500	690000
Daily maintenance cost	251531	271521	271521
heavy and intermediate maintenance cost	805000	0	0
Residual value	-402500	0	0
Total amount	1459031	1019021	961521

The cost of the three schemes was ranked as AR-AC-13 < SMA-13 < AC-13, which showed that rubber asphalt AR-AC-13 had better economic benefits. At the same time, AR-AC-13 had excellent pavement performance and better service level. Therefore, rubber asphalt is the most economical and cost-effective.

4. Conclusion

From the perspective of LCCA, this paper analyzed the life-cycle cost of the pavement. The components of the life-cycle cost of the pavement reconstruction and expansion project were determined and the analysis model of each stage was established. The conclusions obtained were as following:

(1) LCCA could effectively control the timing and proportion of cost demand in the life-cycle, which had great economic value for reducing investment risk and maximizing benefit.

(2) By using NPV method to analyze the life-cycle cost of pavement, the cost of each time point could be converted into the cost of the same time point, which was convenient for managers to make investment decisions on the project in the stage of project approval.

(3) Rubber asphalt not only had lower initial construction cost than SMA-13and AC-13, but also has the highest cost performance ratio from the perspective of LCCA.

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