Abstract

Currently, the conception of Pavement Preventive Maintenance (PPM) has been accepted by more and more highway managers. The purpose of this study is to do a thorough and systematic research on the optimal strategy decision and Life-Cycle Cost Analysis (LCCA) of PPM during the whole life cycle of road. In the study, a certain section of Guangshao Freeway was taken as an example, and various data (pavement performance, traffic and climate conditions, economic indicators) were collected and integrated. Then by an in-depth analysis of the research data, “LCCA FOR PPM” was drew up using Visual Basic. Meanwhile, the PPM optimal strategy during a 20-year period was worked out. Finally, there was quantitative comparison of benefits among the optimal plan, traditional pattern and “do nothing” strategy (only with routine maintenance). Result confirms that PPM with optimal strategy shows huge superiority in both cost and benefit considering the whole life cycle of road.

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Keywords: Pavement preventive maintenance; Optimal strategy; Life-cycle cost analysis; Cost and benefit

1. Introduction

PPM is a new concept which differs from traditional idea—roads won’t be repaired until damaged. With the enhancing conservation concept, PPM is been increasingly used in our country, but the theoretical study on PPM is not comprehensive. At present, domestic and international researches on PPM can be divided into two major aspects. On the one hand are researches on PPM timing and measures independently, which can arrive at the optimal timing and measures of PPM (Wang Xiaofeng, 2011). However, some of these studies have not considered the entire life cycle of the road, and others are lack of examples argumentation, which make a poor practical application. On the other hand are reassreaches on the contribution of PPM for the entire life cycle of...
road only considering theoretical models (Su Weiguo, 2010), which are lack of data quantification and examples argumentation as well. Problems of the above two researches are precisely the focus of PPM research and application. In order to maximize the advantages of PPM, the following two points require special attentions: one is the determination of timing and measures of PPM application, which means the selection of optimal PPM strategy for LCCA; the other is the superiority of PPM relative to traditional pattern, namely the contribution of PPM to the life cycle of road. Based on the data of Guangshao Freeway, there is a thorough and systematic research on the above two points in this paper, and the application of PPM will become more and more targeted.

Data collection and collation of the pavement are the premises of PPM planning. On the basis of the analysis of existing data, appropriate theoretical models were selected and research methods were determined in order to develop an appropriate conservation planning. The content and process are shown in Figure 1. Pavement performance prediction model and method of LCCA were first been introduced; then relational analysis and calculations were carried on with the actual data of a certain section of Guangshao Freeway; finally the optimal strategy of PPM timing and measures in 20 years period was been worked out and its contribution to the entire life cycle was been discussed.

![Fig. 1. Process of PPM optimal strategy decision](image)

2. Theoretical Model and Method

2.1 Pavement performance prediction model

Pavement performance prediction model is an important theoretical basis for establishing a conservation plan. Pavement condition index (PCI), which index takes most of the damage types into account, such like crackings, pits and ruts, and it is easy to be detected as well. So PCI is selected to establish pavement performance prediction model in this paper.

According to the research of Tongji University (Sun Lijun, Liu Xiping, 1995), Formula (1) has excellent adaptability to the pavement performance prediction with very clear physical meanings as well. A variety of
decay processes can be simulated using different parameters. Explanations and implications of the parameters can be obtained from the reference.

\[
PCL = PCL_0 \{1 - \exp[-(A / y)^B]\}
\]  

(1)

2.2 Method of LCCA

LCCA is a method based on the principle of economic to evaluate the long-term economic benefit of the optional investment programs. Initial fees for construction, management fees in future, user fees and other costs associated with the period of analysis are considered in the comparison investment solutions. The purpose is to determine the best solution for investments, which means to get the program meeting the performance requirements with lowest long-term cost (Henry H. Rentz, 1998). LCCA used in pavement is considered to be an effective tool to select the most economical and reasonable combination of pavement structure thickness and overlay rebuilding plan.

2.3 Cost-benefit model

According to the concept of LCCA, conservation programs of the analysis period are series of PPM measures. Cost of PPM measures and users are both included and the total cost in 20 years is the sum of PPM measures’ cost taken each time and user fees. Benefit brought by each PPM is the area surrounded by the timeline adjacent to two conservations, the decay curve after conservation and the natural decay curve of pavement, which is shown as “A” in Figure 1, and the total benefit in 20 years period is the sum of benefit of PPM measures taken each time.

Benefit-Cost Ratio (BC) of each program can be determined by the ratio of total benefit and total cost introduced above. Among various conservation programs composed by different conservation measures randomly, program with the largest BC is chosen to be the optimal strategy. Calculation of BC is illustrated in Fig. 2.
3. Data Collection

The uplink section from K2096 +910 to K2125 +552 of Guangshao Freeway was opened to traffic in 2002 with the length of 28.642km. A large repair was taken in 2006, the upper and middle surface layer was milled and rebuilt in 2010. The basic structure of the section, the pavement conditions in 2012 and the traffic conditions are shown in Fig. 3. RQI means riding quality index and PSSI is pavement structure strength index. Data used to obtain the PPM optimal strategy by LCCA method are shown in Table 1.
Table 1. Data preparing for the optimal plan

<table>
<thead>
<tr>
<th>Section NO.</th>
<th>Length(km)</th>
<th>Current PCI</th>
<th>Equivalent thickness of surface layer(cm)</th>
<th>Traffic level</th>
<th>Original deflection(0.01mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28.642</td>
<td>96.412</td>
<td>16.028</td>
<td>Very heavy</td>
<td>10.4154</td>
</tr>
</tbody>
</table>

4. Optimal Strategy Decision of PPM

4.1 Combinations of timing and measures

The conditions of the section is good as can be seen from the previous part, so the timing when PCI down to 90, 85, and 80 can be chosen for alternative timing. Taking the local conditions into account, micro-surfacing, 2.5cm, 4cm and 6cm overlay can be selected as four alternative measures. Micro-surfacing is no longer suitable for pavement when PCI has dropped to 80, so the options available for PPM timing and measures combinations are shown in Table 2 (Yang Qiang, 2008). It should be noted that 2.5cm overlay is no more applicable for road with heavy or very heavy traffic according to the experts' experience. Therefore, eleven options of PPM timing and measures combinations from A to K are applicable for roads with light or middle traffic; while for roads with heavy or very heavy traffic, B, F and I are not suitable and the other eight combinations are alternative options.

Table 2. Combinations of PPM timing and measures

<table>
<thead>
<tr>
<th>NO.</th>
<th>Timing of PPM</th>
<th>Measures of PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>PCI=90</td>
<td>Micro-surfacing</td>
</tr>
<tr>
<td>B</td>
<td>PCI=90</td>
<td>Overlay of 2.5cm</td>
</tr>
<tr>
<td>C</td>
<td>PCI=90</td>
<td>Overlay of 4cm</td>
</tr>
<tr>
<td>D</td>
<td>PCI=90</td>
<td>Overlay of 6cm</td>
</tr>
<tr>
<td>E</td>
<td>PCI=85</td>
<td>Micro-surfacing</td>
</tr>
<tr>
<td>F</td>
<td>PCI=85</td>
<td>Overlay of 2.5cm</td>
</tr>
<tr>
<td>G</td>
<td>PCI=85</td>
<td>Overlay of 4cm</td>
</tr>
<tr>
<td>H</td>
<td>PCI=85</td>
<td>Overlay of 6cm</td>
</tr>
<tr>
<td>I</td>
<td>PCI=80</td>
<td>Overlay of 2.5cm</td>
</tr>
<tr>
<td>J</td>
<td>PCI=80</td>
<td>Overlay of 4cm</td>
</tr>
<tr>
<td>K</td>
<td>PCI=80</td>
<td>Overlay of 6cm</td>
</tr>
</tbody>
</table>

4.2 Optimization result of Visual Basic program

According to the cost-benefit model with the method of LCCA, “LCCA FOR PPM” was been drawed up to calculate the PPM optimal strategy in 20 years analysis period using Visual Basic. A program is formed by random combinations of the alternative PPM timing and measures given in Table 2 in 20 years analysis period. Optimal strategy with largest cost-benefit can be found by comparing each program's cost-benefit. The main interface of the program is shown in Fig. 4.
5. Contribution of PPM to LCCA

Fig. 5 shows the benefit constraint among the “only with routine maintenance strategy” (first strategy), “won’t be repaired until damaged strategy” (second strategy) and “LCCA for PPM strategy” (third strategy) during the entire analysis period. It is assumed that large repair is needed when PCI drops to 70 and it returns to 98 after being repaired. Fig. 5 displays that according to the first strategy, PCI of the section will drop to 70 or less in about 2019, which means the pavement is under unacceptable condition, and if nothing is done at that time, PCI will drop to 37 at the end of the analysis period in 2032. If the second strategy is been applied, about twice major repairs should be taken in 2018 and 2025 during the analysis period. For the third strategy, PPM measures need to be implemented four times during the analysis period, respectively in 2015, 2020, 2024 and 2026.

In order to analyze the cost-benefit of PPM optimal strategy completely, two angles should be required. Firstly, from the point of cost, four times cost of PPM measures is still clearly much less than twice cost of major repairs or even maybe reconstructions. Secondly, from the point of benefit, the second strategy results in the PCI will lower than 80 for more than half of 20 years analysis period, which means the service level of the road is not very good, and the pavement performance level fluctuates widely throughout the whole analysis period. In comparison, the third strategy results in the PCI maintains above 80 in the entire analysis period, which means the service level of the road is very good, and the pavement performance level is also very stable throughout the analysis period. Therefore, from both points of cost and benefit, the use of LCCA method for selecting PPM optimal strategy is of good cost-benefit for the long-term performance of pavement.
6. Conclusion

On the basis of what appear in the present paper, following conclusions have been drawn.
1 Cost-benefit model based on LCCA is summarized in order to get the PPM optimal strategy.
2 “LCCA FOR PPM” is been drawed up to calculate the PPM optimal strategy in 20 years analysis period using Visual Basic.
3 A cost- benefit analysis of PPM optimal strategy considering LCCA is been done by the example of Guangshao Freeway, which shows the superiority of it for the long-term performance of pavement.

References