Developing a Five-Year Maintenance and Rehabilitation (M&R) Plan for HMA and Concrete Pavement Networks

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Abstract

In the face of increased demand and exposure to environmental effects, the condition of road pavements continues to decline while resources for their preservation remain limited. Thus, the task of managing pavements has to be done systematically and objectively. This paper outlines the steps involved in developing a multi-year pavement Maintenance and Rehabilitation (M&R) plan. These include: (1) condition assessment; (2) network inventory and database development; (3) identification of pavement sections requiring M&R; (3) needs analysis; and (4) impact analysis. As a case study, the project was performed on the road network inside the Texas A&M University campus that consists of 13.95 miles of roadway, 80\% and 20\% of which are concrete and HMA pavements respectively. Condition assessment was done according to ASTM D 6433-07 and using the Pavement Condition Index (PCI) as indicator of pavement performance. Data collected were then entered into a database which also contains information on traffic and roadway characteristics. PCI threshold values were established to identify sections that are in need of M&R and the most cost-effective treatment based on long-term performance benefit and life-cycle cost was proposed for each project. Candidate projects were then prioritized by ranking based on benefit-cost analysis. The needs estimate provides meaningful information on the total amount of budget required to correct all deficiencies in the network. Finally, the impact analysis is used to determine the impact of a reduced budget on network condition as well as the amount of backlog that needs to be addressed.

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1. Introduction

A multi-year Maintenance and Rehabilitation (M&R) plan is one essential component of a Pavement Management System (PMS). At the network level, the system contains five general components: inventory of the network, condition assessment, needs analysis, project prioritization, and impact analysis [1]. Each of these components generates certain useful outputs. These include a database of pavement assets, an estimate of the network’s condition in terms of a standard index, annual budgetary needs, project priority list, and “what-if” analysis. All these components were performed in this paper as a 5-year M&R plan for roadway pavements at the Texas A&M University (TAMU) campus was developed. The network consists of 13.95 miles of roadway, 20% of which are asphalt pavements while the remaining 80% are concrete.

2. Data collection and PCI prediction model

The campus road network was divided into data collection zones that were then subdivided into sections. Each section was further divided into sample units as per ASTM D 6433-07 [2] on which field surveys will be conducted. The Pavement Condition Index (PCI) method of quantifying pavement condition was adopted for this study. It was developed by the U.S. Army Corps of Engineers and is a widely used standard by agencies worldwide. The PCI is an index with values ranging from 0 (failed pavement) to 100 (perfect condition) [1]. Field measurements and results of the PCI calculations were entered into a network database that contain information on the sections’ length, width, surface type, estimated age, Annual Average Daily Traffic (AADT), and PCI.

Pavement deterioration was assumed to follow the shape of a sigmoidal curve [3] defined by (1) and (2) shown below where PCI$_i$ is the PCI in the $i^{th}$ year; PCI$_0$ is the PCI immediately after treatment; Age$_i$ is pavement age in the $i^{th}$ year; and $\rho$ and $\beta$ are shape parameters. Table 1 lists the values of the shape parameters for four M&R treatment types: Preventive Maintenance (PM), Light Rehabilitation (LR), Medium Rehabilitation (MR), and Heavy Rehabilitation (HR).

$$PCI_i = PCI_0$$  \hspace{1cm} \text{when Age}_i=0 \hspace{1cm} (1)$$

$$PCI_i = PCI_0 - PCI_0 \exp \left[ - \left( \frac{\rho}{\text{Age}_i} \right)^\beta \right]$$ \hspace{1cm} \text{when Age}_i>0 \hspace{1cm} (2)$$

<table>
<thead>
<tr>
<th>Treatment</th>
<th>PCI$_0$</th>
<th>$\beta$</th>
<th>$\rho$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA HR</td>
<td>100</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>HMA MR</td>
<td>100</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>HMA LR</td>
<td>PCI$_{existing} + 20$</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>HMA PM</td>
<td>PCI$_{existing} + 10$</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>PCC HR</td>
<td>100</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>PCC MR</td>
<td>100</td>
<td>5</td>
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<td>PCC PM</td>
<td>PCI$_{existing} + 10$</td>
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The models were used for three main purposes: determination of treatment life, estimation of the benefits, and calculation of the costs of each treatment. Treatment life is defined as the number of years from the application of the treatment to the year when the PCI is projected to drop below the threshold. On the other hand, the benefit of applying a specific M&R treatment is estimated by the Area Under the Performance Curve (AUPC) [4]-[6] over the analysis period of 35 years. The calculated treatment life was also used to compute the Net Present Value (NPV) of applying an M&R treatment. The AUPC and the NPV of each treatment alternative represent the treatments’ long-term benefit and life-cycle cost respectively.
3. Development of the 5-year M&R plan

Roads were first classified into major and minor roads so that different threshold values may be assigned to them. The PCI threshold values for major and minor roads were taken as 70 and 55 respectively. These represent the boundary PCI values between “satisfactory” and “fair” and “fair” and “poor” respectively as per ASTM D 6433-07 [2].

An M&R treatment is considered viable if it could raise the PCI to 5 points more than the threshold (ie. 75 for major and 60 for minor). The rationale for this was to ensure that a recently treated section would not immediately require another treatment in the next few years. Once the viable M&R treatments have been identified, the first three least expensive treatments were considered for Benefit/Cost (B/C) analysis for major roads while only the first two inexpensive treatments were considered for B/C analysis for minor roads. This allows consideration of more alternatives, even more expensive ones, for major roads while limiting the number of alternatives to the two least expensive ones for minor roads. A discount rate of 4% and an analysis period of 35 years were assumed for B/C calculations [7], [8]. A traffic growth rate of 3% was also assumed.

![Decision Tree Diagram](image)

Fig. 1. (a) viable M&R alternatives and selection of best treatment; (b) complete decision tree with the best M&R treatments

The next step was to identify which among the viable treatments is the best for a particular section. In this step, the B/C ratio of each treatment option was calculated. Fig. 1 (a) shows a portion of the decision tree used. For example, if the section is a major road, has a PCC surface, and has a PCI of 70, the viable alternatives are PM, LR, and MR. In this case, PM has the highest B/C ratio (6.80). Similarly, if the PCI is 65, PM would still be the best treatment with a B/C ratio of 3.63. Thus, for any major PCC section having a PCI between 70 and 65, the treatment to be applied is PM. This process was done for all possible cases and the final decision tree with the best treatments is shown in Fig. 1 (b).

After identifying the best treatment for each section that needed M&R, the next step was to prioritize these sections according to their B/C ratio. Since at this step, sections were compared against sections, the AUPC as a measure of benefit was converted into Vehicle-Miles Travelled on Adequate Roads (VMT-A) to account for traffic and project size in calculating benefit [9], [10].

4. Results and discussion

The procedures for treatment selection (project-level) and project prioritization (network-level) described above were repeated for the next 5 years to create a 5-year M&R plan. With 100% of the needed budget available, all sections received the M&R treatment that they need. Fig. 2 (a) shows the funding requirement for the next five years.

For the limited budget scenario, only 90% of the budget needed in Fig. 2 (a) was considered available. Under this constraint, it is possible that some sections that require M&R may not be treated. Thus, projects
were prioritized to determine which ones receive treatment first. Treatments were applied to sections according to priority until the available budget was exhausted. Sections that were not funded for M&R were then made to compete again for priority in the following year.

Fig. 2. (a) needs estimate; (b) average network PCI as affected by funding availability

Fig. 3. (a) network condition under no budget deficit; (b) network condition under 10% budget deficit

Fig. 4. Backlog under 10 percent budget deficit

In order to assess the effect of a reduced budget, impact analysis was performed. Fig. 2 (b) compares the average network PCI for the No Budget Deficit and Limited Budget scenarios. Fig. 3 (a) and (b) also show the network condition for both scenarios. It could be seen that for both scenarios, the percentage of the network in good condition is increasing, even for the limited funding scenario albeit at a slower rate. However, for the No
Budget Deficit scenario, it could be seen that the percent of network in poor condition is decreasing while for the limited funding scenario, the percent of network in poor condition is hovering steadily around 20%. It could be said from these figures that one must look at these graphs with caution, especially when looking at Fig. 3 (a) and (b) for these may give the impression that a reduced funding does not cause a dramatic decline in pavement condition. A more prudent approach is to look at the graph of percent of network in poor condition since this would underscore the negative effects of reduced funding. This detrimental effect is also highlighted in Fig. 4. It could be seen that the backlog will continue to grow when funds are limited. That is, the longer the funds are held back, the harder it will be to meet the required funding in the future.

5. Summary and conclusion

A five year maintenance and rehabilitation plan was developed for the Texas A&M University campus’ road network. A pavement condition index survey was performed and the data gathered were used to develop an inventory and PCI database for the University’s road network system. PCI deterioration models were utilized to forecast future pavement performance to develop a multi-year M&R plan. A decision tree was developed based on benefit-cost analysis of viable M&R alternatives and the prioritization of projects was performed by ranking the projects in a decreasing order of their B/C ratios. Impact analysis has shown that a reduction of 10% from the required budget may yield an increase in the portion of the network that is in poor condition even though the portion in good condition is relatively unchanged. This suggests that using the percent of network in good condition to assess the consequence of a reduced budget may potentially obscure the true negative impact of a budget cut. Instead, the portion in poor condition as well as the growing backlog of deferred projects must be the ones used to correctly assess the negative impact of reduced funding on network condition.

References