A Stochastic Approach for Pavement Condition Projections and Budget Needs for the MTC Pavement Management System

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Acknowledgment

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Presentation Outline

1. Introduction
2. Overview of the MTC-PMS (StreetSaver)
3. Research Problem
4. Methodology
5. Example
6. Conclusions
Introduction

• Pavement Management Systems (PMS) is a set of tools to assist decision-makers in finding optimum strategies to maintain pavements in serviceable condition over time

• PMS provides means to organize road network massive amount of data

• Provides information needed to justify maintenance and rehabilitation programs.
PMS Prediction Models

Every PMS has a prediction model to forecast the deterioration of the pavement network.

Prediction models are useful at network level to answer questions like what, where, and when with respect to maintenance and rehabilitation actions.
Deterministic vs Probabilistic Models

Deterministic models do not consider the variability in the parameters used.
A probabilistic approach is needed to address the variability in the performance predictions.
The Metropolitan Transportation Commission (MTC)

In 1981 the Metropolitan Transportation Commission in the San Francisco California Bay Area developed a pavement management system used in the nine counties agencies which evolved to StreetSaver.

StreetSaver uses a prediction model based on Pavement Condition Index (PCI)
The MTC-PMS prediction model is deterministic and based on an S shaped curve that represents the deterioration behavior of the pavement over time.
\[ PCI_{PRD} = 100 - \frac{\chi\rho}{1} - \frac{\alpha}{(\ln\left(\frac{\alpha}{AGE - SHIFT}\right))^\beta} \]

**Family Curves**

**Surface Type**

- Arterial AC
- Collector AC
- Residential/Other AC

**Functional Class**
Treatment Selection

MTC’s prediction model connects the projected condition of the pavement management sections to the maintenance and rehabilitation treatments by means of a decision tree.
<table>
<thead>
<tr>
<th>PCI</th>
<th>CONDITION CATEGORY</th>
<th>DECISION TREE</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Category I Very Good Condition</td>
<td>Preventive Maintenance</td>
</tr>
<tr>
<td>70</td>
<td>Category II Good Condition (Non-load related)</td>
<td>Seal Cracks and Surface Seals</td>
</tr>
<tr>
<td>50</td>
<td>Category III Good condition (Load related)</td>
<td>II Seal Coat</td>
</tr>
<tr>
<td>25</td>
<td>Category IV Poor Condition</td>
<td>III Thin Overlay</td>
</tr>
<tr>
<td>0</td>
<td>Category V Poorest Condition</td>
<td>IV Thick Overlay</td>
</tr>
<tr>
<td></td>
<td>[Preventive Maintenance]</td>
<td>V Reconstruct</td>
</tr>
</tbody>
</table>

**Preventive Maintenance:**
- Sealing cracks
- Surface seals

**Rehabilitation:**
- II Seal Coat
- III Thin Overlay
- IV Thick Overlay
- V Reconstruct
Needs and Scenarios Analysis

**Needs Analysis** is based on PCI projections is used to identify the sections needing work, the treatments to apply, and the funding needs.

**Target Driven Scenario Analysis** establishes the sections to be treated and the budget needed to maintain the network in a desired condition level over the planning horizon.

**Budget Scenario Analysis** identifies the sections and treatments to be applied according to the available budget over the analysis period.
The Research Problem

The problem to be addressed is how to determine the reliability of PCI predicted values and budget needs introducing probability distributions and confidence intervals.
Lower and Upper Limits for Outliers

- Projected PCI
- Upper Limit
- Lower Limit
- Age 1
- Age 2
- Age 3
- Age 4
- Age 5
- Age 6
- Age 7
- Age 8
- Age 9
- Age 10
- Age 11
- Age 12
- Age 13
- Age 14
- Age 15
- Age 16
- Age 17
- Age 18
- Age 19
- Age 20
- Age 21
- Age 22
- Age 23
- Age 24
- Age 25
- Age 26
- Age 27
- Age 28
- Age 29
- Age 30
Methodology

1. Establish 95% confidence bounds for predicted PCI values
2. Develop a projection curve beneath the confidence bounds
3. Fit probability distributions for each year of age of the pavement
Methodology

4. Use probability distributions for each year to determine the probability of a PCI projected value

5. Define probability matrix for PCI ranges to apply treatments in the decision tree

6. Assign treatment according to PCI probability for analysis year
START

Calculate PCI from inspection

Assign Treatment for first analysis year

Calculate PCI value after treatment

Project PCI with no treatment through analysis period

Calculate probability for PCI value

Assign Treatment according to probability for analysis year

Increment by one year

All Years analyzed?

YES

END

NO

If PCI >= 70

YES

90 ≤ PCI ≤ 100 Do Nothing
85 ≤ PCI < 90 Crack Seal
80 ≤ PCI < 85 Seal Coat
70 ≤ PCI < 80 Mill and Thick Overlay

NO

60 ≤ PCI < 70 RH2 Thin AC Overlay
50 ≤ PCI ≤ 60 RH3 Thick AC Overlay
25 ≤ PCI < 50 RH4 Thick AC Overlay
PCI < 25 RH5 Reconstruction

NO

All sections analyzed?

YES

NO
Example

Using StreetSaver databases from the cities of Belmont, San Carlos, Milpitas, San Ramon, San Anselmo, and Santa Rosa, California, inspection information were collected from 1,500 Arterial streets paved with asphalt concrete.
Example

With the inspection date and the construction date, the age of the pavement was calculated for each inspection, and was linked to the PCI value.
The data was sorted from 0 to 30 years of age and separated in yearly bins
The proposed new values are: \( \alpha = 100, \beta = 0.633, \) and \( \rho = 98; \) with these values a set of projected PCI values for 20 years were defined using the projected PCI equation.
Example

StreetSaver’s decision tree has trigger PCI values to choose management sections for treatment and to establish the treatments to apply. For preventive maintenance the PCI value has to be between 70 and 100.
The proposed ranges are:

<table>
<thead>
<tr>
<th>PCI Value</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>From 90 to 100</td>
<td>Do Nothing</td>
</tr>
<tr>
<td>From 85 to 89</td>
<td>Crack Seal</td>
</tr>
<tr>
<td>From 80 to 84</td>
<td>Seal Coat</td>
</tr>
<tr>
<td>From 70 to 79</td>
<td>RH1 Mill and Thick Overlay</td>
</tr>
</tbody>
</table>
Example

To apply a rehabilitation treatment the PCI value has to be from 0 to 69

<table>
<thead>
<tr>
<th>PCI Value</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>From 60 to 69</td>
<td>RH2 Single Chip Seal</td>
</tr>
<tr>
<td>From 50 to 59</td>
<td>RH3 Thin AC Overlay 1.5 in.</td>
</tr>
<tr>
<td>From 25 to 49</td>
<td>RH4 Thick AC Overlay 2.5 in.</td>
</tr>
<tr>
<td>From 0 to 24</td>
<td>RH5 Reconstruction</td>
</tr>
</tbody>
</table>
Deterministic Analysis

An analysis was performed using a single management section for a period of 6 years with the actual $\alpha$, $\beta$, and $\rho$ parameters, and compared to the results of the analysis of the same section using the new parameters.
## Analysis Results

<table>
<thead>
<tr>
<th></th>
<th>Standard Parameters</th>
<th>Calculated Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PCI After Treatment</td>
<td>Treatment Cost</td>
</tr>
<tr>
<td>Year 1</td>
<td>94.5</td>
<td>3288.9</td>
</tr>
<tr>
<td>Year 2</td>
<td>90.85</td>
<td>0</td>
</tr>
<tr>
<td>Year 3</td>
<td>89.1</td>
<td>24.6</td>
</tr>
<tr>
<td>Year 4</td>
<td>86.72</td>
<td>0</td>
</tr>
<tr>
<td>Year 5</td>
<td>85.76</td>
<td>36.3</td>
</tr>
<tr>
<td>Year 6</td>
<td>90.56</td>
<td>3812.7</td>
</tr>
<tr>
<td>Average</td>
<td>89.58</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>7162.5</td>
</tr>
</tbody>
</table>
Stochastic Analysis

Probability distributions were found for the data arranged in bins from 1 to 6 years of age, and the normal distribution was among the top 5 ranks, so to have uniformity, the normal distribution was chosen for all ages.
## Model Statistical Parameters

<table>
<thead>
<tr>
<th>AGE</th>
<th>MEAN</th>
<th>STANDARD DEVIATION</th>
<th>VARIANCE</th>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Year</td>
<td>92.6667</td>
<td>3.0551</td>
<td>9.333</td>
<td>90</td>
<td>96</td>
</tr>
<tr>
<td>2 Years</td>
<td>90.825</td>
<td>3.5001</td>
<td>12.251</td>
<td>81</td>
<td>95</td>
</tr>
<tr>
<td>3 Years</td>
<td>89.1154</td>
<td>5.1172</td>
<td>26.186</td>
<td>81</td>
<td>98</td>
</tr>
<tr>
<td>4 Years</td>
<td>87.4545</td>
<td>4.5222</td>
<td>20.45</td>
<td>76</td>
<td>93</td>
</tr>
<tr>
<td>5 Years</td>
<td>82.8438</td>
<td>6.3759</td>
<td>40.652</td>
<td>73</td>
<td>92</td>
</tr>
<tr>
<td>6 Years</td>
<td>83.1875</td>
<td>5.4444</td>
<td>29.641</td>
<td>70</td>
<td>93</td>
</tr>
</tbody>
</table>
Stochastic Analysis

Probabilities were calculated for the treatment PCI ranges to construct the PCI ranges probability matrix finding the probability of each value as:

\[ P(\text{PCI} \leq a) = P(Z \leq (a-\mu)/\sigma) = \Phi((a-\mu)/\sigma) \]
## PCI Ranges Probability Matrix

<table>
<thead>
<tr>
<th>Year</th>
<th>PCI&lt;100</th>
<th>PCI&lt;90</th>
<th>PCI&lt;85</th>
<th>PCI&lt;80</th>
<th>PCI&lt;70</th>
<th>PCI&lt;60</th>
<th>PCI&lt;50</th>
<th>PCI&lt;25</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.99181</td>
<td>0.19134</td>
<td>0.00604</td>
<td>0.00002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.99562</td>
<td>0.40683</td>
<td>0.04803</td>
<td>0.00099</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.9833</td>
<td>0.56865</td>
<td>0.21065</td>
<td>0.03744</td>
<td>0.00009</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0.99723</td>
<td>0.71321</td>
<td>0.29361</td>
<td>0.04962</td>
<td>0.00006</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0.99644</td>
<td>0.86914</td>
<td>0.63237</td>
<td>0.32778</td>
<td>0.02198</td>
<td>0.00017</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0.99899</td>
<td>0.89457</td>
<td>0.63036</td>
<td>0.27909</td>
<td>0.00771</td>
<td>0.00001</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Stochastic Analysis

An analysis was run for six years using 10 management sections with different inspection PCI’s.

Results from the deterministic method were compared to the new stochastic approach.
## Stochastic Analysis

<table>
<thead>
<tr>
<th>Inspected PCI</th>
<th>Category</th>
<th>Average PCI After Treatment</th>
<th>Treatment Cost</th>
<th>StreetSaver</th>
<th>Stochastic Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>I</td>
<td>90.67</td>
<td>7159.1</td>
<td>90.67</td>
<td>89.36</td>
</tr>
<tr>
<td>89</td>
<td>I</td>
<td>89.58</td>
<td>7162.5</td>
<td>89.58</td>
<td>88.52</td>
</tr>
<tr>
<td>86</td>
<td>I</td>
<td>88.41</td>
<td>7168.1</td>
<td>88.41</td>
<td>88.61</td>
</tr>
<tr>
<td>81</td>
<td>I</td>
<td>87.79</td>
<td>7166.6</td>
<td>87.79</td>
<td>86.14</td>
</tr>
<tr>
<td>75</td>
<td>I</td>
<td>82.56</td>
<td>7200.4</td>
<td>82.56</td>
<td>87.39</td>
</tr>
<tr>
<td>68</td>
<td>II</td>
<td>76.2</td>
<td>7572</td>
<td>76.2</td>
<td>89.35</td>
</tr>
<tr>
<td>68</td>
<td>III</td>
<td>90.99</td>
<td>12638.3</td>
<td>90.99</td>
<td>92.19</td>
</tr>
<tr>
<td>52</td>
<td>II</td>
<td>84.37</td>
<td>24583</td>
<td>84.37</td>
<td>86.27</td>
</tr>
<tr>
<td>52</td>
<td>III</td>
<td>84.37</td>
<td>24583</td>
<td>84.37</td>
<td>86.27</td>
</tr>
<tr>
<td>45</td>
<td>IV</td>
<td>90.99</td>
<td>26327.1</td>
<td>90.99</td>
<td>92.19</td>
</tr>
<tr>
<td>30</td>
<td>IV</td>
<td>70.79</td>
<td>57678.2</td>
<td>70.79</td>
<td>82.6</td>
</tr>
<tr>
<td>23</td>
<td>V</td>
<td>91.02</td>
<td>58214.6</td>
<td>91.02</td>
<td>91.12</td>
</tr>
</tbody>
</table>
Conclusions

The pavement sections are in better condition than the projected PCI with the current deterministic approach.

With the recalibrated PCI parameters, the projected pavement condition is closer to reality.
Conclusions

With the stochastic model, the decision makers at the agencies will know better the confidence level of the projected PCI, and the budget needs.

In this particular example the PCI is more realistic and the budget is lower.

The stochastic model is recommended to improve StretSaver’s functionality.