THE USE OF MEASURED PAVEMENT PERFORMANCE INDICATORS AND TRAFFIC IN DETERMINING OPTIMUM MAINTENANCE ACTIONS FOR A TOLL ROAD IN SOUTH AFRICA

AND COMPARISON WITH HDM-4 PERFORMANCE PREDICTIONS

Surita Madsen-Leibold
• Introduction
  - Project location and nature of the study

• Road pavement
  - Structure
  - Maintenance actions

• Data collection and monitoring
  - Climate; traffic; pavement performance
Pavement performance modelling

Comparison of predicted with actual performance
INTRODUCTION
Introduction

• Significance and nature of the study
  ▪ First BOT contract in SA
  ▪ Extensive data collected on traffic and pavement performance over last 17 years
  ▪ Data used to determine optimal maintenance actions
  ▪ Data used to compare actual to HDM-4 predicted pavement performance
Project Layout

- N1 Section 26
- N1 Section 25
- N1 Section 24
- N1 Section 23
- Middelfontein
- Bela Bela
- Polokwane

End of Contract: km 25.6
Start of Contract: km 42.6

Google Earth
ROAD PAVEMENT
### Section 1 (Old)

**Initial Construction (1988):**
- 150 G1 (1988)
- 150 C3 (1988)
- 150 C4 (1988)

**Maintenance Interventions:**
1. **1997:** Repair and 13.2 mm reseal with SBR modified binder
2. **2003:** 2.5% surface repairs and 15% 6.7 mm reseal with SBS binder in the slow lane
3. **2008:** 6.7/13.2 mm inverted reseal (full width and shoulders)

### Section 2 (New)

**Initial Construction (1997):**
- 35 AC (1997)
- 125 G1 (1997)
- 125 C3 (1997)
- 150 C3 (1997)
- 150 G7 (1997)
- 150 G7 (1997)

**Maintenance Interventions:**
4. **2008:** 13.2 mm reseal (full width and shoulders)

* Schematic only
DATA COLLECTION AND MONITORING
Climate

[Graph showing temperature trends for Mokopane and Polokwane from January to December.]

- Mokopane Max
- Mokopane Min
- Polokwane Max
- Polokwane Min
Traffic

• Data collection
  - Two High-Speed Weigh-In-Motion (HSWIM) stations along route: Kranskop (Section 1) and Pietersburg (Section 2)
  - Period 1997 to date

• Parameters determined/obtained
  - Vehicles classified in toll classes 1, 2, 3 and 4
  - Average daily traffic (ADT) determined for four classes
  - E80/HV determined for trucks (classes 2, 3, 4)
Traffic

- **Toll Classes**
  - Class 1 (Light vehicles): motor vehicles, with or without a trailer, including motorcycles
  - Class 2 (Medium heavy vehicles): heavy vehicles with two axles.
  - Class 3 (Large heavy vehicles): heavy vehicles with three or four axles.
  - Class 4 (Extra large heavy vehicles): heavy vehicles with five or more axles
Traffic

CTO Kranskop (Bela-Bela)

CTO Constantia (Pietersburg)

Average annual daily traffic

Year

0 2000 2005 2010 2015


ADT  ADTT  ADLT

ADT  ADTT  ADLT
Pavement performance monitoring

• Data collection
  - Annual visual assessments (THM9) degree and extent 200m long segments
  - Regular instrument measurements in slow lane WTs: Profilometer (IRI, Rutting,); FWD defects
<table>
<thead>
<tr>
<th>Applicable Specification</th>
<th>Parameter</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional condition (during operation)</td>
<td>Road roughness (International Roughness Index – IRI in m/km)</td>
<td>&lt; 2.9 over 90 % of 5km sections&lt;br&gt; &lt; 3.6 over 95 % of 5km sections&lt;br&gt; 4.6 maximum</td>
</tr>
<tr>
<td></td>
<td>Skid resistance (Sideway-force coefficient)</td>
<td>&gt; 0.4 over 90 % of 1km sections&lt;br&gt; 0.35 minimum</td>
</tr>
<tr>
<td></td>
<td>Rut Depths (mm)</td>
<td>&lt; 15 over 90 % of 1km sections&lt;br&gt; 25 maximum</td>
</tr>
<tr>
<td></td>
<td>Structural failures (length of patches, potholes etc)</td>
<td>&lt; 50m per 1km sections</td>
</tr>
<tr>
<td>Structural condition (at end of contract)</td>
<td>Deflection at end of contract</td>
<td>Do &lt; 370 µm (90th percentile per uniform section)&lt;br&gt;BLI &lt; 180 µm (90th percentile per uniform section)&lt;br&gt;ROC &gt; 120 µm (90th percentile per uniform section)</td>
</tr>
<tr>
<td></td>
<td>Visual condition per uniform section at end of contract</td>
<td>VCI &gt; 50 per 1 km segment&lt;br&gt; Maximum annual change in VCI is 25%&lt;br&gt;Degree&lt;br&gt;Crocodile cracking ≤ 3&lt;br&gt;Longitudinal cracking ≤ 3&lt;br&gt;Pumping All&lt;br&gt;Patching ≤ 3&lt;br&gt;Extent*&lt;br&gt;Crocodile cracking ≤ 5&lt;br&gt;Longitudinal cracking ≤ 10&lt;br&gt;Pumping ≤ 5&lt;br&gt;Patching ≤ 5&lt;br&gt;* % of length</td>
</tr>
</tbody>
</table>
Pavement performance monitoring

• **Optimization of maintenance actions**
  - Continuous condition monitoring data was used to predict future pavement condition and to time maintenance actions to ensure conformance to the contractual condition criteria
PAVEMENT PERFORMANCE MODELLING
Pavement performance modelling

- **Modelling the road**
  - Software used: HDM-4 Version 2
  - Two uniform sections: Sections 1 and 2 based on difference in pavement, traffic, maintenance actions
  - Period: 1997 to 2014
  - Road modelled as four lane carriageway; 17.8 m wide

- **Primary variables in HDM-4 deterioration models**
  - Pavement structure, type and age
  - Traffic loading
  - Climate
  - Maintenance actions and timing
  - Initial pavement condition and condition after each maintenance action
  - Calibration factors
## Pavement performance modelling

<table>
<thead>
<tr>
<th>Climate Parameter</th>
<th>unit</th>
<th>Naboomspruit (Mookgapong)</th>
<th>Mokopane</th>
<th>Polokwane</th>
<th>Project road section</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum Temperature</td>
<td>°C</td>
<td></td>
<td>-0.6</td>
<td>-2.3</td>
<td>-1.2</td>
</tr>
<tr>
<td>Maximum Temperature</td>
<td>°C</td>
<td></td>
<td>39.4</td>
<td>37.6</td>
<td>38.8</td>
</tr>
<tr>
<td>Average Temperature Range</td>
<td>°C</td>
<td></td>
<td>14.2</td>
<td>13.7</td>
<td>13.9</td>
</tr>
<tr>
<td>Mean Temperature</td>
<td>°C</td>
<td></td>
<td>20.7</td>
<td>18.6</td>
<td>19.6</td>
</tr>
<tr>
<td>Days T &gt;32°C</td>
<td>No</td>
<td></td>
<td>59.3</td>
<td>23.0</td>
<td>41.1</td>
</tr>
<tr>
<td>Temperature Classification</td>
<td></td>
<td></td>
<td>Subtropical-Hot</td>
<td>Subtropical-Hot</td>
<td>Subtropical-Hot</td>
</tr>
<tr>
<td><strong>Moisture</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Monthly Precipitation (MMP)</td>
<td>mm</td>
<td>52.4</td>
<td>32.2</td>
<td>42.4</td>
<td>42.3</td>
</tr>
<tr>
<td>Duration of dry season</td>
<td>months</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Thornthwaite’s Moisture Index (Im)</td>
<td></td>
<td>-20 to 0</td>
<td>-20 to 0</td>
<td>-40 to 0</td>
<td>-20 to 0</td>
</tr>
<tr>
<td>Moisture Classification</td>
<td></td>
<td>Sub-Humid Dry</td>
<td>Sub-Humid Dry</td>
<td>Sub-Humid Dry/Semi-Arid</td>
<td>Sub-Humid Dry</td>
</tr>
</tbody>
</table>
## HDM-4 Climate Zones (SA Coverage)

<table>
<thead>
<tr>
<th>CZ_NAME</th>
<th>MOISTCLASS</th>
<th>TEMTYPE</th>
<th>DAYS GT32</th>
<th>ANN TEMPRGE</th>
<th>FREEZE IDX</th>
<th>MOSIT IDX</th>
<th>MM P</th>
<th>MEAN TEMP</th>
<th>DRY SEASON</th>
<th>PC TDS</th>
<th>PC TDW</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA - Arid (Im &lt; -40)</td>
<td>Arid</td>
<td>Subtropical-Hot</td>
<td>60</td>
<td>17</td>
<td>60</td>
<td>-50</td>
<td>12</td>
<td>21</td>
<td>10.8</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>SA - Semi Arid (-40&lt;Im&lt;-20)</td>
<td>Semi-Arid</td>
<td>Subtropical-Hot</td>
<td>60</td>
<td>17</td>
<td>50</td>
<td>-30</td>
<td>38</td>
<td>18</td>
<td>8</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>SA - Sub Humid Dry (-20&lt;Im&lt;0)</td>
<td>Sub-Humid Dry</td>
<td>Subtropical-Cool</td>
<td>40</td>
<td>13</td>
<td>30</td>
<td>-10</td>
<td>48</td>
<td>16</td>
<td>6</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>SA - Sub Humid Moist (0&lt;Im&lt;20)</td>
<td>Sub-Humid Moist</td>
<td>Subtropical-Hot</td>
<td>30</td>
<td>12</td>
<td>10</td>
<td>10</td>
<td>66</td>
<td>18</td>
<td>6</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>SA - Humid (Im &gt; 20)</td>
<td>Humid</td>
<td>Temperate-Cool</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td>50</td>
<td>92</td>
<td>18</td>
<td>6</td>
<td>0</td>
<td>15</td>
</tr>
</tbody>
</table>

## HDM-4 Calibration Values ( Typical )

<table>
<thead>
<tr>
<th>CZ_NAME</th>
<th>MOISTCLASS</th>
<th>kcia</th>
<th>kcpa</th>
<th>kciw</th>
<th>kcpw</th>
<th>kvp</th>
<th>kgm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA - Arid (Im &lt; -40)</td>
<td>Arid</td>
<td>1.5</td>
<td>0.2</td>
<td>1.5</td>
<td>0.3</td>
<td>0.3</td>
<td>0.39</td>
</tr>
<tr>
<td>SA - Semi Arid (-40&lt;Im&lt;-20)</td>
<td>Semi-Arid</td>
<td>1.3</td>
<td>0.3</td>
<td>1.3</td>
<td>0.3</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>SA - Sub Humid Dry (-20&lt;Im&lt;0)</td>
<td>Sub-Humid Dry</td>
<td>1.2</td>
<td>0.4</td>
<td>1.2</td>
<td>0.4</td>
<td>0.6</td>
<td>0.61</td>
</tr>
<tr>
<td>SA - Sub Humid Moist(0&lt;Im&lt;20)</td>
<td>Sub-Humid Moist</td>
<td>1.1</td>
<td>0.6</td>
<td>1.1</td>
<td>0.6</td>
<td>0.9</td>
<td>0.61</td>
</tr>
<tr>
<td>SA - Humid (Im &gt; 20)</td>
<td>Humid</td>
<td>1.1</td>
<td>0.6</td>
<td>1.1</td>
<td>0.6</td>
<td>0.9</td>
<td>0.88</td>
</tr>
</tbody>
</table>
COMPARISON OF PREDICTED WITH ACTUAL PERFORMANCE
Comparison of predicted with actual performance

- **Processing of visual assessment data**
  - Visual assessment data in terms of degree and extent for 200 m segments
  - HDM-4 predictions for defects generally in terms of % of total road area
  - Used cracking index to compare measured with predicted

\[
CI = \sum_{i=1}^{5} W_i \cdot C_i
\]

Where:
- \( W_i = \) Weighing factor for crack type \( i \),
- and \( C_i = \) Percentage (%) cracked area for crack type \( i \)
- All cracks: degree 1 to 5
- Wide cracks: degree 3 to 5
Comparison of predicted with actual performance

### Crack Types and Weighing Factors Used for Cracking Index

<table>
<thead>
<tr>
<th>Crack Type</th>
<th>Weighting Factor</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crocodile Cracks</td>
<td>1.67</td>
<td>Includes Wheelpath And General Crocodile Cracking</td>
</tr>
<tr>
<td>Map Cracks</td>
<td>0.80</td>
<td>None</td>
</tr>
<tr>
<td>Longitudinal Cracks</td>
<td>0.72</td>
<td>Includes Only Longitudinal Cracking In The Wheelpath</td>
</tr>
<tr>
<td>Transverse Cracks</td>
<td>0.77</td>
<td>None</td>
</tr>
<tr>
<td>Block Cracks</td>
<td>1.04</td>
<td>Includes Block Cracks With Spacing Of 0.5 m And Greater</td>
</tr>
</tbody>
</table>

### Conversion Between Extent Rating for Cracking and the % Cracked Area

<table>
<thead>
<tr>
<th>Extent Rating</th>
<th>Crocodile Cracks</th>
<th>Surface or Map Cracks</th>
<th>Longitudinal Cracks</th>
<th>Transverse Cracks</th>
<th>Block Cracks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>0.7</td>
<td>0.5</td>
<td>3.5</td>
</tr>
<tr>
<td>2</td>
<td>3.5</td>
<td>3.5</td>
<td>1.7</td>
<td>1.6</td>
<td>7.0</td>
</tr>
<tr>
<td>3</td>
<td>6.25</td>
<td>6.25</td>
<td>3.2</td>
<td>2.5</td>
<td>10.5</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>10</td>
<td>5.7</td>
<td>5.3</td>
<td>14.5</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>20</td>
<td>7.3</td>
<td>6.1</td>
<td>20</td>
</tr>
</tbody>
</table>
Comparison of predicted with actual performance

Cracking - Section 1

% All Structural Cracking

Year end


Actual

HDM4 Prediction

0.0% 1.0% 2.0% 3.0% 4.0% 5.0% 6.0%

2003 S1(6)
2008/9 S216/13
Comparison of predicted with actual performance

Cracking - Section 2

% All Structural Cracking

Year end


Actual HDM4 Prediction

2008/9 S1(13)

(13)
Comparison of predicted with actual performance

Rutting - Section 1

<table>
<thead>
<tr>
<th>Year end</th>
<th>Actual</th>
<th>HDM4 Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>2003/9</td>
<td>6.0/13</td>
<td>6.0/13</td>
</tr>
</tbody>
</table>

Average Rutting (mm)

Year end

0.0  2.0  4.0  6.0  8.0  10.0  12.0  14.0
Comparison of predicted with actual performance

Rutting - Section 2

Average Rutting (mm)

Year end


Actual  HDM4 Prediction
Comparison of predicted with actual performance

**Roughness - Section 1**

- **Average IRI (m/km)**
- **Year end**
- **1996**
- **1998**
- **2000**
- **2002**
- **2004**
- **2006**
- **2008**
- **2010**
- **2012**
- **2014**

- **Actual**
- **HDM4 Prediction**

Data points:
- **2003 S1(6)**
- **2008/9 S2(16/13)**
Comparison of predicted with actual performance

Roughness - Section 2

Average IRI (m/km)

Year end


Actual  HDM4 Prediction

1.0  1.2  1.4  1.6  1.8  2.0  2.2  2.4  2.6  2.8  3.0
Comparison of predicted with actual performance

• Concluding remarks
  ▪ The predictions are of the same order of magnitude than the actual measurements, but the rate of distress development differs
  ▪ Some measurement data (instrument and visual data) are inconsistent; this influence comparability

• Suggestions to improve comparability
  ▪ Deterioration modelling calibration factors are to be adjusted and/or calibrated with actual performance
  ▪ Heavy vehicles; structural distresses pre-dominantly in slow lane - recommend modelling of slow lanes only
  ▪ Accuracy of field measurements can be improved by ensuring calibration of equipment, diligent quality control, independent verification of visual assessments and use of laser technology to detect cracked areas
Thank You