Long-term flexible pavement performance modelling

Andy Collop
Director, NTEC
Outline

• Introduction
• LTPPM
• Summary & future developments
Introduction

• Long-Term Pavement Performance Model (LTPPM) developed with University of Cambridge in late 1990s (Prof. Cebon)

• Original objective was to investigate the effects of dynamic loading on long-term pavement performance (move away from 4th power law)

• **Deterministic** iterative procedure (profile tracking)

• Flexible (asphalt) pavements
Aggregate traffic approach

Vehicle A  Vehicle B  Vehicle Z

ESALs (4th Power Law)

Sum ESALs

Performance

Pavement Structure

"AGGREGATE TRAFFIC" APPROACH
Aggregate damage approach

Vehicle A

Vehicle B

Vehicle Z

Pavement Structure

Pavement Performance Model

Sum Road Damage

Performance

“AGGREGATE DAMAGE” APPROACH
Outline

• Introduction
• LTPPM
• Summary & future developments
Damage prediction

- Dynamic vehicle/axle group models
- Primary response calculation
- Asphalt layer thickness variations
- Damage calculation
- Feedback mechanisms
Spatial repeatability

- All heavy goods vehicles are reasonably similar in design
- They travel at similar speeds
- With similar magnitude loads
- Over a similar surface profile
- Are the loads applied to the pavement surface random or do the peak loads occur in similar locations (spatial repeatability)?
Full-scale experiments
Data from 542 vehicles

- Location of Peak Loads / m (60mph, 3Hz)
- Vehicle Speed / m/s

- A2+2(steel), 81 vehicles
- A2+2(air), 38 vehicles
- A2+3(air), 57 vehicles
- A2+3(steel), 55 vehicles
- Rig2, 275 vehicles
- other, 36 vehicles

± 1m
Spatial Repeatability Index

Probability Distribution, $P(SRI)$

- Measured data
- Gaussian fit
  (SDN = 0.287)

Sensor noise
Asphalt damage

- Fatigue damage included as a loss in stiffness of the asphaltic material
- Data from ALF trials in Australia used to develop relationship
- FWD tests undertaken regularly
- Back-calculated asphalt stiffness related to expected level of fatigue damage
- Minimum normalised stiffness of 0.2
Normalised stiffness

Normalised Asphalt Modulus

Exponential model

Mulgrave - BB
Mulgrave - FWD
Callington - BB

$R^2 = 0.742$
$(D < 1)$

Cumulative Fatigue Damage $D$

Normalized Asphalt Modulus
Example

• Simulations to investigate the effect of changing to “road friendly” air suspensions
  • Major road (350mm asphalt)
  • Minor road (150mm asphalt)
  • 3 layer structure
  • Quarter car vehicle model
  • 4-18°C temperature variations
• Results compared to EU approach
Surface profile evolution

Initial profile

36 million load passes (10 years)

72 million load passes (20 years)
Rutting evolution

![Graph showing rutting evolution over load passes (Million) and average rut depth (mm). The graph compares Steel fleet and Road friendly fleet. There is a marked 'Critical' rut depth indicated. The x-axis represents Load Passes (Million) ranging from 0 to 1.2 million with a label indicating 20 years. The y-axis represents Average Rut Depth (mm) ranging from 0 to 20 mm. The Steel fleet line is solid, while the Road friendly fleet line is dashed.](image-url)
Fatigue evolution

- Steel fleet
- Road friendly fleet

95th Percentile Fatigue Damage

'Critical' fatigue damage

Load Passes (Million)

20 years
Example predictions

- Percentage increase in life changing from steel to road friendly (air) suspensions

<table>
<thead>
<tr>
<th></th>
<th>Major</th>
<th>Minor</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC</td>
<td>24%</td>
<td>42%</td>
</tr>
<tr>
<td>LTGPPM</td>
<td>0% - 3%</td>
<td>39% - 90%</td>
</tr>
</tbody>
</table>
Economic evaluation

- Based on annual expenditure on maintenance of roads in England in 98/99 (£ million, 94/95 prices)
Outline

• Introduction
• LTPPM
• Summary & future developments
• Deterministic LTPPM described based on “aggregate damage” approach

• LTPPM comprises:
  i. Dynamic vehicle simulation
  ii. Pavement primary response simulation
  iii. Material damage simulation
  iv. Deterioration feedback

• Different modes of deterioration predicted for different classes of pavement
• Changing from steel to air increases life of major road by <3% (£<10 million)

• Changing from steel to air increases life of minor road by between 40% and 90% (£100 million - £240 million)

• Most significant savings predicted on minor (thin) roads

• 4\textsuperscript{th} power approach overestimates benefits on major roads and underestimates benefits on minor roads
Future developments

• Funding from EU (ASSET), NARC & NSWRTA
• Produce a validated user-friendly long-term flexible pavement performance model
• Will Goodrum (Cambridge): Oct 08 – Sept 10
• Dr Riccardo Isola (Nottingham): Feb 09 – Jan 11
• Programmer (Cambridge): Nov 09 – Nov 10
Program structure

GUI
Global Options
Microclimate
Mechanical

Climate Call
Climate Params.
Temperature & Moisture Dist’n.
Temp Dist’n.
Climate Params.

Input Parameters
Recast for Model

Microclimate Model

Calculate Layer Properties

Damage Calculation
Elastic Layer
ε(t)

Modelling
A
B
C
N
Layer props and forces
Layer damage and deformation responses
δ(t)

Update profile

Vehicle Models
Tyre forces
Surface profiles

NTEC
Long-term flexible pavement performance modelling

Andy Collop
Director, NTEC