Overview of HDM-4
Road Deterioration and User Effects Models

Henry Kerali

The World Bank
History of the HDM model

- de Weille 1966
- Highway Cost Model 1971
- Kenya Study 1971-75
- Caribbean Study 1977-82
- India Study 1976-82
- Brazil Study 1975-84
- HDM-II 1981
- HDM-III 1987
- HDM-4 2000 ISOHDM

Institutions:
- RTIM (TRRL)
- RTIM2 (TRL)
- RTIM3 (TRL)
HDM-4 Analytical Framework

• Predicts road network performance as a function of:
  – Traffic volumes and loading
  – Road pavement type and strength
  – Maintenance standards
  – Environment

• Quantifies benefits to road users from:
  – Savings in vehicle operating costs (VOC)
  – Reduced road user travel times
  – Decrease in number of accidents
  – Environmental effects
  + Exogenous Costs & Benefits (user specified)
Life Cycle Analysis

1. Input Data
2. Predict Road Deterioration
3. Predict Road Work Effects
4. VOC, Accident & Time costs
5. Discount Annual Costs & Compare
6. Repeat for all years
7. Output NPV, IRR,..
Road Deterioration Models
Purpose of Deterioration Models

• Road investment decision support systems must have some form of pavement deterioration modeling capability
• Objective is to predict the future condition and the effects of maintenance
Life Cycle Analysis

- Predict long term pavement performance
- Predict effects of maintenance standards
- Calculate annual costs: Road Agency + Road User
Pavement Performance

- Pavement Types modelled:
  - Bituminous (AC, ST, etc.)
  - Unsealed (Gravel, Earth, Sand, etc.)
  - Concrete (JPCP, JRCP, CRCP, etc.)
  - Block (Bricks, etc.)

- Models from pavement performance experiments in:
  - Brazil, Kenya, India, South Africa
  - France, USA, Sweden, Finland, Australia
# Bituminous Pavement Types

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>Surface Material</th>
<th>Base Type</th>
<th>Base Material</th>
<th>Pavement Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM</td>
<td>AC HRA PMA RAC CM PA SMA</td>
<td>GB</td>
<td>CRS GM</td>
<td>AMGB</td>
</tr>
<tr>
<td></td>
<td>AB</td>
<td>AB GM</td>
<td>AMAB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SB</td>
<td>CS LS</td>
<td>AMSB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AP</td>
<td>TNA FDA</td>
<td>AMAP</td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>CAPE DBSD SBSD SL PM</td>
<td>GB</td>
<td>CRS GM</td>
<td>STGB</td>
</tr>
<tr>
<td></td>
<td>AB</td>
<td>AB GM</td>
<td>STAB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SB</td>
<td>CS LS</td>
<td>STSB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AP</td>
<td>TNA FDA</td>
<td>STAP</td>
<td></td>
</tr>
</tbody>
</table>
# Pavement Defects Modeled in HDM-4

<table>
<thead>
<tr>
<th>Bituminous</th>
<th>Concrete</th>
<th>Block*</th>
<th>Unsealed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracking</td>
<td>Cracking</td>
<td>Rutting</td>
<td>Gravel loss Roughness</td>
</tr>
<tr>
<td>Rutting</td>
<td>Joint spalling</td>
<td>Surface texture Roughness</td>
<td></td>
</tr>
<tr>
<td>Ravelling</td>
<td>Faulting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potholing</td>
<td>Failures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roughness</td>
<td>Serviceability rating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edge break</td>
<td>Roughness</td>
<td>*not in current release</td>
<td></td>
</tr>
<tr>
<td>Surface texture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skid resistance</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Plus deterioration of drains
Unsealed Roads
Unsealed Road Deterioration ...
Concrete Roads

- Joint Spalling
- Punch outs
- Cracking
- Faulting
- Slab failures
- Riding Quality

Models From
- USA
- Chile
Bituminous Pavements

Predicted defects:
- Cracking
- Ravelling
- Edge Break
- Potholes
- Riding Quality
- Skidding
Bituminous Road Deterioration.
Bituminous Road Deterioration ..
Initiation and Progression Periods

- Cracking, ravelling and potholing have initiation and progression periods
Cracking Model!

\[ICA = K_{cia} \{CDS^2 a_0 \exp[a_1 SNP + a_2 (YE4/SN^2) + CRT] \}\]

- **ICA**: time to cracking initiation, in years
- **CDS**: construction quality
- **SNP**: structural number of pavement
- **YE4**: traffic loading
- **K_{cia}**: calibration factor
- **CRT**: effect of maintenance
Cracking Initiation Calibration

![Crack Initiation Graph]

- Kci = 1.00
- Kci = 1.80
- Kci = 0.55
All Cracking Progression

dACA = K_{c_\text{pa}} \left( \frac{CRP}{CDS} \right) z_A \left[ (z_A a_0 a_1 \delta t_A Y E 4 SNP^a_2 + SCA^{a_1})^{1/a_1} - SCA \right]

- CRP = retardation of cracking progression due to preventive treatment

- Progression of All cracking commences when $\delta t_A > 0$ or $ACAa > 0$
• Rutting = F(age, traffic, strength, compaction)
Interactions Between Defects

Cracking Area

Water ingress

Lower strength

Rut depth

Faster deformation

Uneven Surface

Spalling

Potholes

Patches

ROUGHNESS

RUE Models

Further cracking

Shear

Patches

Uneven surface
Roughness

- Roughness = F(age, strength, potholes, cracking, ravelling, rutting)
Road Work Effects Models
Road Work Effects

• Pavement deterioration grouping:
  – Surface
  – Structural

• Surface deterioration can be halted at almost any point by maintenance

• Structural deterioration rates can be reduced by maintenance, but never halted.
Road Works Effects

Condition

Traffic / Time

Reconstruct

Overlay
Road Maintenance & Improvement

- Affects long term pavement performance
- Funding requirements depend on specified maintenance standards & unit costs
Road Work Classification

• Preservation
  – Routine
    • Patching, Edge repair
    • Drainage, Crack sealing
  – Periodic
    • Preventive treatments
    • Rehabilitation
    • Pavement reconstruction
  – Special
    • Emergencies
    • Winter maintenance

• Development
  – Improvements
    • Widening
    • Realignment
    • Off-carriageway works
  – Construction
    • Upgrading
    • New sections

World Bank
Maintenance Interventions

• Scheduled
  – Fixed intervals of time between interventions
  – Interventions at fixed points of time

• Responsive
  – Pavement condition
  – Pavement strength
  – Surface age
  – Traffic volumes/loadings
  – Accident rates
Maintenance May Affect

- Pavement strength
- Pavement condition
- Pavement history
- Maintenance cost

REMEMBER ... the type of treatment dictates what it will influence
Road User Effects Modelling
Road User Effects

• Vehicle operating costs
  – fuel, oil, tyres, parts consumption
  – vehicle utilisation & depreciation
• Travel time
  – passengers
  – cargo
• Road accidents
• Energy consumption
• Vehicle emissions & noise
Features in HDM-4

- Effects of traffic congestion on speed, fuel, tyres and maintenance costs
- Non-motorised transport modelling
- Effects of roadworks on users
- Traffic safety impact
- Vehicle emissions impact
- Vehicle noise impact
Motorised Vehicles

Motorised

Motorcycles
- Motorcycles
- Small car
- Medium car
- Large car

Passenger cars
- Light delivery
- Light goods
- 4 wheel drive

Utilities
- Light truck
- Heavy truck
- Medium truck
- Articulated truck

Trucks
- Minibus
- Light bus
- Medium bus
- Heavy bus
- Coach

Buses

Category

Class

Type
Implications of New Model

• Lower rates of fuel consumption than HDM-III for many vehicles
• Effect of speed on fuel significantly lower for passenger cars
• Considers other factors -- eg surface texture and type -- on fuel
• Model can be used for congestion analyses
Annual Distribution of Hourly Flows

Flow Periods
- Peak
- Next to Peak
- Medium flow
- Next to Low
- Overnight

Number of Hours in the Year
HDM-4 Speed-Flow Model

- $S_1$
- $S_2$
- $S_3$
- $S_{nom}$
- $S_{ult}$

Flow in PCSE/h

Speed in km/h
Vehicle Parts Replacement Costs

The diagram illustrates the relationship between roughness in IRI m/km and parts consumption as a percentage of the new vehicle price per 1000 km for different vehicle types:

- PC and LDV
- MT
- HT
- AT
- HB

The graph shows a clear upward trend as roughness increases, indicating higher parts consumption costs for vehicles exposed to more uneven road surfaces.
Capital Costs

• Comprised of depreciation and interest costs
• HDM-III used a simple linear model
• Affected by operating conditions through the effects of speed on utilisation and speed on service life (de Weille’s method)
• HDM-4 uses ‘Optimal Life’ method or constant life method
Roughness on Depreciation

Depreciation Cost in Baht/km

Roughness in IRI m/km
Safety

- HDM-4 does not predict accident rates
- User defines a series of “look-up tables” of accident rates
- The rates are broad, macro descriptions relating accidents to a particular set of road attributes
  - Fatal
  - Injury
  - Damage only
Accident Groups

- Road type, class, use
- Traffic level
- Geometry, pavement type, ride quality, surface texture, presence of shoulders
- Non-motorised traffic
- Intersection type
NMT User Costs and Benefits

- Travel speed and time
- Wear and tear of NMT vehicles and components
- Fares/User charges
- Degree of conflicts with MT traffic
- Accident rates
- Energy consumption
Non-Motorised Transport
NMT Utilisation
Emissions Model

Estimate quantities of pollutants produced as a function of:
- Road characteristics
- Traffic volume/congestion
- Vehicle technology

- Hydrocarbon
- Carbon monoxide
- Nitrous oxides
- Sulphur dioxide
- Carbon dioxide
- Particulates
- Lead
Energy Balance Analysis

• Compares total life-cycle energy consumption of different transport policies
• Three energy use categories:
  – Motorised vehicles
  – Non-motorised vehicles
  – Road construction and maintenance
Energy Analysis Output

• Total energy consumption
• Total consumption of renewable and non-renewable energy
• Total national and global energy use
• Specific energy consumption (per km)
Discussions