Introduction to HDM-4

Henry Kerali
Lead Transport Specialist
The World Bank
Transport and Development

- Transport sector is vital for economic & social development
- Roads constitute the largest component of transport
- Roads require a balance of:
  - Maintenance (or Preservation)
  - Development (or Improvement)
- Objective of Road Management
  - Consistent and Rational Policy Objectives
  - Sufficient and Reliable Funding
  - Effective Procedures & Management Tools
HDM-4 Objectives.

Economic basis for selecting investment alternatives

Road standards

Pavement standards

Alignments
HDM-4 Objectives

Minimize Road Agency and Road User Costs

- Non-motorized transport facilities
- Traffic congestion
- Vehicle emissions
- Travel times
- Transport costs
- Road accidents
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-IV 2000 ISOHDM

RTIM (TRRL)
RTIM2 (TRL)
RTIM3 (TRL)
**HDM-4 Concept**

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

- Quantifies benefits to road users from:
  - Savings in vehicle operating costs (VOC)
  - Reduced road user travel times
  - Decrease in number of accidents
  - Environmental effects
Optimum Transport Costs

Cost

Total

Optimum

Road User

Road Works

Design Standards
Purpose:

To optimise the overall performance of the network over time in accordance with POLICY OBJECTIVES and within budgetary constraints.

Typical objectives:

- Minimise transport costs
- Preserve asset value
- Provide and maintain accessibility
- Provide safe and environmentally friendly transport
Life Cycle Costs

Road Agency Costs
- Management, Operations
- Labor, Equipment, Materials
- Land acquisition
- Maintenance and Rehabilitation

Road User Costs
- Vehicle operation
- Travel time
- Road accidents
Comparison of Project Alternatives

Discounted RAC
(Road works + RUC)

Without Overlay

With Overlay

End of Analysis

NPV
Comparison of Project Alternatives

Discounted RAC

Cost of Paving

Without Paving

RUC

Project Life (years)

End of Analysis

NPV
Life Cycle Analysis

**Input Data**

1. Predict Road Deterioration
2. Predict Road Work Effects
3. VOC, Accident & Time costs
4. Discount Annual Costs & Compare

Output: NPV, IRR, ...

Repeat for all years
Road Deterioration

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

![Road Condition vs. Time (years) or Traffic Loading](chart.png)

- Road Condition:
  - Good
  - Poor

- Time (years) or Traffic Loading

- Maintenance Standard
- Rehabilitation
- Pavement Performance Curve
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
Principles Of Deterioration Models

- Models are structured empirical
- Individual distresses modelled separately
- Relationships are incremental and recursive
  \[ dY = K a_0 f(X_1, X_2, X_3, \text{etc}) \]
- Modelled sequentially through to roughness
- Maintenance intervention at end of each year
ICA = \( K_{cia} \{ CDS^2 \cdot a_0 \exp[a_1 SNP + a_2 (YE4/SN^2)] + CRT \} \)

- **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
All Cracking Progression

\[ d\text{ACA} = K_{\text{cpa}} \left( \frac{\text{CRP}}{\text{CDS}} \right) z_A \left[ (z_A \ast a_0 \ast a_1 \ast \delta t_A \ast \text{YE4} \ast \text{SNP}^a_2 \right. \\
\left. + \text{SCA}^{a_1} \right)^{1/a_1} - \text{SCA} \]
**Pavement Deterioration Concept**

- **Area of Cracking**: Time
- **Rut depth**: Time
- **Water ingress**: Lower strength
- **Faster deformation**: Uneven surface
- **Uneven Surface**: Spalling, Potholes, Patches
- **Spalling**:
- **Potholes**:
- **Patches**:
- **Further cracking**: ROUGHNESS

Diagram elements include:
- **Roughness**: Central node
- **Water ingress**: Node connected to ROUGHNESS
- **Faster deformation**: Node connected to ROUGHNESS
- **Uneven surface**: Node connected to ROUGHNESS
- **Shear**: Node connected to ROUGHNESS
- **Patches**: Node connected to ROUGHNESS

Graphical elements show directional relationships and timelines.

Pavement deterioration concepts include:
- Spall
- Pothole
- Uneven surface
- Patches
- Water ingress
- Rut depth
Concrete Roads

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

Models From
- USA
- Chile
Predicted defects:

- Cracking
- Ravelling
- Edge Break
- Potholes
- Riding Quality
- Skidding
Bituminous Road Deterioration.
Bituminous Road Deterioration
Unsealed Roads
Unsealed Road Deterioration
Unsealed Road Deterioration ...
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
Road Works
Road Work Effects

Condition

Traffic / Time

Reconstruct

Overlay
Road User Effects
RUE Components

- MT Vehicle operating costs (VOC)
- MT Travel time costs (TTC)
- NMT Time and operating costs (NMTOC)
- Accident costs (AC)

\[
RUE = RUC + \text{Emissions} + \text{Energy} + \text{Noise}
\]
\[
RUC = VOC + TTC + NMTOC + AC
\]
**Road User Effects**

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

- Effects of traffic congestion on speed, fuel, tyres and maintenance costs
- Non-motorised transport modelling
- Effects of road works on users
- Traffic safety impact
- Vehicle emissions impact
- Vehicle noise impact
Motorised Vehicles
Impact of Road Condition on VOC

- Road Condition (IRI)
  - Good
  - Poor

- Road User Costs ($/veh-km)
  - Car
  - Pickup/utility
  - Bus
  - Heavy Truck
  - Rickshaw
Non-Motorised Transport
### Role of HDM-4

<table>
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<tr>
<th>Management Function</th>
<th>HDM-4 Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>Strategy Analysis</td>
</tr>
<tr>
<td>Programming</td>
<td>Programme Analysis</td>
</tr>
<tr>
<td>Preparation</td>
<td>Project Analysis</td>
</tr>
</tbody>
</table>
Road Management Functions

📍 Planning
- Setting standards and policies
- Long term estimates of expenditure

📍 Programming
- Medium term work programmes

📍 Preparation
- Detailed project design and work packaging

📍 Operations
- Implementation of works in field
HDM-4 Applications

- Road sector policy studies
- Strategic planning of road network development, improvement & maintenance
- Determination of funding requirements
- Preparation of multi-year road work programmes
- Economic appraisal of individual road projects
- Research studies
  - Road pricing
  - Vehicle regulations
  - Pavement design standards
Standards & Policies

- Road pricing
  - road use costs (to define fuel levies)
  - congestion charges
  - weight-distance charges
- Vehicle regulations
  - axle load limits
  - energy consumption, vehicle emissions & noise
- Engineering Standards
  - sustainable road network size
  - pavement design and maintenance standards
Strategy Analysis

Analysis of entire road networks to determine funding needs and predict performance under budget constraints

Objectives:

- Determine budget allocations for road maintenance and improvement
- Prepare work programs
- Determine long term network performance
- Assess impact on road users
Strategic Analysis Approach

Road Network

Matrix

Resource Constraints

Preservation Evaluation

Optimisation Module

Optimal Strategy under Budgetary Constraints

Revenues, Sector budgets

Developmen t Candidates

G  F  P
H
M
L
Effect of budget levels

Primary Roads

Average Roughness (IRI)

Annual Budget

- $10m
- $15m
- $20m

Target = 3.5 IRI
Budget Allocations

**Average Roughness (IRI)**

- **Feeder Roads**: $30m/yr
- **Secondary Roads**: $35m/yr
- **Primary Roads**: $20m/yr
Optimal budget requirements

US $ m/year.

- Development
- Improvement
- Periodic
- Routine

Years 2003-2006
Programme Analysis

Objective: prioritise candidate road projects in each year within annual budget constraint

Annual budgets obtained from strategic maintenance plan.
Use specified standards to screen network & identify candidate projects, e.g.

- road sections which exceed specified condition
- roads with inadequate capacity
- pavements which need strengthening
- upgrade pavements with high traffic volumes
Procedure ..

- Determine maintenance or improvement options
- Specify budget limits & periods
- Optimise using selected objective
- Produce optimal list of projects for budget period
## Work Programme Output

<table>
<thead>
<tr>
<th>Priority Rank</th>
<th>Road Section</th>
<th>Length (km)</th>
<th>Province or District</th>
<th>Type of Road Work</th>
<th>Scheduled Year</th>
<th>Cost ($m)</th>
<th>Cumulative S$m</th>
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Project Appraisal

Project types
- New construction, upgrading
- Reconstruction, resealing
- Widening, lane addition
- Non-Motorised Transport lanes

Economic indicators
- Net Present Value (NPV)
- Economic Rate of Return (ERR)
- Benefit Cost Ratio (BCR), NPV/C
- First Year Rate of Return (FYRR)
Project Level Outputs

- Sensitivity analysis results
  - Scenario analysis
  - Road condition indicators
  - Road user cost details
  - Energy & emissions
HDM Technology Set

Knowledge Base

Software

Models

RDWE

SEE

RUE
Conclusions – Why HDM-4?

- Transparency of analysis
- Life cycle analysis capable of:
  - Short, Medium & Long term analyses
  - What-if analysis
- Internationally accepted analysis framework
- Availability of technical expertise
- Local calibration
Web sites:

http://hdm4.piarc.org
http://www.bham.ac.uk