LIFE CYCLE MANAGEMENT OF ROAD ASSETS
(Emphasis on Long Life Pavements)

Prepared for Master Class / Workshops
In Sydney, Melbourne and Brisbane
September and October, 2011

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University of Waterloo
Canada
LIFE CYCLE MANAGEMENT OF ROAD ASSETS
(WITH EMPHASIS ON LONG LIFE PAVEMENTS)

Background Notes
Master Class/Workshops
Sydney, Melbourne
and
Brisbane
October, 2011

Dr. Ralph Haas, CM, FRSC, FCAE
The Norman W. McLeod Engineering Professor and
Distinguished Professor Emeritus
University of Waterloo, Canada
Assessing road assets

Fundamentals of life cycle analysis

Example of LCA for long life pavement design

Performance indicators

Sustainability and Green Roads

User costs, noise, emissions

Recommendations
<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>Long Term Perf. Based Contract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed and Within ROW</td>
<td>Pavements</td>
<td>Most types included</td>
</tr>
<tr>
<td></td>
<td>Bridges</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WIMS</td>
<td></td>
</tr>
<tr>
<td>Unfixed and Fixed Outside ROW</td>
<td>Buildings</td>
<td>Some may be sold or leased</td>
</tr>
<tr>
<td></td>
<td>Veh./Equipment</td>
<td></td>
</tr>
<tr>
<td>Other Assets</td>
<td>People</td>
<td>Mainly contractor responsibility</td>
</tr>
<tr>
<td></td>
<td>Software, etc.</td>
<td></td>
</tr>
</tbody>
</table>
ASSESSING ROAD INFRASTRUCTURE

- Physical Condition (smoothness, structural distress, level of service, etc.)
- Asset value (depending on accounting base and method)
- Other (litter control, vegetation, lighting, etc.)

and

- Environmental impacts, sustainability, user costs, noise, energy consumption, emissions
ASSESSMENT OF A LARGE INTERURBAN ROAD NETWORK

<table>
<thead>
<tr>
<th>IRI Range</th>
<th>Percent of km</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;=1</td>
<td>40.00%</td>
</tr>
<tr>
<td>1 &gt; IRI &lt;= 1.5</td>
<td>30.00%</td>
</tr>
<tr>
<td>1.5 &gt; IRI &lt;= 2</td>
<td>25.00%</td>
</tr>
<tr>
<td>IRI &gt; 2</td>
<td>10.00%</td>
</tr>
</tbody>
</table>

V.Good, Good, Fair, Poor
ESSENTIAL TECHNICAL REQUIREMENTS

LONG LIFE / PERPETUAL PAVEMENTS

Include:

Good materials and their characterization, good design, construction and maintenance, and ......

Very Importantly

- Structural analysis methodology

  and

- Performance prediction methodology

For M-E Design
FUNDAMENTALS

P, Wheel load
(1) Radius of loaded area
(2) Tire pressure (may not be uniform)
(3) Surface tensile stress or strain
(4) Lateral shear strain or deformation
(5) Tensile strain or stress at bottom of AC layer
(6) Vertical stress, strain or deflection at surface of subgrade

MECHANISTIC PART

Relation / Correlation Between Fundamental Pavement Response(s) and Pavement Performance

EMPIRICAL PART

Measure of Serviceability or Deterioration
Minimum Acceptable
Age and/or Accumulated Loads
Life-Cycle Period
FACTORS AFFECTING PERFORMANCE

ENVIRONMENT
- Moisture
- Radiation
- Freeze-thaw Cycles
- Temperature (Min., Max., ° Days, etc.)

STRUCTURE
- Layer Thicknesses
- Layer Types & Properties
- Variations in Thickness & Properties
- Subgrade Type & Properties

CONSTRUCTION
- Timing Methods
- Variance
- As-Built Quality

TRAFFIC
- Axle Group Loads
- Tire Types & Pressures
- Axle Spacing, Speed, Repetitions

MAINTENANCE
- Treatments
- Timing Methods
- Quality

Life-Cycle Period
Measure of Serviceability or Deterioration
Minimum Acceptable
Age and/or Accumulated Loads

Minimum Acceptable
Life-Cycle Period

Minimum Acceptable
Age and/or Accumulated Loads
LIFE CYCLE ANALYSIS

Require: LOS vs Age (Performance) Model
Cost / Cash Flow Calculation (eg. PW)
Asset Value vs Age Calculation
Risk Analysis
METHODS OF LCCA

1. Benefits / Cost Ratio

2. Internal Rate of Return

3. Equivalent Uniform Annual Costs

4. Cost-Effectiveness

5. Present Worth

Which Method is Best for Infrastructure?
(applicability, understanding, consistency)
## Applicability of LCCA Methods: Highways

<table>
<thead>
<tr>
<th></th>
<th>Arterials</th>
<th>Expressways</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Public</td>
<td>Private</td>
</tr>
<tr>
<td><strong>Short Term</strong></td>
<td>C/E</td>
<td>PWC</td>
</tr>
<tr>
<td></td>
<td>PWC</td>
<td>AC</td>
</tr>
<tr>
<td><strong>Medium Term</strong></td>
<td>C/E</td>
<td>PWC</td>
</tr>
<tr>
<td></td>
<td>PWC</td>
<td>AC</td>
</tr>
<tr>
<td><strong>Long Term</strong></td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
INTERNAL RATE OF RETURN METHOD

Discount rate at which costs and benefits of an investment are equal

\[
(NPV_{x1} = PWB_{x2,n} - PWC_{x1,n} = 0)
\]
RATE OF RETURN EXAMPLE

- Multi-lane urban bypass
- 50 year life cycle

Financial Feasibility of an ETR?

- Two long-life (50 year) pavement designs:
  A. Heavy duty flexible pavement
  B. Plain jointed PCCP
- Cost estimates, traffic estimates, toll charge scheme, rehabilitation and maintenance interventions schedule, etc. in TAC Proc.

See Transp. Assoc. of Canada Proc. 2005
**RATE OF RETURN EXAMPLE**

NPV ($ x 10^6) / lane - km for $i =$

<table>
<thead>
<tr>
<th>Altern.</th>
<th>5%</th>
<th>12%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (Flex.)</td>
<td>15.455</td>
<td>1.760</td>
<td>-1.261</td>
</tr>
<tr>
<td>B (PCC)</td>
<td>15.389</td>
<td>1.699</td>
<td>-1.339</td>
</tr>
</tbody>
</table>

NPV = 0 at IRR ≈ 16%
PERFORMANCE INDICATORS FOR PROPERLY FUNCTIONING ASSET MANAGEMENT SYSTEMS

Ralph Haas
Susan Tighe
Lynne Cowe Falls

Excerpts From:
ARRB Conference
Cairns
May, 2003
OBJECTIVES OF PERFORMANCE INDICATORS’

- Assessing condition, function and safety, (smoothness, structural distress, level of service, mobility, etc.)
- Asset value (depending on accounting base and method)
- Monitoring effectiveness of policies
- Providing information to users
- Resource allocation tool
- Diagnostic tool

... and more ...
<table>
<thead>
<tr>
<th>Policy Objective</th>
<th>Performance Indicator</th>
<th>Implementation Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of Service to Users</td>
<td>• Network smoothness (% good, fair or poor)</td>
<td>• 90% + fair or better</td>
</tr>
<tr>
<td></td>
<td>• Annual user costs ($/km)</td>
<td>• Increase ≤ CPI</td>
</tr>
<tr>
<td></td>
<td>• Provision of mobility (ave. speed by road class)</td>
<td>• &gt; 50% speed limit</td>
</tr>
<tr>
<td>Safety Goals</td>
<td>• Accident reductions (%)</td>
<td>• Fatalities and injuries by ≥ 1% annually</td>
</tr>
<tr>
<td>Preservation of Investment</td>
<td>• Asset value of road network ($)</td>
<td>• Increase of ≥ 0.5% annually</td>
</tr>
</tbody>
</table>
What is Sustainable Transportation

...... A balance between transportation’s economic and social benefits vs. the need to protect the environment ..... 

Simply put - Do things today that don’t Screw up the Future
Green Roads is a rating system designed to distinguish high-performance sustainable new or redesigned/rehabilitated roads.

It awards credits for approved sustainable choices/practices and can be used to certify projects based on point value.
USER COSTS

- Delays due to maintenance and rehabilitation
- Vehicle operating costs
- Accidents
- Discomfort, etc.
USER DELAY COST FACTORS:

- Delay time and value(s) of time
- Traffic volume
- Types and percent of vehicles
- Speed
- Road capacity
- Traffic control plan
- Length of work zone
- Geometric characteristics
EXAMPLE (Pavement)

Plan 1: Stop and go (flag person)  4 days  Paving
Plan 2: Divert to shoulder

<table>
<thead>
<tr>
<th>AADT</th>
<th>Plan 1 UDC</th>
<th>Plan 2 UDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,000</td>
<td>$40,000</td>
<td>$420</td>
</tr>
<tr>
<td>10,000</td>
<td>$550,000</td>
<td>$190,000</td>
</tr>
</tbody>
</table>
May 2004

POSITION PAPER

The European Union Road Federation
TIRE/PAVEMENT NOISE STUDY

By

Douglas I. Hanson
Robert S. James
Christopher NeSmith

August 2004
Building roads consumes energy...

Amount of Energy Required to Build 1 Lane-Mile of Pavement

- **3-inch Concrete Pavement** (Continuously Reinforced):
  - Raw Materials Extraction: 3%
  - Manufacturing: 94%
  - Placement: 3%
  - Total Energy: 3.7 TJ

- **12-inch Asphalt Pavement** (Hot Mix Asphalt):
  - Raw Materials Extraction: 7%
  - Manufacturing: 91%
  - Placement: 2%
  - Total Energy: 3.0 TJ

Notes:
- 90%+ from manufacturing
- Numbers change a lot depending on assumption

Amount of energy consumed by 100 US households in a year (4 TJ)
- On average, a US household consumes 11,000 KWh of energy per year
- Does not include anything outside of the house (e.g., cars, fuel, etc.)

Total Energy Consumed (TJ):

4.0 TJ
First and foremost, the right engineering for materials, structural design, construction and ongoing maintenance

and

◆ Long life performance models
RECOMMENDATIONS

Continued

- Specifically adapted life cycle analysis model
- Specifically adapted performance indicators
- Specifically adapted Green Roads rating system
- Comprehensive energy consumption and emissions model