Comparative Eco-Efficiency Analysis between Hot In-place Recycling and Milling-and-Filling

Ms. Ruijun Cao, Dr. Zhen Leng, Dr. Mark Shu-Chien Hsu
Department of Civil and Environmental Engineering
The Hong Kong Polytechnic University

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Outline

1. Objective
2. Eco-efficiency Analysis
3. Case Study
4. Service Life Sensitivity Analysis
5. Conclusions
Objective

To quantify and visualize advantages and disadvantages of two asphalt pavement rehabilitation techniques in terms of economy and environment by employing Eco-efficiency analysis (EEA):

- Hot In-place Recycling (HIPR)
- Milling- and-Filling (M&F)
Eco-Efficiency Analysis (1/4)

Initially developed by a German chemicals company BASF

- Environmental Impact
- Economic Performance

Identify

The best alternative (Competing products, Processes, or Services)
Eco-Efficiency Analysis (2/4)

The general framework of Eco-efficiency Analysis

**Definition of goal and scope of the study**

**ECOLOGY**
- Life Cycle Inventory
- Life Cycle Impact Assessment
  1. Classification
  2. Characterization
  3. Weighting

**ECONOMY**
- Life Cycle Costing
  - Agency cost
  - User cost
- Aggregation

**Interpretation**

Purpose of EEA:
1. Strategic planning
2. Product development
3. Policy creation
4. Environmental labeling
5. Marketing
6. Other

**Integrated assessment and evaluation**
Eco-Efficiency Analysis (3/4)-Integration

Step 1: Normalization
The impact of each of environmental categories is normalized with respect to one another.

Normalized Environmental Impacts

- HIPIR
- M&F

0
0.5
1

Emissions
Risk potential
Toxicity potential
Raw material consumption
Energy consumption
Step 2: Weighting
Combine the normalized values via a weighting scheme to form a total index for the environmental impact categories.

Emissions 20%
Energy consumption 25%
Raw material consumption 25%
Toxicity potential 20%
Risk potential 10%

WEIGHTING FACTORS [%]
Emissions 20%
Energy consumption 25%
Raw material consumption 25%
Toxicity potential 20%
Risk potential 10%
Step 3: Eco-efficiency portfolio position

The EI and the NF\(_C\) are used to calculate the portfolio position.
(Kicherer et al., 2007)

\[
PP_{E,\alpha} = \frac{EI_\alpha}{(\Sigma EI)/j}
\]

\[
PP_{C,\alpha} = \frac{NF_{C,\alpha}}{(\Sigma NF_C)/j}
\]

Where,

- \(PP_{E,\alpha}\) = Environmental impact portfolio position for product \(\alpha\)
- \(PP_{C,\alpha}\) = Cost impact portfolio position for product \(\alpha\)
- \(EI_\alpha\) = Environmental impact of product \(\alpha\)
- \(NF_{C,\alpha}\) = Normalization factor for the costs of product system \(\alpha\)
- \(j\) = Number of products under consideration
Step 3: Eco-efficiency portfolio position
The EI and the NF$_C$ are used to calculate the portfolio position. (Kicherer et al., 2007)
Yingbin Avenue

Location
Xianyang, Shaanxi, China

Rehabilitation
Method: HIPR
Time: 2015
Length: 3.8km
# Case Study (1/4) - Basic Information

<table>
<thead>
<tr>
<th>Construction Scheme</th>
<th>HIPR (Real case)</th>
<th>M &amp; F (Mock case)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wearing course: AC-10 30mm</td>
<td>Wearing course: AC-13 40mm</td>
</tr>
<tr>
<td></td>
<td>Base course: AC-25 50mm</td>
<td>Base course: AC-25 50mm</td>
</tr>
<tr>
<td>Before</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service Life</td>
<td>15 years (Assumption)</td>
<td>15 years (Assumption)</td>
</tr>
</tbody>
</table>
Case Study (2/4)-System Boundary

Materials Extraction and Production Phase

Transportation Phase

Construction Phase

End-of-Life Phase

Quarry/Asphalt Production Plant

Hot Asphalt Mixing Plant (Type 3000)

Construction Site

Scrap Yard

Heating & Softening current pavement

Lifting & Remixing with new HMA and rejuvenator

Milling & Removing current pavement

Laying down the new HMA

Paving

Compacting
Case Study (3/4)-Data Acquisition

- **Environmental Impact Data**

<table>
<thead>
<tr>
<th>Life Cycle Phase</th>
<th>Software</th>
<th>Function</th>
<th>Developer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material production phase</td>
<td>Simapro 7.0</td>
<td>Model the GHGs, energy and raw material used in the material extraction phase</td>
<td>PRe Consultants</td>
</tr>
<tr>
<td>Transportation phase</td>
<td>MOVES 2014a</td>
<td>Evaluate the GHGs and energy during the transportation of material</td>
<td>US EPA</td>
</tr>
<tr>
<td>Construction phase</td>
<td>NONROAD</td>
<td>Provides emission factors for various ranges of horsepower of different construction equipment.</td>
<td>US EPA</td>
</tr>
<tr>
<td>End-of-life phase</td>
<td></td>
<td>“Cut-off” allocation method</td>
<td></td>
</tr>
</tbody>
</table>
Case Study (3/4)-Data Acquisition

• Cost Data

Assumptions
AADT: 15000
Speed limit: 90km/h → 60km/h (work zone speed)

<table>
<thead>
<tr>
<th>Cost</th>
<th>Reference</th>
<th>Developer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agency Cost</td>
<td>Construction cost</td>
<td>Contract &amp; JTG/T b06-02-2007</td>
</tr>
<tr>
<td></td>
<td>Energy consumption</td>
<td>Ministry of Communications of PRC</td>
</tr>
<tr>
<td>User cost</td>
<td>Traffic delay cost</td>
<td>Real Cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FHWA</td>
</tr>
</tbody>
</table>
### Case Study (4/4) - Results

- **Normalized numerical results**

<table>
<thead>
<tr>
<th>Environmental Impacts</th>
<th>Normalized results</th>
<th>HIPR</th>
<th>M&amp;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions (20%)</td>
<td>0.72</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Energy consumption (25%)</td>
<td>1</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td>Raw material consumption (25%)</td>
<td>0.52</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Toxicity potential (20%)</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Risk potential (10%)</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Overall environmental impact</strong></td>
<td>0.84</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost Performance</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Agency cost (50%)</td>
<td>0.71</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>User cost (50%)</td>
<td>1</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td><strong>Total Cost performance</strong></td>
<td>0.95</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Normalized results**
- $P_{PE}$: 0.91
- $P_{PC}$: 0.97

**Same service life:**
- **15 years**

- Reduce 28%
- 7% more
- Save 48%

- Reduce 16%
- Save 29%
- Almost same
- Reduce 5%
Case Study (4/4)-Results

- **Graphical Results**

It is clear to identify that the HIPR has the higher eco-efficiency than M&F for this case.
Service Life Sensitivity Analysis (1/3)

Five Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>M&amp;F service life (year)</th>
<th>HIPR service life (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>B</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>D</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>E</td>
<td>15</td>
<td>11</td>
</tr>
</tbody>
</table>
Service Life Sensitivity Analysis (2/3)

Scatter plot showing:
- Emissions
- Risk potential
- Toxicity potential
- Energy consumption
- Raw material consumption

Comparing two scenarios:
- HIPR-A
- M&F-A

Scenario A
Service Life Sensitivity Analysis (2/3)

Emissions
0.5
1
Risk potential
Toxicity potential
Energy consumption
Raw material consumption

Scenario A
Scenario B

HIPR-A
HIPR-B
M&F-A
M&F-B
Service Life Sensitivity Analysis (2/3)

![Graph showing Service Life Sensitivity Analysis]

- Emissions
- Energy consumption
- Toxicity potential
- Raw material consumption

Scenario A
Scenario B
Scenario C
Service Life Sensitivity Analysis (2/3)

- Emissions
- Energy consumption
- Toxicity potential
- Raw material consumption

Scenarios:
- Scenario A
- Scenario B
- Scenario C
- Scenario D
Service Life Sensitivity Analysis (2/3)
Service Life Sensitivity Analysis (3/3)

![Diagram showing the relationship between Costs (relative) and Environmental impact for different scenarios labeled A to E, with HIPR and M&F categories.]
Service Life Sensitivity Analysis (3/3)
Service Life Sensitivity Analysis (3/3)
Service Life Sensitivity Analysis (3/3)
Service Life Sensitivity Analysis (3/3)
Service Life Sensitivity Analysis (3/3)

Costs (relative)

Environmental impact

High Eco-efficiency

Low Eco-efficiency

M&F  HIPR

15  11
Conclusions

• In this project, the decreasing service life of HIPR witnesses its reduction of relative eco-efficiency compared with M&F techniques. For the presented case study, when the ratio of service life of two alternatives reaches 12/15 (HIPR/M&F), the M&F starts to show its advantages.

• EEA shows its high potential as an effective sustainability assessment tool for comparing asphalt pavement rehabilitation alternatives.

• Time period, region, system boundaries, transportation distance, crude source distribution, and treatment of refinery allocation will all affect the final eco-efficiency results. Therefore, further research is recommended on the sensitivity analysis about the effects of various factors to obtain more comprehensive results.
Thanks you!

ruijun.c.cao@connect.polyu.hk