A Performance-based Sustainability Assessment tool for Road pavements and Railway tracks

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WP3- SUP&R assessment

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Greenroads® Summary
Silver Certified
SR 522 Bothell Crossroads
Bothell, WA

Total Score* 43
Project Requirements 11/11
Environment & Water 9/21
Access & Equity 13/30
Construction Activities 5/14
Materials & Resources 10/23
Pavement Technologies 5/20
Custom Credits 1/10

*Score does not include Project Requirements
Sustainability performance-based DSS
Methodology & Tool development

EU Stakeholders survey

Establish conceptual framework for comprehensive sustainability assessment

Define indicators to evaluate sustainability

Develop weighting methodology for assessment tool

Validate and benchmark sustainability assessment tool

MCDA TOOL

Tailored methodology with literature review

CASE STUDY
STEP 1: Framework - Objective Hierarchy

STEP1: Framework - Objective Hierarchy

- Increase the Level of Sustainability with Respect to Pavements

  - Enhance Human Capital
    - Maximize Positive Impacts Towards or Minimize Negative Impacts Towards
      - Healthy People
      - Healthy Community
      - Healthy Economy
  - Preserve the Natural Environment and Ecosystems
    - Healthy Natural Environment
    - Healthy Ecosystems
    - Healthy Climate and Resources

STEP1: Framework - Concept

DPSIR & Performance Management


Framework - Concept

Goal
Preserve the Natural Environment & Ecosystems

Objective
Maximize healthy resources

Response
Driver – Traffic growth leading to pavement construction and maintenance
Pressure – Resource use
State – Resources available, Biodiversity, GHG concentration, etc.
Impacts – For example: Resource depletion, biodiversity loss, global warming potential, resource costs, etc.

Performance Indicators
For example: GHG emissions (production, transport), Virgin material use, Waste diverted from landfills, Energy consumption (production), etc.

Target
Developed based on models and data

Data
Results from evidence based assessment (e.g., LCA) conducted to determine impacts

Evaluation
Is response adequate to meet the objective and targets?
STEP 2: Definition of indicators (short list)

SUSTAINABLE ASSESSMENT FRAMEWORK

Means objectives

Sub-categories

Organized by

Rail

Literature review

1° step of indicators selection

2° step of indicators selection

Short list of rail indicators

Library of best practices

Three criteria:
- Unique and Clear definition
- Measurability
- Recurrence

Four criteria:
- sensitivity
- updatable data
- available data
- non-corruptibility

66 indicators

FINAL LIST (threshold)
### STEP 2: Definition of indicators (railways)

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Means objectives</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse GHG (primarily CO₂ emission)</td>
<td>Healthy Climate and Resources</td>
<td>Various gaseous compounds (principally carbon dioxide) that absorb infrared radiation and trap heat in the atmosphere.</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>Healthy Climate and Resources</td>
<td>Amount of energy consumed in the process of construction or maintenance.</td>
</tr>
<tr>
<td>Recycled content (Slag and ashes, RAP)</td>
<td>Healthy Natural Environment</td>
<td>Recycled content recovered from existing structure of total discarded/waste material.</td>
</tr>
<tr>
<td>Water depletion</td>
<td>Healthy Natural Environment</td>
<td>Amount of water used for the required operations of construction or maintenance.</td>
</tr>
<tr>
<td>Acidification potential</td>
<td>Healthy Natural Environment</td>
<td>Increase in the concentration of the hydrogen ions (H+) in water and soil. This alters the pH of that medium which may cause damage to the organic and inorganic materials.</td>
</tr>
<tr>
<td>Eutrophication potential (EP)</td>
<td>Healthy Ecosystems</td>
<td>Potential presence of nutrients that can cause over-fertilisation of water and soil which in turn can result in increased growth of biomass.</td>
</tr>
<tr>
<td>Ozone depletion potential (ODP)</td>
<td>Healthy Ecosystems</td>
<td>Indicates the potential for emissions of chlorofluorocarbon (CFC) compounds and other halogenated hydrocarbons to deplete the ozone layer.</td>
</tr>
<tr>
<td>Safety impact</td>
<td>Healthy People</td>
<td>Accidents in property damage, medical, and legal costs.</td>
</tr>
<tr>
<td>User comfort</td>
<td>Healthy People</td>
<td>Factor that evaluates passenger’s feeling about vibration environment.</td>
</tr>
<tr>
<td>Noise or vibration reduction</td>
<td>Healthy Community</td>
<td>Reduction of noise/vibration level in order to reduce the acoustic impact on the users and population.</td>
</tr>
<tr>
<td>Life cycle cost</td>
<td>Healthy Economy</td>
<td>The total cost of the purchase and installation, and the use and the maintenance during the life cycle.</td>
</tr>
</tbody>
</table>
DEFINITION OF ALTERNATIVES, MCDA and SA

Step 1: Select Indicators
- Economic
- Environmental
- Social

Step 2: Define Alternatives
- Evaluation Matrix: Definition
- Evaluation Matrix: Graphical Visualization

Step 3: Filter Evaluation Matrix
- Dominance Analysis
- Correlation Analysis (Pearson’s correlation coefficients and parametric t-test)
- Univariate and Multivariate Descriptive Statistics
- Final Selection of Indicators

Step 4: Define Weighting Method
- Subjective Methods: SUP&R ITN (AHP); Manually Defined Weights
- Objective Methods: Entropy; Mean Weights

Step 5: Define PROMETHEE Method Parameters
- Preference Functions
- Thresholds (relative or absolute values)

Step 6: Visualize MCDA Results
- Ranking of alternatives provided by PROMETHEE method
- Net Outranking Flows; Deviation Values; Preference Function Values

Step 7: Perform Uncertainty Analysis
- Alternatives’ Scores
- Weighting Method
- PROMETHEE Parameters

Mean Objectives
Sub-categories
Qualitative Scales
Stakeholders Engagement
AHP Survey
SUP&R ITN Weights
Exporting Module
- Inputs
- Data
- Parameters
- Intermediate Results
- Final Results
- Sensitivity Analysis
- Scenarios

Library
- Library
- Mean Objectives
- Sub-categories
- Indicators
- Qualitative Scales

SUSTAINABILITY PERFORMANCE-BASED DECISION SUPPORT SYSTEM
Case Study: Road Pavement

• Initial pavement structure and M&R plan
Definition of the alternative (asphalt mixtures for road surface)

<table>
<thead>
<tr>
<th>Item</th>
<th>Type of mixture</th>
<th>HMA, 0% RAP</th>
<th>WMA-CECABASE(^\circ), 0% RAP</th>
<th>Foamed WMA, 0% RAP</th>
<th>HMA, 50% RAP</th>
<th>WMA-CECABASE(^\circ), 50% RAP</th>
<th>Foamed WMA, 50% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin aggregate Quantity (%/m)</td>
<td></td>
<td>94.4</td>
<td>94.4</td>
<td>94.4</td>
<td>48.4</td>
<td>48.37</td>
<td>48.36</td>
</tr>
<tr>
<td>Virgin aggregate Water content (%/a)</td>
<td></td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>RAP Quantity (%/m)</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td>48.4</td>
<td>48.37</td>
<td>48.36</td>
</tr>
<tr>
<td>RAP Water content (%/RAP)</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Bitumen Penetration grade</td>
<td></td>
<td>35/50</td>
<td>35/50</td>
<td>35/50</td>
<td>35/50</td>
<td>35/50</td>
<td>35/50</td>
</tr>
<tr>
<td>Bitumen Quantity (%/m)</td>
<td></td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
<td>3.2</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>WMA agent Type</td>
<td></td>
<td></td>
<td>surfactant</td>
<td>water</td>
<td>surfactant</td>
<td>water</td>
<td></td>
</tr>
<tr>
<td>WMA agent Quantity (%/m)</td>
<td></td>
<td></td>
<td>0.054</td>
<td>0.077</td>
<td>-</td>
<td>0.054</td>
<td>0.077</td>
</tr>
<tr>
<td>Mixture density (kg/m(^3))</td>
<td></td>
<td>2360</td>
<td>2340</td>
<td>2260</td>
<td>2370</td>
<td>2360</td>
<td>2360</td>
</tr>
</tbody>
</table>
**Table 1. Evaluation matrix.**

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>GW (Kg CO$_2$-eq)</th>
<th>ED (MJ)</th>
<th>SM C (%)</th>
<th>WC (m$^3$)</th>
<th>AC (kg SO$_2$-eq)</th>
<th>EU (kg PO$_4$-eq)</th>
<th>SOD (kg CHC$_{11}$-eq)</th>
<th>PM (kg PM$_{10}$-eq)</th>
<th>TC (Hr)</th>
<th>LCH AC (€)</th>
<th>LCR UC (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HMA, 0%RAP WMA-CECABA SE®, 0%RAP Foamed WMA, 0%RAP</td>
<td>1257 898 69679 068</td>
<td>0 24</td>
<td>24</td>
<td>103</td>
<td>451</td>
<td>0.823</td>
<td>2871</td>
<td>46.1</td>
<td>42</td>
<td>12663 06</td>
<td>2145</td>
</tr>
<tr>
<td>2</td>
<td>CECABA SE®, 0%RAP Foamed WMA, 0%RAP</td>
<td>1236 348 69442 583</td>
<td>0 41</td>
<td>23</td>
<td>102</td>
<td>449</td>
<td>0.818</td>
<td>2847</td>
<td>40.9</td>
<td>21</td>
<td>12702 96</td>
<td>2042</td>
</tr>
<tr>
<td>3</td>
<td>HMA, 0%RAP WMA, 0%RAP</td>
<td>1223 723 68680 490</td>
<td>0 23</td>
<td>99</td>
<td>101</td>
<td>443</td>
<td>0.811</td>
<td>2809</td>
<td>40.9</td>
<td>21</td>
<td>12590 28</td>
<td>2042</td>
</tr>
<tr>
<td>4</td>
<td>HMA, 50%RAP WMA-CECABA SE®, 50%RAP Foamed WMA, 50%RAP</td>
<td>1202 024 63620 766</td>
<td>11 22</td>
<td>34</td>
<td>978</td>
<td>427</td>
<td>0.750</td>
<td>2713</td>
<td>46.1</td>
<td>42</td>
<td>12047 73</td>
<td>2145</td>
</tr>
<tr>
<td>5</td>
<td>CECABA SE®, 50%RAP Foamed WMA, 50%RAP</td>
<td>1181 481 63536 209</td>
<td>11 39</td>
<td>36</td>
<td>964</td>
<td>425</td>
<td>0.748</td>
<td>2691</td>
<td>40.9</td>
<td>21</td>
<td>12090 36</td>
<td>2042</td>
</tr>
<tr>
<td>6</td>
<td>Foamed WMA, 50%RAP</td>
<td>1178 377 63380 866</td>
<td>11 22</td>
<td>32</td>
<td>963</td>
<td>424</td>
<td>0.748</td>
<td>2679</td>
<td>40.9</td>
<td>21</td>
<td>12032 25</td>
<td>2042</td>
</tr>
</tbody>
</table>

Key: HMA- hot mix asphalt; WMA- warm mix asphalt; RAP- reclaimed asphalt pavement; GW- global warming; ED- Energy demand; SM- Secondary materials consumption; WC- Water consumption; AC- acidification; EU- Eutrophication; SOD- Stratospheric ozone depletion; PM- Particulate matter; TC- Traffic congestion; LCHAC- Life cycle highway agency costs; LCRUC- Life cycle road user costs.
Step 4: Define Weighting Method
Step 4: Define Weighting Method
Weights and preference functions

Table 1. Weights, preference functions and thresholds considered for each indicator.

<table>
<thead>
<tr>
<th>Sustainability indicator</th>
<th>Weight (%)</th>
<th>Preference Function</th>
<th>p</th>
<th>q</th>
</tr>
</thead>
<tbody>
<tr>
<td>GW</td>
<td>3.17</td>
<td>V- Shape with linear preference and indifference area</td>
<td>51688.65</td>
<td>3976.05</td>
</tr>
<tr>
<td>ED</td>
<td>3.29</td>
<td>V- Shape with linear preference and indifference area</td>
<td>4093831.30</td>
<td>314910.10</td>
</tr>
<tr>
<td>SMC</td>
<td>4.75</td>
<td>V- Shape with linear preference and indifference area</td>
<td>7.15</td>
<td>0.55</td>
</tr>
<tr>
<td>WC</td>
<td>15.12</td>
<td>V- Shape with linear preference and indifference area</td>
<td>1229.15</td>
<td>94.55</td>
</tr>
<tr>
<td>AC</td>
<td>4.08</td>
<td>V- Shape with linear preference and indifference area</td>
<td>484.90</td>
<td>37.30</td>
</tr>
<tr>
<td>EU</td>
<td>4.08</td>
<td>V- Shape with linear preference and indifference area</td>
<td>172.25</td>
<td>13.25</td>
</tr>
<tr>
<td>SOD</td>
<td>4.08</td>
<td>V- Shape with linear preference and indifference area</td>
<td>0.04875</td>
<td>0.00375</td>
</tr>
<tr>
<td>PM</td>
<td>30.90</td>
<td>V- Shape with linear preference and indifference area</td>
<td>124.80</td>
<td>9.60</td>
</tr>
<tr>
<td>TC</td>
<td>20.76</td>
<td>V- Shape with linear preference and indifference area</td>
<td>3.39</td>
<td>0.26</td>
</tr>
<tr>
<td>LCHAC</td>
<td>4.89</td>
<td>V- Shape with linear preference and indifference area</td>
<td>43596.15</td>
<td>3353.55</td>
</tr>
<tr>
<td>LCRUC</td>
<td>4.89</td>
<td>V- Shape with linear preference and indifference area</td>
<td>66.95</td>
<td>5.15</td>
</tr>
</tbody>
</table>

Key: GW- global warming; ED- Energy demand; SMC- Secondary materials consumption; WC- Water consumption; AC- Acidification; EU- Eutrophication; SOD- Stratospheric ozone depletion; PM- Particulate matter, TC- Traffic congestion; LCHAC- Life cycle highway agency costs; LCRUC- Life cycle road user costs; p- preference threshold; q- indifference threshold.
Sustainability Ranking

Flow

Alternatives

1. HMA, 0% RAP
2. WMA, CECABASE 0% RAP
3. Foamed WMA, 0% RAP
4. HMA, 50% RAP
5. WMA, CECABASE 50% RAP
6. Foamed WMA, 50% RAP

Positive flow
Negative flow
Net flow
Step 7: Sensitivity Analysis

<table>
<thead>
<tr>
<th>Alternative Name</th>
<th>Ranking</th>
<th>Positive outranking Row</th>
<th>Negative outranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional VTAC</td>
<td>6</td>
<td>0.0654</td>
<td>0.3494</td>
</tr>
<tr>
<td>VTAC: WMA-CERBASE additive_0 URAP</td>
<td>5</td>
<td>0.1029</td>
<td>0.4384</td>
</tr>
<tr>
<td>VTAC: Foam WMA_0 URAP</td>
<td>4</td>
<td>0.1785</td>
<td>0.3246</td>
</tr>
<tr>
<td>VTAC: HMA_50 URAP</td>
<td>2</td>
<td>0.4824</td>
<td>0.1664</td>
</tr>
<tr>
<td>VTAC: WMA-CERBASE additive_50 URAP</td>
<td>3</td>
<td>0.4084</td>
<td>0.1974</td>
</tr>
<tr>
<td>VTAC: Foam WMA_50 URAP</td>
<td>1</td>
<td>0.4739</td>
<td>0.03101</td>
</tr>
</tbody>
</table>

![Graph showing sensitivity analysis results](image-url)
SUSTAINABILITY PERFORMANCE-BASED DECISION SUPPORT SYSTEM

ER1, ER1bis - Sustainability Assessment framework:
• Objectives
• Categories
• Indicators identity

ER2,
• Selection methodology

ER3
• Multi-Criteria Decision Analysis (Rating tool)
SUP&R ITN Tool

General SA Framework

ER1, ER1bis - Sustainability Assessment framework:
- Objectives
- Categories
- Indicators identity
- Stakeholders engagement (Weighting set)

System specific tasks:
- Road Pavements
- Railway trackbeds

ER2,
- Review of system specific scientific papers, reports, etc
- Selection methodology (ER2)
- Railway indicator selection
- Sust Assess SUP&R railway technologies

ER3
- Multi-Criteria Decision Analysis (Rating tool)
- Review of papers, reports, SRS
- Pavement indicator selection
- Sust Assess SUP&R railway technologies
Acknowledgements

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