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

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SUP&R ITN Research Project
How can we design Sustainable technologies for Road Pavements and Railway Trackbeds?

**Design:**
- Pavement/Railway structure
- Design Life/Mechanical performance prediction
- M & R strategies

**Final Design**

**Sustainability Assessment**
- Sustainability Performance prediction and rating

Good? Bad?

Good
Sustainability Rating Systems (SRS) in Transp.Infr.Eng

<table>
<thead>
<tr>
<th>Infrastructures</th>
<th>Road Infrastructures (in use)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• CEEQUAL (UK)</td>
<td>• GREENROADS (USA)</td>
</tr>
<tr>
<td>• Envision (USA)</td>
<td>• FHWA INVEST (USA)</td>
</tr>
<tr>
<td>• BREEAM Infrastructures (NL)</td>
<td>• GreenPave (CA)</td>
</tr>
<tr>
<td>• IS rating system (AUS)</td>
<td>• BE$^2$ST- In-Highway</td>
</tr>
<tr>
<td></td>
<td>• I-LAST (IL, USA)</td>
</tr>
<tr>
<td></td>
<td>• GreenLITES (NYS, USA)</td>
</tr>
<tr>
<td></td>
<td>• LCE4ROADS</td>
</tr>
</tbody>
</table>
SRS Conclusions and suggestions

- SRS are usually **qualitative based**, although few recent tools are defined for a quantitative assessment.

- A third-party assessment system allows behaviour changing, however **self-assessment is a good first step for design workshops**.

- **European, Flexible, User-friendly framework** mainly based on quantitative measurements is needed!
Performance-based Sustainability assessment tool
Road Pavement and Railway trackbed technologies
The Team

WP3 leader: DAVIDE LO PRESTI
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James Bryce
ER1a – University of Nottingham

Stefanie Brodie
ER1b – University of Nottingham

Sara Bressi
ER2 – University of Palermo, IT

Joao Oliveira Dos Santos
ER3 – IFSTTAR, FR
Methodology & Tool development

- Establish conceptual framework for comprehensive sustainability assessment
- Define indicators to evaluate sustainability
- Develop weighting methodology for assessment tool
- Validate and benchmark sustainability assessment tool

Tailored methodology with literature review

EU Stakeholders survey

CASE STUDY

MCDA TOOL
STEP1: 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

GOALS

OBJECTIVES AND INDICATOR

IDENTITY

STEP 1: Framework - Concept

DPSIR & Performance Management


STEP1: Framework - Concept

Goal
Preserve the Natural Environment & Ecosystems

Objective
Maximize healthy resources

Response
Increase the use of recycled material in the production of pavements

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?

- Comparative analysis
- Design workshops
STEP 2: Definition of indicators (short list)

SUSTAINABLE ASSESSMENT FRAMEWORK

Rail

Literature review

Library of best practices

<table>
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<tr>
<th>Publication year</th>
<th>Nº of publications</th>
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<td>1995</td>
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<td>2014</td>
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<td>2015</td>
<td>21</td>
</tr>
<tr>
<td>2016</td>
<td>22</td>
</tr>
<tr>
<td>2017</td>
<td>23</td>
</tr>
</tbody>
</table>
STEP 2: Definition of indicators (short list)

SUSTAINABLE ASSESSMENT FRAMEWORK

Rail

Literature review

1° step of indicators selection

2° step of indicators selection

Library of best practices

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

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

66 indicators
STEP 2: Definition of indicators (short list)

SUSTAINABLE ASSESSMENT FRAMEWORK

Means objectives

Sub-categories

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

Organized by

FINAL LIST (threshold)

66 indicators
## 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>
STEP 3: EU survey with Stakeholders (weights)

Approximately **fifty** stakeholders have been interviewed. It was asked them to judge the relative importance of the means objectives and sub-categories.

- public/institutional representative
- public administration,
- self-employed professional,
- universities,
- Enterprises
- other social agents

<table>
<thead>
<tr>
<th>Means objectives</th>
<th>Weights of the means objectives</th>
<th>Sub-category</th>
<th>Weights of the sub-categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy Climate and Resources</td>
<td>11,25</td>
<td>Recycling and Materials Conservation</td>
<td>15,63</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long-life Pavements</td>
<td>11,97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GHG Emissions and Non-renewable Resources</td>
<td>11,87</td>
</tr>
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<td></td>
<td></td>
<td>Land Resources</td>
<td>11,06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energy</td>
<td>10,83</td>
</tr>
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<td></td>
<td></td>
<td>Local Materials</td>
<td>10,56</td>
</tr>
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<td></td>
<td></td>
<td>Climate Change</td>
<td>10,42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Renewable resources</td>
<td>10,25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Albedo</td>
<td>7,46</td>
</tr>
</tbody>
</table>
Step 4 – SUSTAINABILITY ASSESSMENT TOOL (MCDA)

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

DEFINITION OF ALTERNATIVES, MCDA and SA

- European
- Multi-sector
- Flexible
- User-friendly
- Quantitative
Step 4 – SUSTAINABILITY ASSESSMENT TOOL (MCDA)
Case Study: Road Pavement

Initial pavement structure and M&R plan

- **Initial construction**
  - Tack Coat
  - BBGA3 14 cm

- **Maintenance 1**
  - Tack Coat 100% + STAC 2.5 cm 75% + AC 4 cm 25%
  - Operation Date: 2024

- **Maintenance 2**
  - Tack Coat 100% + STAC 2.5 cm 50% + AC 4 cm 50%
  - Operation Date: 2032

- **Maintenance 3**
  - Tack Coat 100% + AC 4 cm 100% of surface
  - Operation Date: 2040

- **EOL Milling slow lane**
  - STAC 2.5 cm 100% of surface
  - Operation Date: 2045

- **Bituminous pavement with maintenance policy based on LAURENT (2004)**
### Case Study: Road Pavement

**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®, 0% RAP</th>
<th>Foamed WMA, 0% RAP</th>
<th>HMA, 50% RAP</th>
<th>WMA-CECABASE®, 50% RAP</th>
<th>Foamed WMA, 50% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Virgin aggregate</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity (%/m)</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>
<td></td>
</tr>
<tr>
<td>Water content (%/a)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<tr>
<td><em>RAP</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity (%/m)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>48.4</td>
<td>48.37</td>
<td>48.36</td>
<td></td>
</tr>
<tr>
<td>Water content (%/RAP)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<tr>
<td><em>Bitumen</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Penetration grade</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>
<td>35/50</td>
</tr>
<tr>
<td>Quantity (%/m)</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>
<td>3.2</td>
</tr>
<tr>
<td><em>WMA agent</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>-</td>
<td>surfactant</td>
<td>water</td>
<td>-</td>
<td>surfactant</td>
<td>water</td>
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</tr>
<tr>
<td>Quantity (%/m)</td>
<td>-</td>
<td>0.054</td>
<td>0.077</td>
<td>-</td>
<td>0.054</td>
<td>0.077</td>
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</tr>
<tr>
<td><em>Mixture density</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kg/m³)</td>
<td>2360</td>
<td>2340</td>
<td>2260</td>
<td>2370</td>
<td>2360</td>
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</tbody>
</table>
## Case Study: Road Pavement

### Evaluation matrix

<table>
<thead>
<tr>
<th>Alternative scenario</th>
<th>Sustainability indicators</th>
<th>ID</th>
<th>Name</th>
<th>GW (Kg CO(_2)-eq)</th>
<th>ED (MJ)</th>
<th>SMC (%)</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></td>
<td></td>
<td>HMA, 0%RAP WMA-CECABA SE(^\circ), 0%RAP Foamed WMA, 0%RAP</td>
<td>1257 898</td>
<td>69679 068</td>
<td>0</td>
<td>24</td>
<td>24</td>
<td>103 76</td>
<td>451 3</td>
<td>0.823</td>
<td>2871 42</td>
<td>46.1 12663 06</td>
<td>2145</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>HMA, 0%RAP WMA-CECABA SE(^\circ), 0%RAP Foamed WMA, 0%RAP</td>
<td>1236 348</td>
<td>69442 583</td>
<td>0</td>
<td>41</td>
<td>23</td>
<td>102 21</td>
<td>449 5</td>
<td>0.818</td>
<td>2847 40</td>
<td>40.9 12702 96</td>
<td>2042</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>HMA, 0%RAP WMA-CECABA SE(^\circ), 0%RAP Foamed WMA, 0%RAP</td>
<td>1223 723</td>
<td>68680 490</td>
<td>0</td>
<td>23</td>
<td>99</td>
<td>101 17</td>
<td>443 1</td>
<td>0.811</td>
<td>2809 40</td>
<td>40.9 12590 28</td>
<td>2042</td>
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<tr>
<td>4</td>
<td></td>
<td></td>
<td>HMA, 50%RAP WMA-CECABA SE(^\circ), 0%RAP Foamed WMA, 0%RAP</td>
<td>1202 024</td>
<td>63620 766</td>
<td>11</td>
<td>22</td>
<td>34</td>
<td>978 8</td>
<td>427 3</td>
<td>0.750</td>
<td>2713 46</td>
<td>46.1 12047 73</td>
<td>2145</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>HMA, 50%RAP WMA-CECABA SE(^\circ), 0%RAP Foamed WMA, 0%RAP</td>
<td>1181 481</td>
<td>63536 209</td>
<td>11</td>
<td>39</td>
<td>36</td>
<td>964 5</td>
<td>425 9</td>
<td>0.748</td>
<td>2691 40</td>
<td>40.9 12090 36</td>
<td>2042</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>HMA, 50%RAP WMA-CECABA SE(^\circ), 0%RAP Foamed WMA, 0%RAP</td>
<td>1178 377</td>
<td>63380 866</td>
<td>11</td>
<td>22</td>
<td>32</td>
<td>963 0</td>
<td>424 8</td>
<td>0.748</td>
<td>2679 40</td>
<td>40.9 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; 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.
Case Study: Road Pavement

Define Weighting Method
Case Study: Road Pavement

Visualize MCDA results
Case Study: Road Pavement

Sensitivity analysis (weights)
Case Study: Road Pavement

Sustainability Ranking

Flow Alternatives

- Positive flow
- Negative flow
- Net flow

1. 6th: HMA, 0%RAP
2. 5th: Foamed WMA, CECABASE 0%RAP
3. 4th: WMA, 0%RAP
4. 3rd: HMA, 50%RAP
5. 2nd: Foamed WMA, CECABASE 50%RAP
6. 1st: HMA, 0%RAP

Alternatives
Conclusions
Flexible Performance-based Sustainability Assessment

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

ER2,
- Review of system-specific scientific papers, reports, etc.
- Selection methodology

ER3
- Multi-Criteria Decision Analysis (Rating tool)
- Review of system-specific scientific papers, reports, etc.

Flexible Performance-based Sustainability Assessment

Conclusions
Conclusions

SUP&R MCDA tool

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

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

System specific tasks:
- Road Pavements
- Railway trackbeds
ACKNOWLEDGMENTS

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SUPeRITN
Sustainable Pavement & Railway Initial Training Network

www.superitn.eu

#sustainablepavement(s)
#sustainablerailway(s)
The next one...

This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement number 607524.

Sustainable Multi-functional Automated Resilient Transport Infrastructures

15 Marie Curie researchers in place

http://smartietn.eu
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PROJECTS:
- Sustainable Pavements
- Sustainable Railways
- Sustainability Assessment of Transport Infrastructures