Holistic optimisation of noise reducing devices

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1. Context and objectives
2. Environmental situations and acoustical parameters
3. Non-acoustical parameters
4. Execution of optimisations
5. Results analysis
6. Conclusions and perspectives
1. **Context and objectives**
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QUIESST: “QUIetening the Environment for a Sustainable Surface Transport”

Within the 7th EU framework program:
- Theme: Transport (including Aeronautics)
- FP7-SST-2008-RTD-1
  Activity: 7.2.1 - The greening of Surface Transport
  Area: 7.2.1.1 - The Greening of Products and Operations
  Topic: SST.2008.1.1.3 – Holistic Noise and Vibration Abatement
- Started November 2009
Objectives:
The concept of QUIESST is to merge [...] the consideration of the “true” intrinsic acoustic characteristics of Noise Reducing Device, together with their extrinsic acoustic characteristics, and their sustainability in a holistic way [...].

Topics:
- the near field / far field relationship (WP2)
- the in-situ measurement of “true” sound absorption and airborne sound insulation (WP3)
- the comparison of the existing laboratory tests results of European NRD with the corresponding in-situ measurement test results (WP4)
- the holistic approach of NRD optimization (WP5)
- the sustainability of NRD (WP6)
2 types of NRD characteristics/performances:

**Acoustical**
- Sound pressure level
- Insertion Loss
- etc…

**Non-acoustical**
- Construction cost
- Global Warming Potential
- Waste production
- etc…

The goal of WP5 IS NOT to design new optimized NRDs
The goal of WP5 IS to assess the potential acoustical and/or non-acoustical “gains” that can be expected for different sets of environmental configurations from multiple-criteria NRD optimisations
1. Context and objectives

2. Environmental situations and acoustical parameters

3. Non-acoustical parameters

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6. Conclusions and perspectives
Different environmental situations studied:

1. Types of environments: rural (large distance, grass covered ground) & urban (smaller distances, asphalt covered ground)

2. Topographies: flat, embanked and depressed topographies

3. Noise sources: road source (50 km/h for urban env., 90 km/h for rural env.) & railway sources (French high speed train at 300 km/h)

4. Noise reducing devices: 4 noise reducing devices families + a reference (straight, 4 m high concrete barrier)
Environmental situations and acoustical parameters

Graphs showing A-weighted spectra for different environments:
- Rural environment
- Urban environment
Environmental situations and acoustical parameters

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Unit</th>
<th>Range</th>
<th>Number of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel width</td>
<td>m</td>
<td>[0.1; 0.5]</td>
<td>1</td>
</tr>
<tr>
<td>Panel length</td>
<td>m</td>
<td>[1; 5]</td>
<td>1</td>
</tr>
<tr>
<td>Tilting</td>
<td>Deg</td>
<td>[-5; +5]</td>
<td>1</td>
</tr>
<tr>
<td>Material</td>
<td>N/A</td>
<td>N/A</td>
<td>2</td>
</tr>
<tr>
<td>Bezier control points</td>
<td>m</td>
<td>[(-1.5; 0.1); (1.5; 0.1)]</td>
<td>4</td>
</tr>
</tbody>
</table>

$\alpha_1$, $\alpha_2$, $d$
Environmental situations and acoustical parameters

Acoustical parameters:

- two groups of 6 receivers at 2 and 4 meters on each side of the barrier
- acoustical performance expressed as a gain (or loss) compared to the reference screen

Illustration of the railway source, rural environment, depressed topography case

Illustration of the road source, urban environment, embanked topography case
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Economical parameters considered are:

1. Construction costs
2. Maintenance costs
3. Demolition costs (transportation but no material re-use)

*Construction, demolition and maintenance costs, from the “Ministerie van Infrastructuur en Milieu” of Nederland*

<table>
<thead>
<tr>
<th>NRD height [m]</th>
<th>Construction cost [€/m]</th>
<th>Demolition cost [€/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1449</td>
<td>312</td>
</tr>
<tr>
<td>4</td>
<td>2678</td>
<td>379</td>
</tr>
<tr>
<td>6</td>
<td>3884</td>
<td>446</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NRD height [m]</th>
<th>Construction cost [€/m²/year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concretes and bricks</td>
<td>2,93</td>
</tr>
<tr>
<td>Timber</td>
<td>1,46</td>
</tr>
<tr>
<td>PMMA</td>
<td>1,48</td>
</tr>
</tbody>
</table>

Construction & demolition costs independent of the NRD material (manpower >> material costs)

Maintenance costs depend on the material used
Non-acoustical parameters: environmental impact

Environmental impacts calculated according to Life Cycle Assessment’s principles:

- **Energetic resources and raw materials**
- **Production**
- **Transport**
- **Setting up**
- **Use**
- **End of life**

- **Recycled matter**

- **Emissions (water, air, soil), solid waste**
4 environmental parameters:
- Energy, MJ
- Global Warming Potential (GWP), kg CO2 equivalent
- Waste (non hazardous and inert), kg
- Water consumption, Litre

Choice based on:
- indicators interdependence
- environmental relevance

<table>
<thead>
<tr>
<th>No.</th>
<th>Environmental impact</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Consumption of energy resources</td>
<td>MJ</td>
</tr>
<tr>
<td>2</td>
<td>Resource depletion / Abiotic resources Depletion (ADP)</td>
<td>kg antimony equivalent</td>
</tr>
<tr>
<td>3</td>
<td>Water consumption</td>
<td>Litre</td>
</tr>
<tr>
<td>4</td>
<td>Solid waste</td>
<td>kg</td>
</tr>
<tr>
<td>5</td>
<td>Climate change / Global Warming Potential (GWP)</td>
<td>kg CO2 Equivalent</td>
</tr>
<tr>
<td>6</td>
<td>Atmospheric acidification / Acidification potential of land and water sources (AP)</td>
<td>kg SO2 Equivalent</td>
</tr>
<tr>
<td>7</td>
<td>Air pollution</td>
<td>m³</td>
</tr>
<tr>
<td>8</td>
<td>Water pollution</td>
<td>m³</td>
</tr>
<tr>
<td>9</td>
<td>Stratospheric Ozone Depletion Potential (ODP)</td>
<td>kg CFC-R11 equivalent</td>
</tr>
<tr>
<td>10</td>
<td>Formation of photochemical ozone / Formation Potential of tropospheric Ozone Photochemical oxidants (POCP)</td>
<td>kg ethylene equivalent</td>
</tr>
<tr>
<td>11</td>
<td>Eutrophication potential (EP)</td>
<td>Kg (PO₄)³⁻ equivalent</td>
</tr>
</tbody>
</table>
Example of a NRD’s LCA:

LCA of a wood concrete/reinforced concrete NRD

<table>
<thead>
<tr>
<th>Functionnal Unit</th>
<th>Energy</th>
<th>Global Warming Potential</th>
<th>Waste: non hazardous + inert</th>
<th>Water consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m² of concrete NRD (during 50 years)</td>
<td>2027,33 MJ</td>
<td>24,51 kg CO2 eq</td>
<td>330,91 kg</td>
<td>351.64 L</td>
</tr>
</tbody>
</table>
## Non-acoustical parameters: environmental impact

<table>
<thead>
<tr>
<th>Material</th>
<th>Mass density (kg/m³)</th>
<th>Reference Service Life (year)</th>
<th>Energy (MJ)</th>
<th>Global Warming Potential (kg CO₂ eq)</th>
<th>Waste (non-hazardous and inert) (kg)</th>
<th>Water consumption (Litre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced concrete</td>
<td>2400</td>
<td>50</td>
<td>1,14E+03</td>
<td>1,43E+02</td>
<td>2,42E+01</td>
<td>1,82E+03</td>
</tr>
<tr>
<td>Wood concrete</td>
<td>600</td>
<td>50</td>
<td>7,87E+03</td>
<td>3,67E+02</td>
<td>4,03E+01</td>
<td>1,69E+03</td>
</tr>
<tr>
<td>Pouzzolane concrete</td>
<td>1500</td>
<td>50</td>
<td>5,46E+03</td>
<td>6,18E+01</td>
<td>5,35E+00</td>
<td>2,02E+02</td>
</tr>
<tr>
<td>Brick</td>
<td>1000</td>
<td>50</td>
<td>3,02E+03</td>
<td>2,51E+02</td>
<td>7,17E+00</td>
<td>4,89E+02</td>
</tr>
<tr>
<td>PMMA</td>
<td>1190</td>
<td>25</td>
<td>1,45E+05</td>
<td>8,40E+03</td>
<td>1,07E+02</td>
<td>2,03E+04</td>
</tr>
<tr>
<td>Rockwool</td>
<td>70</td>
<td>25</td>
<td>1,92E+04</td>
<td>1,05E+03</td>
<td>3,39E+02</td>
<td>1,00E+04</td>
</tr>
<tr>
<td>Timber</td>
<td>472</td>
<td>20</td>
<td>2,22E+04</td>
<td>1,49E+02</td>
<td>2,47E+01</td>
<td>1,27E+03</td>
</tr>
<tr>
<td>Perforated aluminium</td>
<td>2430</td>
<td>25</td>
<td>1,46E+05</td>
<td>9,28E+03</td>
<td>2,56E+03</td>
<td>4,39E+04</td>
</tr>
<tr>
<td>Perforated steel</td>
<td>7020</td>
<td>25</td>
<td>3,40E+04</td>
<td>2,29E+03</td>
<td>2,21E+03</td>
<td>2,50E+04</td>
</tr>
<tr>
<td>Transport, lorry 20-28t, fleet average 100km</td>
<td>-</td>
<td>-</td>
<td>2,99E+02</td>
<td>1,93E+01</td>
<td>2,82E+00</td>
<td>7,76E+01</td>
</tr>
</tbody>
</table>
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Execution of optimisations

Numerical models:

> Sound propagation model: 2D implementation of the Boundary Element Method

> Optimisation models: evolutionary algorithm, associated with non-dominated sorting for multi-objective optimisations

Optimisation parameters:

> Populations with 50 individuals

> Evolution over 10 generations

> Gaussian mutation
Calculation times:

- Three environmental cases
- Three topographies
- Three acoustic objectives (diffraction side, reflection side, both sides)
- 4 NRD families

\~ 50 000 performance evaluations

<table>
<thead>
<tr>
<th></th>
<th>Flat</th>
<th>Embanked</th>
<th>Depressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>1.6</td>
<td>4.1</td>
<td>13.1</td>
</tr>
<tr>
<td>Rural</td>
<td>0.45</td>
<td>1.45</td>
<td>64.9</td>
</tr>
<tr>
<td>Railway</td>
<td>0.65</td>
<td>17.3</td>
<td>70.7</td>
</tr>
</tbody>
</table>
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Results analysis

Performance aggregation: performance indicators are aggregated according to their type:

- 1 acoustical indicator
- 1 environmental indicator
- 1 cost indicator

Point cloud representation:
Results analysis

Representation of performance indicators with a grading system and radar plots:

Sound level indicators:
- $\Delta L > 12 \text{ dB} \Rightarrow \text{grade} = 10$
- $12 \text{ dB} > \Delta L > 9 \text{ dB} \Rightarrow \text{grade} = 8$
- $9 \text{ dB} > \Delta L > 6 \text{ dB} \Rightarrow \text{grade} = 6$
- $6 \text{ dB} > \Delta L > 3 \text{ dB} \Rightarrow \text{grade} = 4$
- $3 \text{ dB} > \Delta L > 1 \text{ dB} \Rightarrow \text{grade} = 2$
- $1 \text{ dB} > \Delta L \Rightarrow \text{grade} = 0$

Environmental or cost indicators:
- $X < 0.1 \Rightarrow \text{grade} = 10$
- $0.1 > X > 0.25 \Rightarrow \text{grade} = 8$
- $0.25 > X > 0.5 \Rightarrow \text{grade} = 6$
- $0.5 > X > 1 \Rightarrow \text{grade} = 4$
- $1 > X > 2 \Rightarrow \text{grade} = 2$
- $X > 2 \Rightarrow \text{grade} = 0$
Results analysis

Example with a homogeneous NRD: rural, flat, road source
Optimisation on: material, panel width & tilting

Various NRD solutions:

- **Acoustically “good” solution**

- **Environmentally “good” solution**

- **Mean solution**
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Conclusions

• Holistic optimisation process developed for acoustical, environmental and cost performances

• Benefit from optimisations potentially high

• Wide variety of optimised barriers in the last generation

Helpful tool for noise reducing device design
Thank you for your attention!

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