An Operative GIS-Based Methodology for Quantifying Impacts of Past, Present and Future Cumulative Actions of Projects

Assessing and Managing Cumulative Environmental Effects

- What works?
- What doesn’t?
- How do we improve cumulative effects assessment and management?

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A special topic meeting of the International Association for Impact Assessment

IAIA Italia
Operative GIS-Based Methodology

Let’s see the space-time framework of the methodology

**CONCEPTUAL MODEL**

\[ D = \text{Domain of assessment} \]
\[ m = \text{Stressor elements} \]
\[ K = \text{Vulnerability elements} \]

The model characterizes their **interaction** in a space-time frame

**STRESSOR VULNERABILITY INTERACTION FRAME - SVIF**
Each stressor element $m_i$ is characterized by stressor attributes or pressure attributes in space-time frame so that we write them in a space-time function $a_{ij}(r,t)$.

$$m_i=\sum a_{ij}(r,t) \ u_j$$

Ex.
Emission of traffic produces several pollutants each one with is concentrations, with its “story”.

$$m_1=a_{11}(r,t) \ u_1+a_{12}(r,t) \ u_2+...$$

Stressor element
Concentration function (sampled function or modelling simulation)
Space of $a_{11}$ function corresponding with one of our GIS space

$$m_{street1}=a_{1PM10}(r,t) \ u_{PM10}+a_{1noise}(r,t) \ u_{noise}+...$$
\[ \mathbf{m}_{street1}(r^*, t) = a_{11}(r^*, t) \, \mathbf{u}_1 + a_{12}(r^*, t) \, \mathbf{u}_2 \]

We can also represent in GIS mode:
It is possible to introduce a general stressor frame \( \sigma(r,t) \) which takes into consideration all stressor elements of assessment domain.

\[
\begin{array}{c|c|c|c}
\sigma(r,t) & u_{PM10} & u_{\text{noise}} & \ldots \\
\hline
m_{\text{street1}} & a_{1PM10} & a_{1\text{noise}} & \\
\hline
m_2 & a_{2PM10} & a_{2\text{noise}} & \\
\hline
m_3 & a_{3PM10} & a_{3\text{noise}} & \\
\hline
\ldots & \ldots & \ldots & \\
\end{array}
\]

This column takes into consideration contributions given by all stressor elements ON PM10 space.

This row takes into consideration different contribution given only by \( m_{\text{street1}} \) ON all pressure attributes (indicators).

\( \sigma(r,t) \) is defined on Domain of assessment and represents the STATE OF ANTHROPIC PRESSURE ON THE SYSTEM

→ it is now necessary to introduce environment in the model
Environment is represented by K elements of our conceptual model so that it is possible to define a similar to $\sigma(r,t)$, matrix for it.

**VECs frame**

<table>
<thead>
<tr>
<th>$\varepsilon(r,t)$</th>
<th>$v_1$</th>
<th>$v_2$</th>
<th>$\ldots$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_1$</td>
<td>$b_{11}$</td>
<td>$b_{12}$</td>
<td></td>
</tr>
<tr>
<td>$k_2$</td>
<td>$b_{21}$</td>
<td>$b_{22}$</td>
<td></td>
</tr>
<tr>
<td>$k_3$</td>
<td>$b_{31}$</td>
<td>$b_{32}$</td>
<td></td>
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<tr>
<td>$\ldots$</td>
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</tr>
</tbody>
</table>

$k_h = \Sigma b_{hk}(r,t) v_k$

For example:

$K_{\text{urban area}} = b_{\text{urban density}}(r,t) v_{\text{density}} + b_{\text{urban children density}}(r,t) v_{\text{children density}}$
CALCULATING CUMULATIVE IMPACTS

**STRESSOR ELEMENTS**

TENSOR OF STRESSOR $\sigma(r,t)$

<table>
<thead>
<tr>
<th>u-frame</th>
<th>$u_1$</th>
<th>$u_2$</th>
<th>$u_{OTHER}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE 1</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>TYPE 2</td>
<td>0</td>
<td>✔</td>
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<tr>
<td>OTHER type</td>
<td>...</td>
<td>...</td>
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</tbody>
</table>

Pressure attribute associated with ranking analysis of models (University of Brescia)

**VULNERABILITY ELEMENTS**

TENSOR OF VULNERABILITY $\varepsilon(r,t)$

<table>
<thead>
<tr>
<th>v-frame</th>
<th>$v_1$</th>
<th>$v_2$</th>
<th>$v_{other}$</th>
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<tbody>
<tr>
<td>$K_1$</td>
<td>✔</td>
<td>0</td>
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<tr>
<td>$K_2$</td>
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<td>✔</td>
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<tr>
<td>$K_{other}$</td>
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</table>

Vulnerability attribute

**MATRIX OF CORRELATION $\theta$**

<table>
<thead>
<tr>
<th></th>
<th>$u_1$</th>
<th>$u_2$</th>
<th>$u_{OTHER}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_1$</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>$v_2$</td>
<td>0</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>$v_{other}$</td>
<td>...</td>
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$i = \sigma \cdot \varepsilon$
It is possible to study the **interaction frame** previously introduced by conceptual model

\[ i = \sigma \cdot \epsilon = \begin{bmatrix} u_{1V1} & u_{1V2} \\ u_{2V1} & u_{2V2} \end{bmatrix} \]

\[ i_{u1v1} = a_{11} \cdot b_{11} \cos \theta_{11} \]

**Entity of pressure**  
**Entity of vulnerability**  
**Entity of tipological interaction**
For example, if $a_{11}$ is concentration of PM10 [$\mu g/mc$] and $b_{11}$ is urban density [people/mq], we can study interaction through report analysis.

$$b_{11} = [l_1 \ldots l_m]$$

$$a_{11} = [L_1 \ldots L_n]$$

DCGIS GEO-REPORT
Calculation of past, present and future cumulative impacts:

a) Cumulative $\sigma$-frame $\int \sigma dt$

b) Cumulative $\sigma \cdot \varepsilon$-frame $\int \sigma \cdot \varepsilon dt = \int idt$

$\sigma(r,t)$ and $i(r,t)$ have Lij state “outcomes” and we can compute then in past, present and future or having an instantaneous value of the matrix function.

$\int \sigma dt = 3$ \hspace{1cm} $\int \sigma dt = 5$

$\int idt = 5$ \hspace{1cm} $\int idt = 9$

$\int \sigma dt = 6$ \hspace{1cm} $\int idt = 12$

$\sigma(r,T) = 6$ \hspace{1cm} $i(r,T) = 12$
Cumulative impacts: an example

TENSOR OF STRESSOR
σ(r,t)

<table>
<thead>
<tr>
<th></th>
<th>( u_{PM10} )</th>
<th>( u_{dB} )</th>
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</thead>
<tbody>
<tr>
<td>( m_1 )</td>
<td>0</td>
<td>( a_{1,dB} )</td>
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</tbody>
</table>
DCGIS tool produces cumulative impact matrixes for specific stressor-vulnerability interaction.

<table>
<thead>
<tr>
<th>TIME</th>
<th>ACTION 1</th>
<th>ACTION 2</th>
<th>ACTION 3</th>
<th>ACTION 4</th>
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<tbody>
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<td>8</td>
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CONCLUSIONS

- DCGIS methodology provide a general framework for cumulative impact analysis and evaluation, working with different kinds of analitical model defining pressure and vulnerability indicators;

- Mathematical vectorial characterization of stressors and vulnerability elements introduce a new algebra for computing impacts in space-time frame;

- A GIS based tool for managing cumulative effects in terms of prevention, protection and mitigation in planning activities and control (scenarios comparative assessment)

- Operative language for managing different levels of complexity with an iterative process of assessment (EIA, SEA and Regional Risk assessment).
...questions?

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