Assessing Infrastructure Critical Locations

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Critical Locations

- Critical Locations are geographical points which, if attacked successfully, cause the most damage to the system.
- “Most damage” refers to the “value” that location has for the Decision Maker (DM).
- The susceptibility to attack is an important element of critical locations.
- They depend on the nature of the threat.
- The derived ranking of the critical locations should be viewed as a first conservative approximation.
The Case Studies

• **Specific Assets**
  - Six buildings on the MIT campus
  - Three infrastructures (electric power, water, natural gas)
  - Binary logic for the elements
  - Critical locations identified via minimal cut sets

• **A Town**
  - Water infrastructure of a European city
  - Network’s capacity and time included.

• **In both Cases**
  - An objectives hierarchy (value tree) is developed with the DM
  - The threat is assumed to be minor.
Natural Gas Network Digraph

Vertices (supply, user, valve, branch)  Arcs (pipe)
## Minimal Cut Sets (Scenarios) Affecting the Assets

<table>
<thead>
<tr>
<th>Number of mcs</th>
<th>Users Impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>107</td>
<td>3</td>
</tr>
<tr>
<td>256</td>
<td>2</td>
</tr>
<tr>
<td>275</td>
<td>1</td>
</tr>
</tbody>
</table>

663 total mcs

Example: (ev1, ev2) impacts electrical service to all six buildings.
The Value Tree

Terrorist Event Impact

Impact on Health, Safety, Environment
Impact on Institute Property and Operations
Impact on Public Image
Stakeholder Impact

Impact Categories

Performance Measures

Impact on People
Impact on Environment
Physical Property Damage
Interruption of Academic Activities and Operations
Intellectual Property Damage
Impact on External Public Image
Impact on Internal Public Image
Programs Affected

0.295 0.196 0.049 0.056 0.128 0.083 0.055 0.138
### Constructed Scale: Interruption of Academic Activities & Operations

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Disutility</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Extreme interruption (greater than 6 months)</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>Major interruption (1 to 6 months)</td>
<td>0.57</td>
</tr>
<tr>
<td>2</td>
<td>Moderate interruption (1 to 4 weeks)</td>
<td>0.19</td>
</tr>
<tr>
<td>1</td>
<td>Minor interruption (less than 1 week)</td>
<td>0.06</td>
</tr>
<tr>
<td>0</td>
<td>No interruption</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Prioritization Methodology

- Performance Index (expected disutility)

\[
\overline{PI}_j = \sum_{i}^{K_{pm}} w_i \overline{d}_{ij}
\]

- \(\overline{PI}_j\) expected performance index for vulnerability \(j\)
- \(w_i\) weight of the performance measure \(i\)
- \(\overline{d}_{ij}\) expected disutility of performance measure \(i\) for vulnerability \(j\)
- \(K_{pm}\) number of performance measures
Problems with Expected Values

\[ d_{ij} = \Pr(A \cap \text{mcs}_j) \times \sum_k \Pr(d_i^k / \text{mcs}_j) \times d_i^k \]

\[ \Pr(A \cap \text{mcs}_j) = \Pr(A) \times \Pr(\text{mcs}_j / A) \]

• Assume the presence of a minor threat → Ignore \( \Pr(A) \).

• Handle \( \Pr(\text{mcs}_j/A) \) qualitatively in susceptibility assessment.

• \( \Pr(d_i^k / \text{mcs}_j) \) Probability of disutility level \( k \) for PM\( _i \)

• Assess disutility level \( k \) for PM \( i \) conservatively
Performance Index for Screening

\[ \text{PI}_j = \sum_{i=1}^{K_{pm}} w_i d_{ij} \]

- \( \text{PI}_j \): performance index for minimal cut set \( j \)
- \( d_{ij} \): disutility of performance measure \( i \) for minimal cut set \( j \) (assessed conservatively)
## PI Values for MCS

<table>
<thead>
<tr>
<th>PI</th>
<th>Number of mcs</th>
<th>mcs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.24742</td>
<td>1</td>
<td>(ev1, ev2)</td>
</tr>
<tr>
<td>0.15881</td>
<td>47</td>
<td>(ev23, ev6), (ev1, ev5), (ea20, ev4),</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.............................................</td>
</tr>
<tr>
<td>0.11508</td>
<td>1</td>
<td>(ev8)</td>
</tr>
<tr>
<td>0.11370</td>
<td>3</td>
<td>(wv14), (wv15), (wa20)</td>
</tr>
<tr>
<td>0.09391</td>
<td>48</td>
<td>(ev21, ev6), (ev20, ev5), (ea17, ev2),</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.............................................</td>
</tr>
<tr>
<td>0.09030</td>
<td>2</td>
<td>(wv16), (wa19)</td>
</tr>
<tr>
<td>0.08861</td>
<td>55</td>
<td>(ev24, ev42), (ea40, ev42), (ea39, ev38),</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.............................................</td>
</tr>
<tr>
<td>...........</td>
<td>...........</td>
<td>.............................................</td>
</tr>
</tbody>
</table>
Susceptibility Categories

- **Extreme** - Completely open, no controls, no barriers
- **High** - Unlocked, non-complex barriers (door or access panel)
- **Moderate** - Complex barrier, security patrols, video monitor
- **Low** - Secure area, locked, complex closure
- **Very Low** - Guarded, secure area, locked, alarmed, complex closure
- **Zero** - Completely secure, no susceptibility
## Rank Critical Locations

<table>
<thead>
<tr>
<th>Vulnerability Category</th>
<th>Number of mcs</th>
<th>Minimal Cut Sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>1</td>
<td>(ev8)</td>
</tr>
<tr>
<td>Orange</td>
<td>0</td>
<td>none</td>
</tr>
<tr>
<td>Yellow</td>
<td>5</td>
<td>(ev21), (ev22), (ev3), (ev34), (ev9)</td>
</tr>
<tr>
<td>Blue</td>
<td>19</td>
<td>(wa20), (wv14), (wv15), (ev11), (ev18), (ev19),</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(ev25), (gv1), (gv2), (gv3), (gv4), (gv5), (gv6),</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(wv1), (wv2), (wv3), (wv4), (wv5), (wv6)</td>
</tr>
<tr>
<td>Green</td>
<td>638</td>
<td>All remaining mcs</td>
</tr>
</tbody>
</table>
Red MCS: ev8 (Electric Manhole, PI = 0.11508)
City Water Service (Pressure Zones)
Water Supply Network

- **Drops** denote tanks (Txx) and resources (Rxx)
- **Lines** denote pipes (Pxx – arrow shows usual flow direction)
Value Tree of the Water Supply Agency

Value

Impact Categories

Health and Safety 0.7052

Image 0.1599

Financial 0.0976

Environment 0.0373

Performance Measures

Temporary Impacts 0.0784

Permament Impacts 0.0288

Internal/Admin 0.0561

General Public 0.0174

Critical Customers 0.0561

Individual Customers 0.0561

Own Property 0.0557

External Property 0.0825

Own Resources 0.0298

General 0.0073

[category] Number of people requiring treatment because of dehydration or water-borne diseases.

[category] Number of deaths attributed to lack of drinking water.

[category] Number of permanent afflictions linked to consumption of polluted water (e.g., meningoencephalitis).

[category] Image of the utility within the City's administration.

[category] Articles in local, regional, national, and international newspapers.

[category] Negative reactions from individual customers (other municipalities, individual customers, etc.).

[category] Negative financial impact to own and external customers.

[category] Cost of cleaning pipes, etc.

[category] Overall loss of productivity of own resources (including time dimension).

[category] Estimated impact on general environment.
Example: *Image with Critical Customers*

<table>
<thead>
<tr>
<th>Level</th>
<th>Disutilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Most critical customers upset</td>
</tr>
<tr>
<td>3</td>
<td>Numerous letters from different customers</td>
</tr>
<tr>
<td>2</td>
<td>Repeated verbal communications, few letters</td>
</tr>
<tr>
<td>1</td>
<td>Few verbal communications</td>
</tr>
<tr>
<td>0</td>
<td>No negative image</td>
</tr>
</tbody>
</table>

Disutilities:
- Level 4: 1
- Level 3: 0.390
- Level 2: 0.166
- Level 1: 0.057
- Level 0: 0
System Vulnerabilities (Malevolent Acts)

Elevated from Blue to Yellow

Downgraded from Yellow to Blue