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Critical Infrastructure Protection Metrics and Tools; Prioritizing Assets in Critical Infrastructure [June 5-7, 2008] [video]

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Prioritizing assets in critical infrastructure systems

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Outline

• Introduction
• The difficulty of prioritizing projects in critical infrastructures
• Prioritizing/selection of projects for investment
  – Protecting critical infrastructures and prioritizing
  – When to prioritize
• Traditional methods of prioritizing projects
  • Economic evaluation methods, e.g., cost-benefit/net present value methods
  • Multi-criteria approaches
    – Problems with traditional methods
• Network theory approach applied to critical infrastructures
  – Ted Lewis’s approach
    • Strengths and weaknesses
  – Interdiction approach
    • Strengths and weaknesses
• Prioritizing and systems analysis
• Conclusion
Introduction

• Prioritizing
  – Important function in capital facilities planning and financing
  – Traditional Methods
    • Economic Evaluation Methods
      – Cost-benefit/net present value analyses
    • Multi-criteria approaches
Critical Infrastructures: Vast and complex systems

• Critical infrastructures
    • Essential services that underpin our society’s “national defense, economic prosperity and quality of life”
    • Transportation, oil and gas production and storage, water supply, emergency services, government services, banking and finance and telecommunications
  – 2003 National Strategy for Homeland Security:
    • “Systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters”
    • Added: Agriculture and Food, Public Health, Defense Industrial Base, Chemical and Hazardous Materials, and Postal and Shipping plus 5 key assets: National Monuments & Icons, Nuclear Power Plants, Dams, Government Facilities, Commercial Key Assets (Major skyscrapers)
The difficulty of prioritizing projects in critical infrastructures

- Critical Infrastructures are so vast, we cannot hope to protect every part of the system.
- We cannot be comprehensive
- We often lack technical knowledge of these critical infrastructures to understand how to protect them

Network Architecture of the Major Refined Oil Transmission and Distribution Pipelines in the Energy Sector
CIs are interdependent

Protecting Critical Infrastructures

• A mandate to reduce the vulnerability of CIs or to increase their resilience

• Prioritizing assets in CIs to reduce their vulnerability to breakdown from natural or intentional causes requires a risk-based analysis:
  – Identifying their contribution to a system’s performance
  – Major hazards they are exposed to
  – Susceptibility to specific hazards
  – The system’s adaptive capacity
When to prioritize

• Prioritizing can be applied at several stages of the planning process
  – Before risk assessment vs. after risk assessment
  – NIPP: calls for prioritizing after risk assessment to set priorities for implementation
    • Does not explicitly recognize the need to prioritize before
    • Prioritizing before crucial because of vast nature of CIs
    • Faced with this issue, sector-specific plans have added screening or filtering processes to evaluate an asset’s criticality

• My focus:
  – initial screening of vast inventories of CIs to facilitate analysis of their vulnerability:
    • criticality analysis
Traditional methods of prioritizing applied to critical infrastructures

- Economic Evaluation Methods
  - Cost-benefit and cost-effectiveness analysis are used in the selection of assets
  - Useful once an element of a system identified as vulnerable
    - Employed to evaluate the economic viability of alternative projects for hardening or making more resilient a specific asset in a system
  - Not useful to identify assets
Traditional methods of prioritizing: Multi-criteria approaches

- Departmental or functional priorities
- Broad Categories of Need
- Urgency-of-need criteria
- Weighted rating of urgency-of-need and related criteria
- Program priorities, goals, and service needs assessment and planning

- Most based on scaling
  - Simple or weighted
- System gets reduced to criteria
- Projects assigned a rating
- Priorities set based on rating
Example of multi-criteria approach to prioritize assets: SAIC’s AASHTO Guidebook

Table 1 - Critical Transportation Assets

<table>
<thead>
<tr>
<th>INFRASTRUCTURE</th>
<th>FACILITIES</th>
<th>EQUIPMENT</th>
<th>PERSONNEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial Roads</td>
<td>Chemical Storage Areas</td>
<td>Hazardous Materials</td>
<td>Contractors</td>
</tr>
<tr>
<td>Interstate Roads</td>
<td>Fueling Stations</td>
<td>Roadway Monitoring</td>
<td>Employees</td>
</tr>
<tr>
<td>Bridges</td>
<td>Headquarters Building</td>
<td>Signal &amp; Control Systems</td>
<td>Vendors</td>
</tr>
<tr>
<td>Overpasses</td>
<td>Maintenance Stations/Yards</td>
<td>Variable Messaging System</td>
<td>Visitors</td>
</tr>
<tr>
<td>Barriers</td>
<td>Material Testing Labs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roads Upon Dams</td>
<td>Ports of Entry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tunnels</td>
<td>District/Regional Complexes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rest Areas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Storm Water Pump Stations</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Toll Booths</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traffic Operations Centers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vehicle Inspection Stations</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weigh Stations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Step 2. Establish and Assign Values to Each Asset

<table>
<thead>
<tr>
<th>CRITICAL ASSET FACTOR</th>
<th>VALUE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deter/Defend Factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A) Ability to Provide Protection</td>
<td>1</td>
<td>Does the asset lack a system of measures for protection? (i.e., Physical or response force)</td>
</tr>
<tr>
<td>B) Relative Vulnerability to Attack</td>
<td>2</td>
<td>Is the asset relatively vulnerable to an attack? (i.e., Due to location, prominence, or other factors)</td>
</tr>
<tr>
<td>Loss and Damage Consequences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C) Casualty Risk</td>
<td>5</td>
<td>Is there a possibility of serious injury or loss of life resulting from an attack on the asset?</td>
</tr>
<tr>
<td>D) Environmental Impact</td>
<td>1</td>
<td>Will an attack on the asset have an ecological impact of altering the environment?</td>
</tr>
<tr>
<td>E) Replacement Cost</td>
<td>3</td>
<td>Will significant replacement cost (the current cost of replacing the asset with a new one of equal effectiveness) be incurred if the asset is attacked?</td>
</tr>
<tr>
<td>F) Replacement/Down Time</td>
<td>3</td>
<td>Will an attack on the asset cause significant replacement/down time?</td>
</tr>
<tr>
<td>Consequences to Public Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G) Emergency Response Function</td>
<td>5</td>
<td>Does the asset serve an emergency response function and will the action or activity of emergency response be affected?</td>
</tr>
<tr>
<td>H) Government Continuity</td>
<td>5</td>
<td>Is the asset necessary to maintain government continuity?</td>
</tr>
<tr>
<td>I) Military Importance</td>
<td>5</td>
<td>Is the asset important to military functions?</td>
</tr>
<tr>
<td>Consequences to the General Public</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J) Available Alternate</td>
<td>4</td>
<td>Is this the only asset that can perform its primary function? (i.e., There are no alternate facilities that will substitute adequately if this asset is damaged or destroyed)</td>
</tr>
<tr>
<td>K) Communication Dependency</td>
<td>1</td>
<td>Is communication dependent upon the asset?</td>
</tr>
<tr>
<td>L) Economic Impact</td>
<td>5</td>
<td>Will damage to the asset have an effect on the means of living, or the resources and wealth of a region or state?</td>
</tr>
<tr>
<td>M) Functional Importance</td>
<td>2</td>
<td>Is there an overall value of the asset performing or staying operational?</td>
</tr>
<tr>
<td>N) Symbolic Importance</td>
<td>1</td>
<td>Does the asset have symbolic importance?</td>
</tr>
</tbody>
</table>

Example

Table 4 – Example Scoring Table for Identifying and Prioritizing Critical Assets

<table>
<thead>
<tr>
<th>CRITICAL ASSET</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>TOTAL SCORE (x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith Bridge</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>43</td>
</tr>
<tr>
<td>Bayside Tunnel</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>43</td>
</tr>
<tr>
<td>Blue Bridge</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>38</td>
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<tr>
<td>Crystal Bridge</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>33</td>
</tr>
<tr>
<td>Interstate 1</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>33</td>
</tr>
<tr>
<td>Interstate 218</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>33</td>
</tr>
<tr>
<td>Interstate 88</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>33</td>
</tr>
<tr>
<td>Rt. 49</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>Rt. 6</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>Johnson Interchange</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>28</td>
</tr>
<tr>
<td>Headquarters Building</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>14</td>
</tr>
</tbody>
</table>
Strengths and Weaknesses of Multi-criteria Approaches

• **Strengths:**
  – Allow stakeholder involvement in selection of criteria, scoring and weighting
  – Do not require extensive calculation, simulation or modeling
    • Can be applied by many individuals without much training

• **Weaknesses**
  – In analytic process, they lose information of the system as a system
    • Interconnectedness is lost
    • Spatial character of CIs
  – They do not address the network aspect of these systems
Network theory approach applied to critical infrastructures: Lewis’s MBVA

Figure 1. MBVA Process: After Taking Inventory: Perform Network, Fault tree, Event tree Analysis, and Budget Allocation.

Barabasi: normal (random distribution of linkages) vs. power law distributions (scale-free)

Scale-free refers to non-random networks where the distribution of linkages follows a power distribution rather than a normal distribution.

Types of network

Figure 3. Random networks are unstructured while scale-free exhibits hub structure. Scale-free networks can be identified by their power law distribution.

(a). Random network with no hubs
(b). Scale-free network with 2 hubs
(c). Small World network with two neighborhoods. Any node can be reached from any other node by 3 or fewer hops.

Characteristics of CIs

- Concentration of assets, critical nodes or hubs
- Networks are non-random, scale-free or small world
- Simple critical node testing
  - Prepare a histogram
  - Does the distribution follow a power law? If so, scale free.
  - If the graph analysis reveals clusters, then small worlds
- Approach has an effective strategy to address cascade failures—protect the hubs
- Simulations
Example of graphing an infrastructure network

Figure 2. A Mathematical Graph is used to Model the California Aqueduct as a Network.
Map of California Aqueducts, (b). Network Nodes and Links Layered on the California Map, and (c). Network Model of Aqueducts as a Graph.

Testing Network Analysis as a Prioritizing Method: The Interstate Highway System

Below is a list of US cities with 6 or more links to the Interstate Highway System:

<table>
<thead>
<tr>
<th>City</th>
<th>Number of Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta</td>
<td>6</td>
</tr>
<tr>
<td>Ann Arbor</td>
<td>6</td>
</tr>
<tr>
<td>Cleveland</td>
<td>6</td>
</tr>
<tr>
<td>Nashville</td>
<td>6</td>
</tr>
<tr>
<td>Oklahoma City</td>
<td>6</td>
</tr>
<tr>
<td>St. Louis</td>
<td>6</td>
</tr>
<tr>
<td>Indianapolis</td>
<td>7</td>
</tr>
<tr>
<td>Dallas/Ft Worth</td>
<td>7</td>
</tr>
<tr>
<td>Chicago</td>
<td>10</td>
</tr>
</tbody>
</table>

Strengths and weaknesses of Lewis’s network theory approach

• **Strengths**
  – Simple test of node degree to identify critical hubs
    • Requires minimal spatial information about a system, and moderate training to apply the test
    • Graphic display, and computer simulations are convincing
    • Most useful for scale-free networks, less so for small world networks

• **Challenges**
  – Fewer linkages may mean more rather than less vulnerability
    • Lack of redundancy may be more important than degree of connectedness
  – Where the sequence or order or direction of flow in a supply chain is important, i.e., when a node is a source, as in oil pipeline transmission systems, other network indicators may be necessary to identify network asset priority
  – Where node is geographically too large, e.g., Chicago, and the network connections too redundant. In general, network analysis at a regional or smaller scale may require subcomponent analysis, such as chokepoints, e.g., tunnels, bridges, vs. entire highway segments.
Interdiction Approaches

• Used by military strategists to minimize the disruption or interdiction of critical nodes or links in a supply network or chain

• In this network theory approach, often network facilities prioritized based on simple, graph theoretic measures following a similar two-step process:
  – First, identify criticality, then vulnerability.

• Two types of indicators are used:
  – Global theoretic measures, e.g., indices of complexity
  – Local network measures, such as the degree of connectedness index that Lewis uses
Strengths and weaknesses of network interdiction approaches

• Strengths
  – Employ larger set of indicators to test for priority, and can obtain better measures of system priorities

• Challenges
  – Greater data requirements on flow and performance
  – More opaque to stakeholders, requires greater mathematical training than other approaches
Prioritizing in CIs requires systems analysis

- Multi-criteria methods fail to address the systems aspects of CIs
- Network analysis is too abstract
  - Reduces systems to nodes and links
- Both multi-criteria methods and network methods are concerned with system performance
- But only systems analysis aims at outlining how vital components achieve system performance
- In systems analysis, two major tools to model performance of a complex system:
  - Causal loop diagrams
  - Stock and flow diagrams
Causal Loop and stock and flow diagrams
Prioritizing in CIs

- Enhanced stock and flow diagrams
  - Incorporating:
    - the condition of components, their availability, cost, rapidity of replacement if disabled, security measures at the asset level, and protocols and regulations controlling the system and component functioning
  - Through GIS or hypertext
In Conclusion

- Reviewed traditional and network-theory approaches for prioritizing assets in critical infrastructure systems
  - Including strengths and weaknesses
- The role of assets in the performance of systems is vital for prioritizing assets in CIs
- Analysis of CIs as systems is necessary to establish role of assets in performance of assets
  - Proposed GIS enhanced stock and flow diagrams to graphically display performance of CIs