Risk Assessment and Management for National Interdependent Infrastructure and Economic Systems

Presented at the Conference on New Directions for Understanding Systemic Risk
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Purpose of this Presentation

• Share with you basic **analytical principles** upon which a systemic risk assessment and risk management process is based

• Share with you a method to measure and analyze risk of extreme and catastrophic events: **The Partitioned Multiobjective Risk Method (PMRM)**

• Introduce the **Inoperability Input-Output Model (IIM)** for infrastructure interdependencies

• Provide **three case studies**, with a focus on **interdependent** infrastructure and economic systems
The industry sectors of the economy are physically and financially interdependent systems.

Critical infrastructures (telecommunications, power, transportation, banking, etc.) are marked by immense complexity.

They share flows of information, security, and physical flows of commodities (among others).

There is a need to assess and manage the risks of extreme natural and man-made hazards to our nation’s Interdependent Infrastructure and Economic Systems.
Three Case Studies
On Risk to Interdependent Infrastructure and Economic Systems

• Commission on High-Altitude Electro Magnetic Pulse (H-EMP) Attacks on the US

• DHS “Crimson Dawn” Exercise (Impact of Raising the Alert Level on the Economy)

• Virginia Bridge-Tunnel Transportation System
All Case Studies
Have the following *common* attributes

- Have large potential financial effects, as opposed to life or death
- Involve major infrastructures at risk
- Focus on rare and extreme events
Risk Assessment and Risk Management of Systems of Systems

Organizational

Knowledge Management

Human

Information Assurance

Hardware

Software
Risk Modeling, Assessment, and Management

Metrics

Survivability Systems

Risk Identification

Complexity

Quantitative Risk Analysis

Interconnect-edness

Inter- & Intra-dependency

Common Definition

Methodology

Manager

PCCIP

Joint Program Office

US Army

National Ground Intelligence Center

FBI

Dept of Homeland Security

US Army Corps of Engrs

Defense Threat Reduction Agency

Virginia Dept of Transport

NASA

VA Governor’s Preparedness Team

National Science Foundation

I3P

H-EMP Commission (SAIC)

Defense Threat Reduction Agency

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NASA

VA Governor’s Preparedness Team

National Science Foundation

I3P

H-EMP Commission (SAIC)

National Ground Intelligence Center

Center for Risk Management of Engineering Systems Est.1987

Yacov Y. Haimes
The Process of Risk Assessment and Risk Management
The Process of Risk Assessment and Risk Management

**Risk Assessment**

- What can go wrong?
- What is the likelihood that it would go wrong?
- What are the consequences?

[Kaplan and Garrick 1981]

**Risk Management**

- What can be done and what options are available?
- What are the associated trade-offs in terms of all costs, benefits, and risks?
- What are the impacts of current management decisions on future options?

[Haimes 1991, 2004]
Motivation for Identification of Systemic Risk

“As the ‘supply chain’ has evolved from the simplicity of a bank’s making and servicing a loan over its life to the complexity of securitization (involving originators, holders, servicers, trustees, and hedging Markets), the focus on core banks and securities firms and major markets must expand to include other potential single points of failure.”

“These new features raise interesting questions about whether the kinds of conceptual models outlined in the preceding two sections fully capture the range of possible causes and propagation channels for systemic risk.”

Hierarchical holographic modeling (HHM) is a holistic philosophy/methodology aimed at capturing and representing the inherent diverse risks of systems and their attributes—their multiple aspects, perspectives, and hierarchies.
Hierarchical
Hierarchical detailed elaboration of each Headtopic is referred to as “Subtopics.”
Hierarchical Holographic Modeling

HHM combines the holographic views with hierarchical analysis to identify sources of risks for all perspectives and levels of a system.
Sources of Risk to Supervisory Control And Data Acquisition (SCADA) systems

- Four teams, each with very different perspectives, were used to develop separate HHMs
  - **Red Team**: Attackers and Hackers
  - **Blue Team**: SCADA operators and owners
  - **Vendor Team**: SCADA developers and vendors
  - **Policy Stakeholder Team**: Government interests and industry associations
Adaptive Multi-Player HHM Game: Multiple Stakeholder Perspectives

• About 60 experts participated in four teams.
• Significantly, there was less than 10% overlap in subtopic elaboration amongst the four teams; thus, reinforcing the value of incorporating multiple views and perspectives of individuals in identifying sources of risks to SCADA systems.
Subtopics outlined in black represent overlap among the four teams.
Risk Filtering, Ranking, and Management (RFRM) Methodology
RISK

A measure of the probability and severity of adverse effects

SAFETY

The level of risk that is deemed acceptable

Multiobjective Trade-off Analysis is at the Heart of Risk Management

Risks, Costs, and Benefits are not commensurate and are measured in different units; therefore, to manage risk, an acceptable balance must be sought in a multi-objective approach through Pareto optimality and direct trade-off analyses.
Multiobjective Trade-off Analysis

\( f_1(\cdot) = \text{Cost of Risk Management} \)

\( \lambda_{12} = - \frac{f_1(\bullet)}{f_2(\bullet)} \) (trade-off)

\( f_2(\cdot) = \text{Risk of …} \)
How do we quantify risk?
How do we measure risk?

With the central tendency measure of risk
(the expected value of risk and its limitations
when it is used as the only metric for risks related
to extreme events)
Limitation of Expected Value of Risk

Risk = \( f(\text{Probability, Damage}) \)

or

Risk = \( f(\text{Likelihood, Consequences}) \)
Limitation of Expected Value of Risk

Managers and decisionmakers are most concerned with the risk associated with a specific case under consideration, and not necessarily with the likelihood of the average adverse outcomes that may result from all similar risk situations.

Using the expected value of risk, is probably the dominant reason for the chaotic state in the quantification of risk.

Decisionmakers are frequently interested in both the low-frequency, high-damage events and in the average risk.

Public perception of catastrophic risks is an important consideration.
Consider the following two cases:

**Case 1: Low investment with high probability of success**
Investment = $10^3$; Probability = $10^{-1}$ (very high)

**Case 2: High investment with low probability of success**
Investment = $10^7$; Probability = $10^{-5}$ (very low)

Both cases make the same contribution to the mathematical expectation of the return on investment:

$10^3 \times 10^{-1} = 10^2$

$10^7 \times 10^{-5} = 10^2$

It is clear to any investor that the two cases are far from being commensurate or equal; leading to the concept to balancing risks and gains of a portfolio.
A conditional expectation is defined as the expected value of a random variable, given that its value lies within a pre-specified range.

(a) probability distribution function $f(x)$
(b) cumulative distribution function $F(x)$
Partitioned Multiobjective Risk Method (PMRM)

Conditional Expectations

\[ f_2(\cdot) = E[X \mid X \leq \beta_1] = \frac{\int_0^{\beta_1} xp(x)dx}{\int_0^{\beta_1} p(x)dx} \]

\[ f_3(\cdot) = E[X \mid \beta_1 \leq X \leq \beta_2] = \frac{\int_{\beta_1}^{\beta_2} xp(x)dx}{\int_{\beta_1}^{\beta_2} p(x)dx} \]

\[ f_4(\cdot) = E[X \mid X > \beta_2] = \frac{\int_{\beta_1}^{\infty} xp(x)dx}{\int_{\beta_2}^{\infty} p(x)dx} \]

\[ f_5(\cdot) = \frac{\int_0^{\infty} xp(x)dx}{\int_0^{\infty} p(x)dx} = \int_0^{\infty} xp(x)dx \]

\( f_2(\cdot) \) represents the risk with high probability of exceedance and low damage.

\( f_3(\cdot) \) represents the risk with median probability of exceedance and medium damage.

\( f_4(\cdot) \) represents the risk with low probability of exceedance and high damage.

\( f_5(\cdot) \) represents the unconditional (conventional) expected value of risk.
Multiobjective Trade-off Analysis for Risk of Extreme Events Using PMRM

Cost of Risk Management ($M) vs. Loss of Capacity (%)

Policy Option A
Policy Option B
Policy Option C
Policy Option D

$f_1(\bullet)$ vs. $f_4(\bullet)$
$f_1(\bullet)$ vs. $f_5(\bullet)$

0% 50% 100%
PMRM and Value-at-Risk (VaR)

• In the **PMRM**, various conditional expected values are used as risk metrics to evaluate potential risk management strategies  
  [Asbeck and Haimes, 1984]

• **Value-at-Risk (VaR)** is another risk metric, defined as the worst loss over a target horizon with a given level of confidence  
  [Jorion, 2001]

• The conditional expected value of risk and VaR are related. VaR is essentially the partition point at which the conditional expected value is calculated

• In finance, conditional expected value is commonly called **Conditional VaR (CVaR)**  
  [Rockafellar and Uryasev, 2000]
Interdependent Infrastructures and Economic Systems

The Inoperability Input-Output Model (IIM)
Three Case Studies
On Risk to Interdependent Infrastructure and Economic Systems

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Inoperability Input-Output Model (IIM)

**Background**

- **Wassily Leontief** developed the Input-Output Model for the U.S. Economy, for which he won the Nobel prize in Economics in 1973.

- **The Inoperability Input-Output Model (IIM)**, which was developed by Haimes and Jiang in 2001, has been markedly improved and extended by the Center’s team.

- Actual economic data from the Bureau of Economic Analysis (BEA) constitute the foundation of model.
  - BEA publishes I-O data of the entire U.S. Economy.
  - BEA annual budget exceeds $80 million.
Inoperability Input-Output Model (IIM)

Calculating propagating Effects

Terrorist Attack

Reductions in the functionality of sector $k$

- $q_{k_1}$
  - e.g., $1 \rightarrow$ coal
  - Impact of $1$ on the inoperability of $k$

- $q_{k_2}$
  - e.g., $2 \rightarrow$ petroleum
  - Impact of $2$ on the inoperability of $k$

- $q_{k_n}$
  - e.g., $j \rightarrow$ transportation
  - Impact of $n$ on the inoperability of $k$

- $q_{1,k}$
  - e.g., $1 \rightarrow$ coal
  - Impact of $k$ on the inoperability of $1$

- $q_{2,k}$
  - e.g., $2 \rightarrow$ petroleum
  - Impact of $k$ on the inoperability of $2$

- $q_{n,k}$
  - e.g., $j \rightarrow$ transportation
  - Impact of $k$ on the inoperability of $n$
Inoperability Input-Output Model (IIM)

Basic Model

\[ \mathbf{x} = \mathbf{A} \mathbf{x} + \mathbf{f} \iff x_i = \sum_j a_{ij} x_j + f_i \]

- Leontief construct based on industry consumption.
  - \( \mathbf{x} \) is the vector of industry outputs
  - \( \mathbf{A} \) is the technical coefficient matrix
  - \( \mathbf{f} \) is the vector of final demand
- Two assumptions: (1) Production = Consumption, (2) Intermediate consumption is proportional to output.
- The IIM is a transformation of the Leontief model to enhance focus on inoperability.
Inoperability I-O Model (IIM)

**Model Components**

- **Leontief Model**

  \[ x = Ax + c \]

  - Production \( x \) → \( x = Ax + c \) → Consumption \( c \)
  - \( A := \text{Technical Coefficient Matrix} \)

- **Inoperability I-O Model (IIM)**

  \[ q = A^* q + c^* \]

  - Terrorist Attack \( c^* \) → \( q = A^* q + c^* \) → Inoperability \( q \)
  - \( A^* := \text{Interdependency Matrix} \)
Inoperability Input-Output Model (IIM)

Basic Model Illustration
Inoperability Input-Output Model (IIM)

Benefits of Applying IIM

- The IIM benefits from:
  - Major Bureau of Economic Analysis (BEA) data collections
  - Numerous other significant applications of BEA data (including GDP Forecasting)
  - Regional sub-model developments that correspond to national data
  - Strong relationship with the business community because of privacy protection
  - A community of users and developers that continue to pursue improvements
  - Nonetheless, critics complain about potential misuse
## Inoperability Input-Output Model (IIM)

### Limitations to Applying IIM

<table>
<thead>
<tr>
<th>Limitation</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Static Model</strong></td>
<td>Slow changing risk scenarios; Dynamic extensions with external databases</td>
</tr>
<tr>
<td><strong>Linear Model/Macro</strong></td>
<td>Small changes compared to overall economy</td>
</tr>
<tr>
<td><strong>Does not account for market-place substitutions</strong></td>
<td>Limit use to cases that: a) don’t have important substitution possibilities or b) derive impacts of substitution as a direct analytical result</td>
</tr>
<tr>
<td><strong>National 500-sector resolution updated on 5 year cycle; Sectors are pre-defined</strong></td>
<td>60-sector resolution updated annually; Sectors well-defined for supplemental industry research</td>
</tr>
</tbody>
</table>
Inoperability Input-Output Model (IIM)

Policy Issues that the IIM Address

- **Identification of security measures** (geographic scope, implementation period, and structure) with large economic consequences.
- **Identification of specific sectors** (regional or national) that **suffer the greatest sustained direct** and indirect economic losses due to particular security measures.
- **Comparison of economic losses due to security measures** with those that would result from a successful attack.
Extensions of the Interoperability Input-Output Model (IIM)

Dynamic IIM (DIIM)
Regional IIM (RE-IIM)
• The DIIM is a dynamic extension on the IIM, focusing on measuring the resilience of the critical infrastructures and describing the dynamic, ripple effects of industry recovery following an attack or a natural disaster.

• The DIIM provides the following risk metrics for evaluating the efficacies of potential risk management options:
  – Inoperability (%) and Economic Loss ($)
  – Industry Resilience Coefficient
  – Recovery Time

• Through the DIIM, the effectiveness of preparedness can be measured.
Dynamic IIM (DIIM)
Dynamic Recovery of Economic Sectors

Sector Symbol | Sector Names
---|---
BRDC | Broadcasting and telecommunications
TRCK | Truck transportation
MPIC | Motion picture and sound recording industries
UTIL | Utilities
OILG | Oil and gas extraction
Regional IIM (RE-IIM) Background

- The lack of spatial explicitness in risk analysis results in only average estimates across geography. Such estimates may lead to overlooking geographically-concentrated risks or significant cross-regional interdependencies.

- Spatially explicitness is added when the economy is regarded as a system of regional decisionmakers with processes coupling the various sub-regions, thus producing distinct predictions for each region determined by the regions characteristics and its interconnectedness with other regions.
Spatial Explicitness:
- Adapt multi-regional formulation [Isard 1998].
- $z^{RS}$ is a vector of cross-regional (CR) transactions from region $R$ to region $S$.
- $z^{RS} = [z_1^{RS}, ..., z_n^{RS}]^T$, where $z_i^{RS}$ is CR flow of commodity $i$ (resource, good, or service).
- Accounts of CR flows form a multiregional interdependency matrix, denoted $T^*$. 
- Raw data from Bureau of Transportation Stats, Bureau of Labor Stats, EIA, etc.
National Commission on High-Altitude Electromagnetic Pulse (H-EMP) Attacks
The electromagnetic properties of many electronic components can make entire systems susceptible to upset or to permanent damage due to the environmental effects of a High-Altitude Electro Magnetic Pulse (H-EMP).

Electronic elements such as integrated semiconductor circuits can be damaged by only a few tens of volts, a few amperes, or less.

HEMP is defined as an intense electromagnetic blast induced by a nuclear explosion at a high altitude.
National Commission on H-EMP
Modeling a Regional H-EMP Attack

- Greater Northeastern Region (GNR)
- 584-mi radius with center: 40.5°N Latitude and -75.54° Longitude
We assessed perturbations to the availability/functionality of electric power and H-EMP-sensitive equipment for nearly 500 economic sectors.

The resulting impacts on users of electric power and H-EMP-sensitive equipment are measured in terms of IIM metrics: inoperability and economic loss.

- **Inoperability** is the normalized production loss representing the ratio of unrealized production with respect to the “as-planned” production level.
- **Economic Loss** represents the value of monetary loss associated with an inoperability value.
National Commission on H-EMP

IIM Metrics – Inoperability and Economic Loss of Power Outage

Coal, railway transportation, kitchenware and plastic manufacturing

Workforce, coal, real-estate, retail, maintenance services
“Thus, there is a strong need for models more capable of capturing the complex interactions between operational infrastructure and then financial flows that the infrastructure supports. Similar models would be helpful in understanding the consequences of a pandemic event that made it impossible for large number of urban employees to work from their offices. Is the existing financial system capable of a smooth transition to a temporarily reduced level of activity? Current models cannot really even frame such a question.”

### Top-10 Sectors with Highest Workforce Earnings
Losses due to a 60-day Power Recovery Scenario 
(GNR)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Index</th>
<th>$M</th>
<th>Sector Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>694</td>
<td>Electric, gas, and sanitary services</td>
</tr>
<tr>
<td>2</td>
<td>34</td>
<td>185</td>
<td>Business services</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>119</td>
<td>Construction</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>94</td>
<td>Health services</td>
</tr>
<tr>
<td>5</td>
<td>29</td>
<td>89</td>
<td>Depository and nondepository institutions and security and commodity brokers</td>
</tr>
<tr>
<td>6</td>
<td>24</td>
<td>79</td>
<td>Transportation</td>
</tr>
<tr>
<td>7</td>
<td>28</td>
<td>69</td>
<td>Retail trade</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>65</td>
<td>Coal mining</td>
</tr>
<tr>
<td>9</td>
<td>37</td>
<td>58</td>
<td>Miscellaneous services</td>
</tr>
<tr>
<td>10</td>
<td>27</td>
<td>54</td>
<td>Wholesale trade</td>
</tr>
</tbody>
</table>

### Top-10 Sectors with Highest Number of Affected Workforce due to a 60-day Power Recovery Scenario (GNR)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Index</th>
<th># Affected</th>
<th>Sector Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>8,019</td>
<td>Electric, gas, and sanitary services</td>
</tr>
<tr>
<td>2</td>
<td>34</td>
<td>4,592</td>
<td>Business services</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>3,408</td>
<td>Construction</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>3,240</td>
<td>Health services</td>
</tr>
<tr>
<td>5</td>
<td>36</td>
<td>2,448</td>
<td>Depository and nondepository institutions and security and commodity brokers</td>
</tr>
<tr>
<td>6</td>
<td>37</td>
<td>2,148</td>
<td>Miscellaneous services</td>
</tr>
<tr>
<td>7</td>
<td>35</td>
<td>2,001</td>
<td>Eating and drinking places</td>
</tr>
<tr>
<td>8</td>
<td>24</td>
<td>1,996</td>
<td>Transportation</td>
</tr>
<tr>
<td>9</td>
<td>29</td>
<td>1,499</td>
<td>Depository and nondepository institutions and security and commodity brokers</td>
</tr>
<tr>
<td>10</td>
<td>32</td>
<td>1,182</td>
<td>Hotels and other lodging places, amusement and recreation services, and motion pictures</td>
</tr>
</tbody>
</table>
Sample IIM Impact Matrix

LEGEND:  
- Red: Top-10 Zone  
- Blue: Top-20 Zone  
- Green: Top-30 Zone
National Commission on H-EMP
Trade-off Analysis Example

Restoring 9% of EMP-vulnerable commodities decreases economic loss by $65 billion/year.

Restoring 2.1% of Power operation decreases economic loss by $65 billion/year.
EMP Power v.s. EMP Commodities Recovery Scenarios
(Initial Perturbation: EMP Power-100%, EMP Commodities-75%)

Baseline Scenario: 60 days 99% recovery for both groups

Reducing power recovery time from 60 days to 30 days save $12,000 million

Reducing EMP commodity sectors recovery time from 60 days to 30 days save $8,094 million

Total Economic Loss (M$)

Time (Day)

(60, 60 Days) — (30, 60 Days) — (60, 30 Days) — (30, 30 Days)
Interdependency Analysis: Impact Analysis of Issuing Alert Levels
By the Department of Homeland Security (DHS)
DHS Alert Levels
Applying the IIM to COA Decisionmaking

Candidate Courses of Action (COA)

Region(s)/Timeframe
Security Measures

Inoperability Input-Output Model (IIM)

% Productivity Loss

$ Econ. Loss

Recoveries

time

US Dept of Commerce Databases
Bureau of Economic Analysis (National data, 482-sector resolution)
Regional I-O Multiplier System (Regional data, 37-sector resolution)
County is smallest region

COA Trade-off Analysis
• About **460,000** members of the National Guard, of which about **50%** are currently part of US workforce.

• This workforce constitutes about **0.14%** of the nation’s **170 million workers**.

• Assuming workers are distributed across economic sectors similar to the national workers, then loss of 0.15% of workers constitutes a productivity loss to all sectors of the economy based on reliance of that sector on workforce.
  
  – IIM calculates the productivity losses to be about **$50 billion annually.** (About **$130 million per day.**)
Most Affected Sectors in Terms of Economic Losses

(Newark Area, 1 week at Red)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Economic Loss ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM</td>
<td>140</td>
</tr>
<tr>
<td>MRI</td>
<td>120</td>
</tr>
<tr>
<td>BSRV</td>
<td>100</td>
</tr>
<tr>
<td>TRNS</td>
<td>80</td>
</tr>
<tr>
<td>HEALTH</td>
<td>60</td>
</tr>
<tr>
<td>RTWQ</td>
<td>40</td>
</tr>
<tr>
<td>RSC</td>
<td>20</td>
</tr>
<tr>
<td>COMM</td>
<td>10</td>
</tr>
<tr>
<td>ETGW</td>
<td>5</td>
</tr>
<tr>
<td>SWRY</td>
<td>3</td>
</tr>
<tr>
<td>UTILITY</td>
<td>2</td>
</tr>
</tbody>
</table>

Most Affected Sectors in Terms of Productivity (%)

(Newark Area, 1 week at Red)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Direct Impact</th>
<th>Indirect Impact (Ripple Effects)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>MRI</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>BSRV</td>
<td>30</td>
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<td>TRNS</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>HEALTH</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>RTWQ</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>RSC</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>COMM</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>ETGW</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>SWRY</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>UTILITY</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Geographic Scope of Alert

Identification of Sectors with Sustained Impacts

(Newark Area, 1 week at Red + lingering demand effects)

Total Losses: $6.3B

Time (in weeks) vs. Economic Loss ($M) vs. Total Loss ($B)
Economic Impact of Security

One-week Red alert with lingering consumer demand reduction would have the following losses:
- $209 Billion for a National alert (almost 1wk of US Gross National Product),
- $50 Billion for the Greater NY Metro Region alert
- $6.3 Billion for the Newark Statistical Area alert.

Comparison with a Successful Attack

Approximate losses to NYC for 9-11 are $83 billion.
Closing 1% fewer of “non-essential” business across the nation reduces economic impact by approximately $13 billion per week.
For more localized security measures the sensitivity is even greater.
The closures of “Eating and Drinking Places” would cause significant losses to “Fishing and Forestry Products”, possibly causing sustained losses of business enterprises.

Particular Security Measures to Affect Impact

Critical Sectors that may Suffer Sustained Economic Damage
Interdependency Analysis: Evaluating Interdependencies of James River Crossings For Virginia Department of Transportation (VDOT)
VDOT Interdependency Analysis
Background Map
VDOT Interdependency Analysis

Databases

**HIGHWAY ASSET FAILURE:**
- Closure
- Congestion
- Collapse

**IMPACT:**
1. **Workforce Commute**
   - Losses from Delayed/Absent Workers

2. **Commodity Flow**
   - Losses from Delayed Commodities

3. **Business Accessibility**
   - Losses from BusinessDemand Reduction

**DATABASES:**
- Journey to Work Data
- Regional Employment Data
- Regional Earnings Data
- Commodity Flow (CF) Data to Destination
- CF Data from Origin
- CF Data through Corridors
- RIMS II Data
- Geographic Location Data
Consider a scenario where both Hampton Roads Bridge-Tunnel and Monitor-Merrimac Bridge-Tunnel will be closed to traffic.

**Northwest Region:**
- Essex
- Gloucester
- Hampton (city)
- James City & Williamsburg
- King and Queen
- King William
- Mathews
- Middlesex
- Newport News (city)
- York & Poquoson

**Southeast Region:**
- Accomack
- Chesapeake (city)
- Greensville & Emporia
- Isle of Wight
- Norfolk (city)
- Northampton
- Portsmouth (city)
- Southampton & Franklin
- Suffolk (city)
- Surry
- Sussex
- Virginia Beach (city)
VDOT Interdependency Analysis

Workforce-IIM: Journey-to-Work Data

<table>
<thead>
<tr>
<th>From</th>
<th>To NW</th>
<th>To SE</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>NW</td>
<td>214,952</td>
<td>22,658</td>
<td>250,705</td>
</tr>
<tr>
<td>SE</td>
<td>22,410</td>
<td>534,551</td>
<td>571,822</td>
</tr>
<tr>
<td>To Totals</td>
<td>247,348</td>
<td>563,811</td>
<td>3,164,052</td>
</tr>
</tbody>
</table>

Destination of Workers Crossing Bridge from SE

- Newport News city VA 52%
- Hampton city VA 34%

Destination of Workers Crossing Bridge from NW

- Virginia Beach city VA 18%
- Norfolk city VA 51%
Distribution of Workers in Newport News (12,000 across river)

- Health care and social assistance: 11%
- Manufacturing: 25%
- Retail trade: 12%
- Administrative and waste services: 7%
- Professional and technical services: 8%
- ...
Assume travelers are distributed across sectors similar to the workers’ distribution across sectors.

Given the scenario perturbation, the estimated annual loss is $110 million to the local economy of Southeastern Virginia.
Preparedness for extreme natural hazards and terrorist attacks is essential for developing resilience in interdependent infrastructure and economic systems, and thus, planning for an acceptable recovery time and cost (both human and monetary loss) during an emergency.

Such an enterprise must be built on a risk assessment and management process that is grounded on a holistic systems philosophy and methodology.
Risk Modeling, Assessment, and Management

Second Edition

Yacov Y. Haimes

An updated and timely new look at the theory and practice of risk management

Since the first edition of Risk Modeling, Assessment, and Management was published, public interest in the field of risk analysis has grown astronomically. Its adaptation across many disciplines and its deployment by industry and government agencies in decision making has led to an unprecedented development of new theory, methodology, and practical tools.

The Second Edition of this well-regarded reference describes the art of risk management and its important applications in such areas as engineering, science, manufacturing, business, management, and public policy. The author strikes a balance between the quantitative and the qualitative aspects of risk management, showing clearly how to quantify risk and construct probability in conjunction with real-world decision-making problems. At the same time, he addresses a host of institutional, political, and cultural considerations.


• C. Lian & Y.Y. Haimes, “Managing the Risk of Terrorism to Interdependent Infrastructure Systems through the Dynamic Inoperability input-Output Model.” To appear in *Systems Engineering*
