Risk Assessment and Management for National Interdependent Infrastructure and Economic Systems

Presented at the Conference on
New Directions for Understanding Systemic Risk
Sponsored by
The National Academies
and
The Federal Reserve Bank of New York

18 May 2006

Yacov Y. Haimes

L. R. Quarles Professor of Systems and Information Engineering
Founding Director (1987), Center for Risk Management of Engineering Systems
University of Virginia

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

Infrastructure Interdependencies

- **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

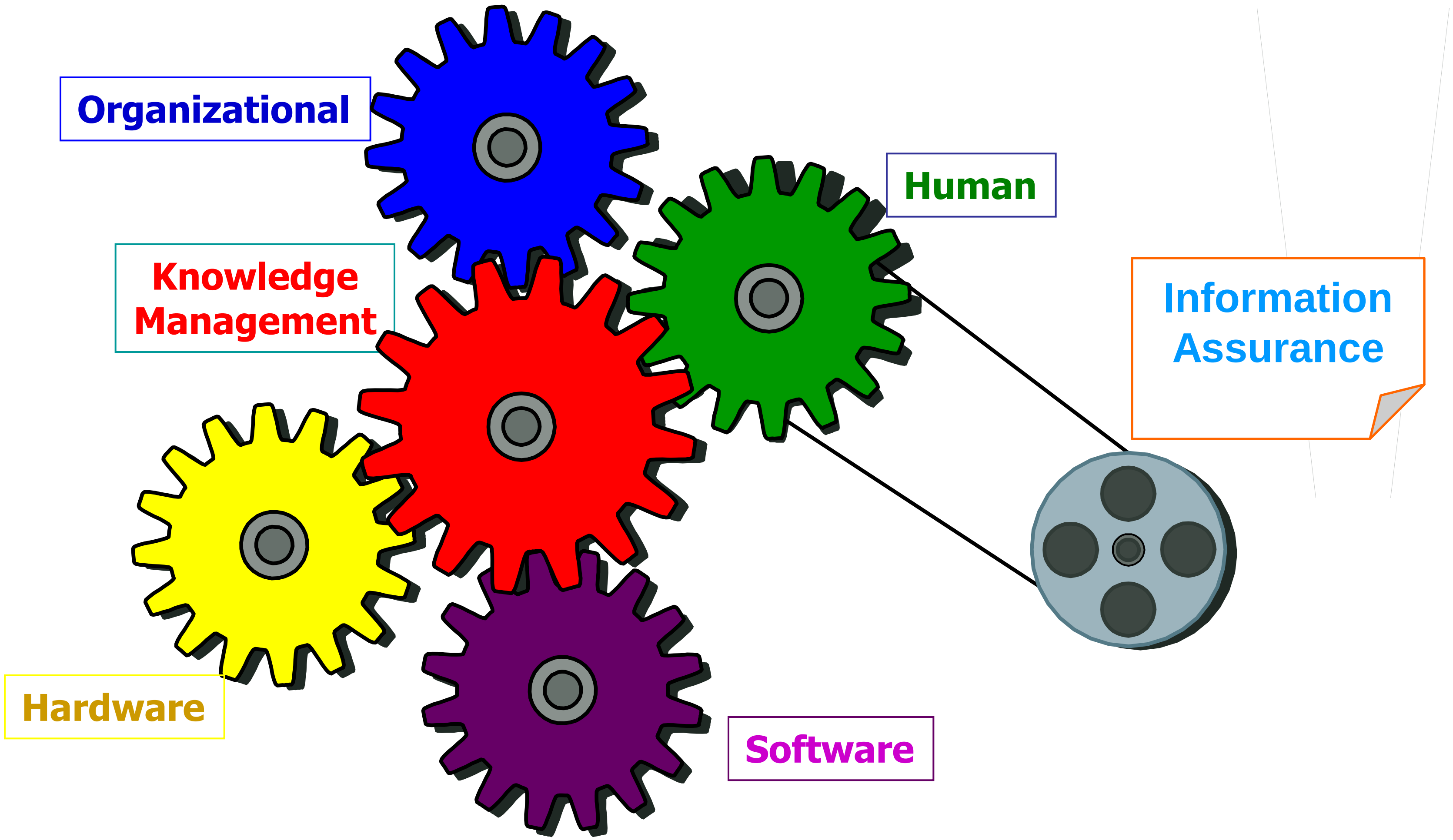
- Commission on High-Altitude Electro Magnetic Pulse (H-EMP) Attacks on the US
- DHS "Crimson Dawn" Exercise (Impact of Raising the Alert Level on the Economy)
- Virginia Bridge-Tunnel Transportation System

All Case Studies

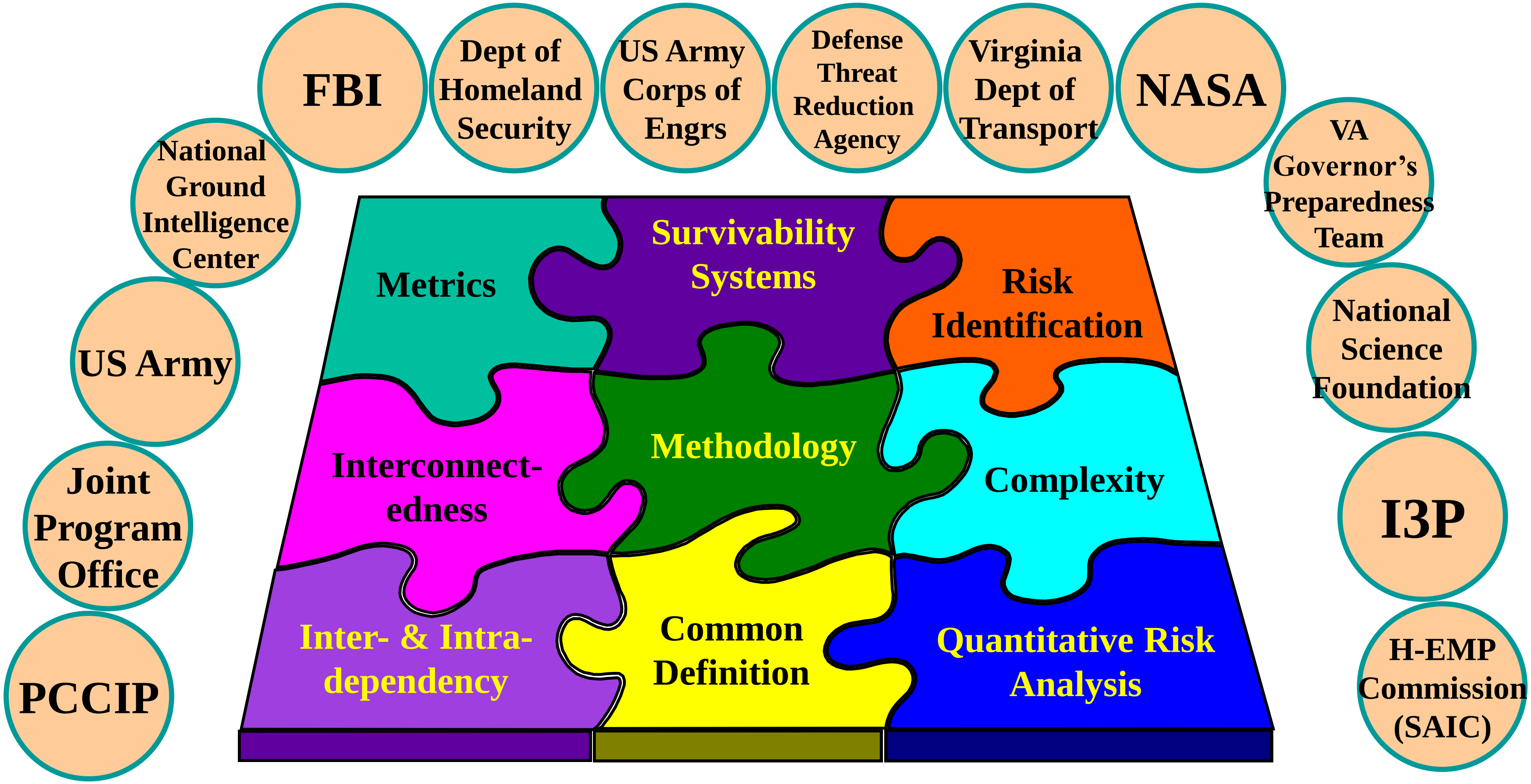
Have the following *common* attributes

- 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



Risk Modeling, Assessment, and Management For Homeland Security (1997-2006)



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

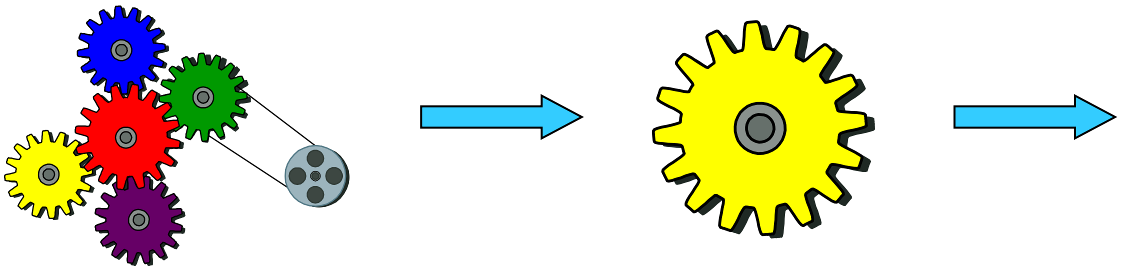
"As the **'supply chain'** has evolved from the simplicity of a bank's making and servicing a loan over its life to the complexity of securitization **(involving originators, holders, servicers, trustees, and hedging Markets)**, the focus on core banks and securities firms and major markets **must expand 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**."

[Systemic Risk and the Financial System: Background Paper: Darryll Hendricks, John Kambhu, and Patricia Mosser, May 2006]

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.

HHM Overview



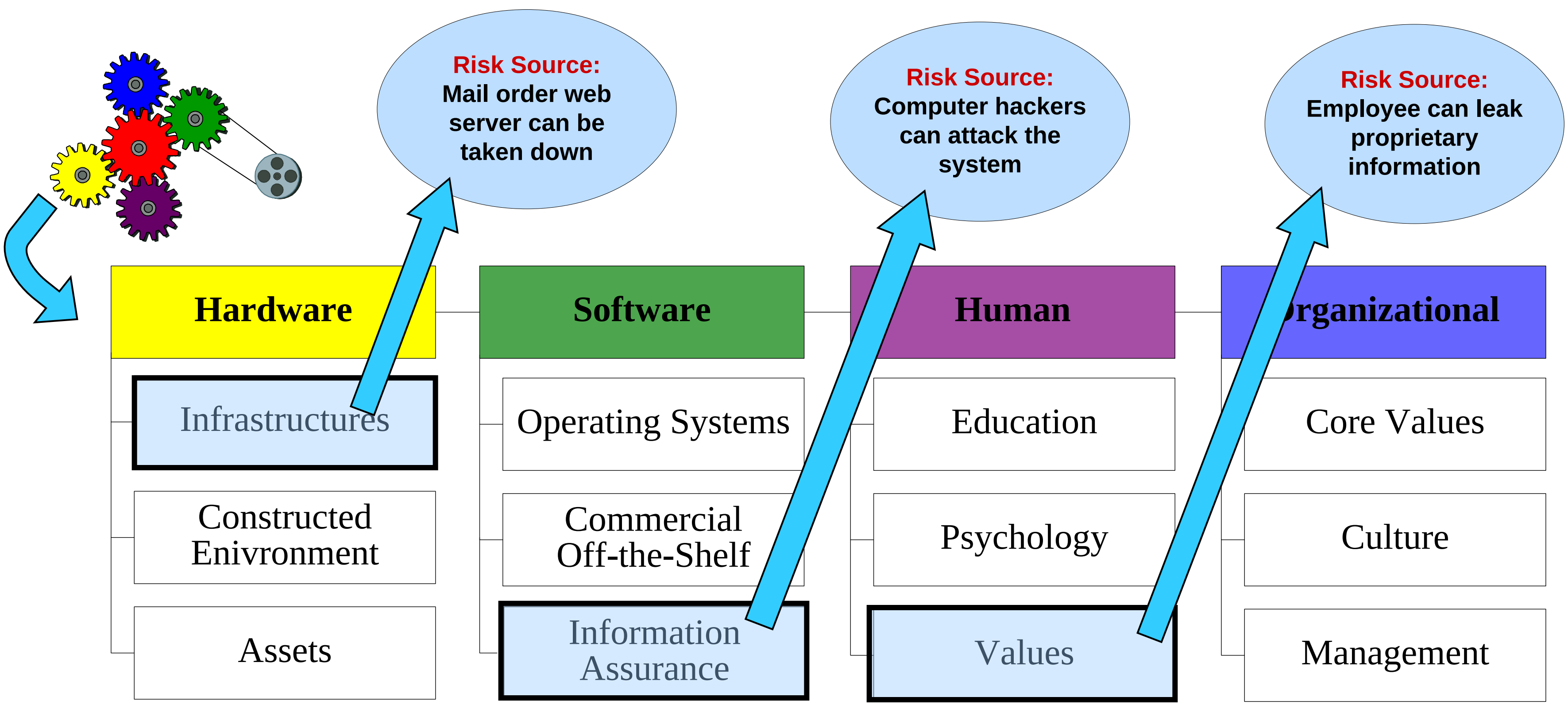
- **Hardware**
  - Infrastructures
    - Water Supply Systems
      - Tanks
      - Pumps
      - Pipes

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

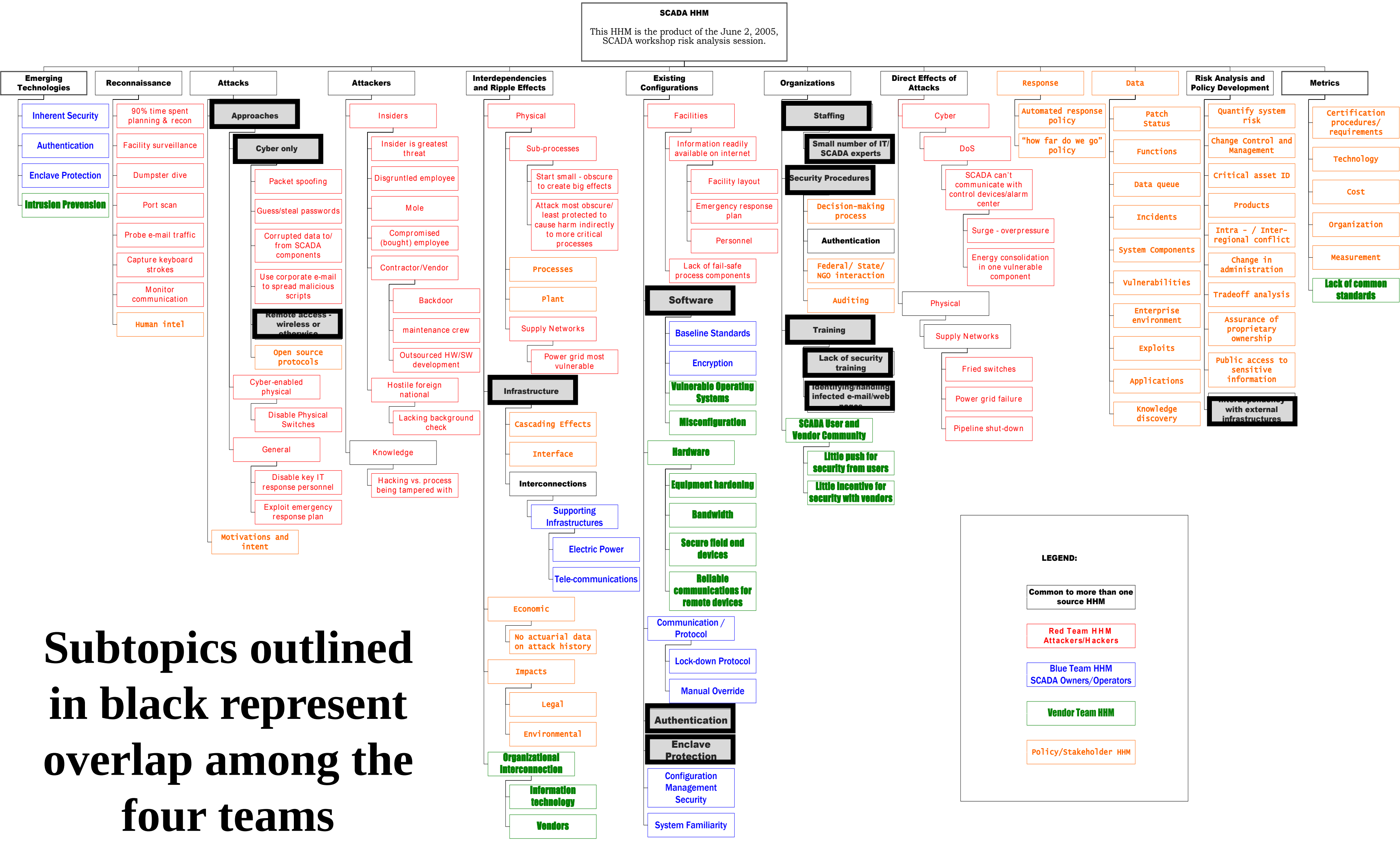
- **Four teams, each with very different perspectives, were used to develop separate HHMs**
  - **Red Team**: Attackers and Hackers
  - **Blue Team**: SCADA operators and owners
  - **Vendor Team**: SCADA developers and vendors
  - **Policy Stakeholder Team**: Government interests and industry associations

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.**

Adaptive Multi-Player HHM Game: Multiple Stakeholder Perspectives

University of Virginia



Subtopics outlined in black represent overlap among the four teams

Adaptive Multi-Player HHM Game: Multiple Stakeholder Perspectives

University of Virginia

2006 Gubernatorial Inauguration in Colonial Williamsburg

- People/Participants
  - Government officials and politicos
    - Focused Attack
    - Attack on future presidential candidate
    - Kidnapping
  - Non-Political Participants
    - Use Historic Fashion as Cover for attack
    - Musicians
      - Instrument Cases
    - Caterers
      - Food containers
      - Catering truck
  - Crowds/ Audiences
    - Panic Stampede
    - Riot
    - Attack on Crowd
    - Shooter as Participant in Parade
    - Explosion under Colonial Williamsburg
  - Trace-back Capability
- Transportation
  - Public Vehicles
    - Cars with Explosives
    - Confederate Ambulance with Pseudo Patient
    - Explosion under Colonial Williamsburg
    - Limousine Hijacked
    - Attack on emergency motorcade
    - Schoolbus or tourbus packed with explosives
    - Impostor VBIED ambulance
  - Mass Transport
    - Biological Attack
    - Shuttle Bus Take-Over
    - Ferry Boat
    - Ferry Boat Explosive Device
    - Suicide Bomber
    - Coordinated VBIED & Airborne Attack
    - Chemical attack
    - Trains
- Transportation (Continued)
  - Parking
  - Aviation
  - Airspace Exploitation
  - General Aviation Attack
  - Aerosol Chemical or Biologic Agent
  - Radiological Dispersal Device "Dirty Bomb"
  - General Aviation
    - Aerial application of toxic substance
    - Aerosol chemical or biologic agent
  - Commerical aviation
  - Individual plane flies into ceremony
  - Helicopters
  - Explosion under Williamsburg, part 2
  - Transportation of dignitaries
- Transportation (Continued)
  - Travel Routes
    - Explosive Devices
    - Diversion Accident
    - Blocked Road
    - VBIED Attack
    - Bridges
      - Rt. 5/162/CSX Rail over Colonial National Hist. Park
      - Rt. 143 over I-64 at Exit 238
      - I-64 over Queen Creek
      - I-64 over Colonial Pkwy and Lakes Head Dr.
      - Rt. 199 over I-64 exit 242
      - Rt. 199 over Rt. 60 and Rt. 143
      - I-64 over Rt. 199 and Rt. 646
      - I-64 over Rt. 199 and Rt. 646 at exit 234
      - Rt. 31 over Lake Powell
      - Rt. 5 over Chickahominy River
    - Railroad
      - Explosion on CSXT Tracks
    - Variable message signs
    - Road cones
- Media
  - Live Broadcasts
    - Broadcast Interference
    - Psychological Attack
    - Multiple Suicide Bomber Attacks
    - Communicated Threat
      - Advance warning to press
      - Letter to Media
    - Foreign Participation
    - Physical Attack Upon Media
    - Roadside Sniper Anywhere in VA
  - Multiple suicide sniper attacks
  - Print and Internet
    - Negative News and Comments
- Public Information
  - Restriction of Inaugural Data
  - Set up JIC
  - Public Address Systems
  - Behaviors/ Response
  - Misinformation to Public
  - Emails to/from Public Officials
    - Compromising email/false emails
  - Disinformation
    - False websites
  - Security Plans
  - Small plane with advertising banner
- Communications
  - Radio Frequency Interference
  - Interoperable Tactical Coummications
  - Data
  - Video
  - Protocols
  - News/Media
    - Take Over Broadcast
  - Voice Comms
    - Coordinated Attack
    - Cell Phones
      - Interception of Communication
      - Using cell phones to set off bomb
    - Walkie-Talkie
  - Control Center
    - Security
- Access to Workstations
  - Network Attack
    - CAN/DDOS
  - Network Exploitation
    - CNE/Remote Access

Legend:

- Red Team
- Blue Team 1
- Blue Team 2
- Topics added during Red Team group session

Risk Filtering, Ranking, and Management (RFRM) Methodology

RISK

A measure of the probability and severity of adverse effects

SAFETY

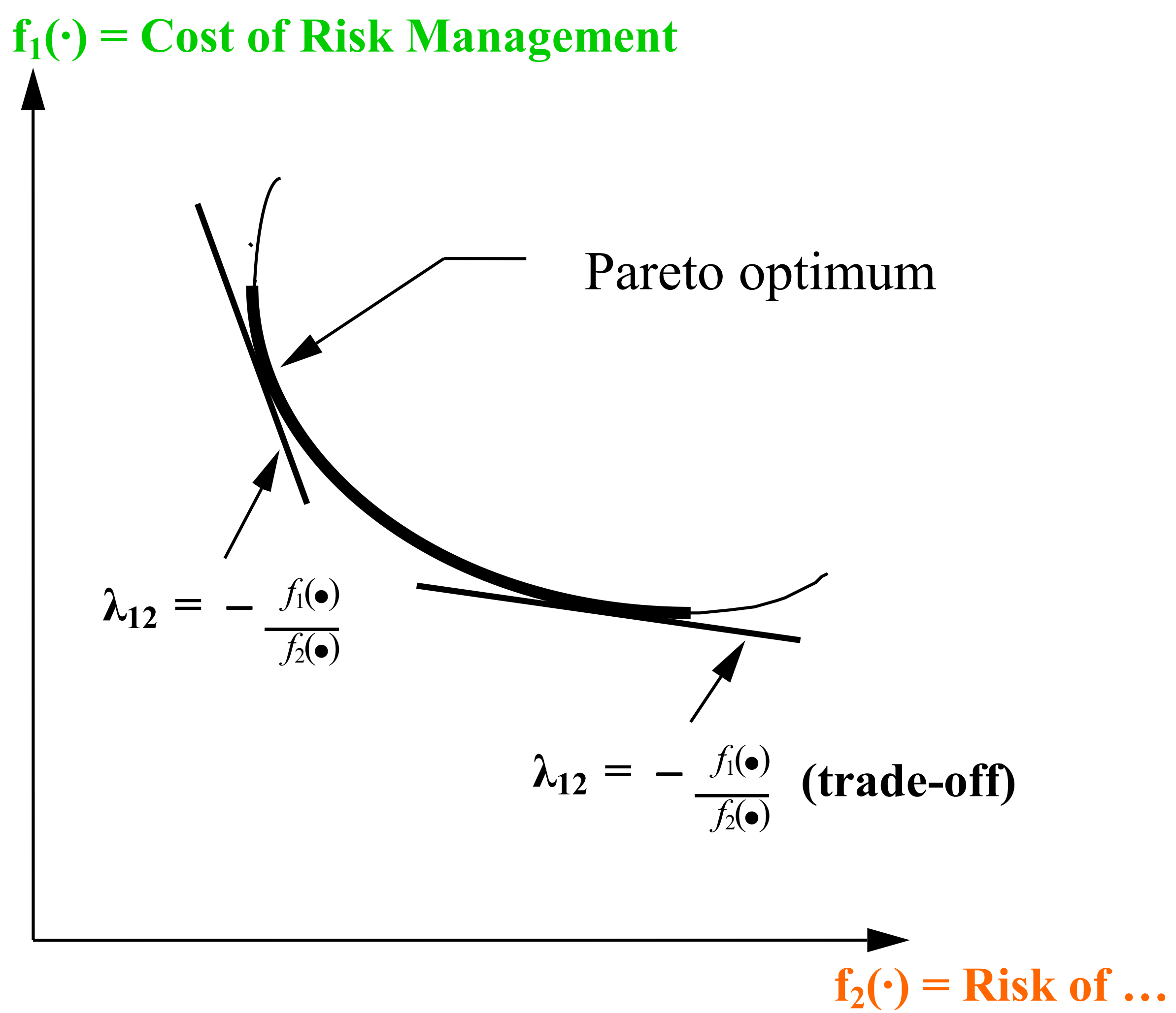
The level of risk that is deemed acceptable

[**William W. Lowrance**, ***Of Acceptable Risk***, **1976]**

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



How do we quantify risk?
How do we measure risk?

With the central tendency measure of risk

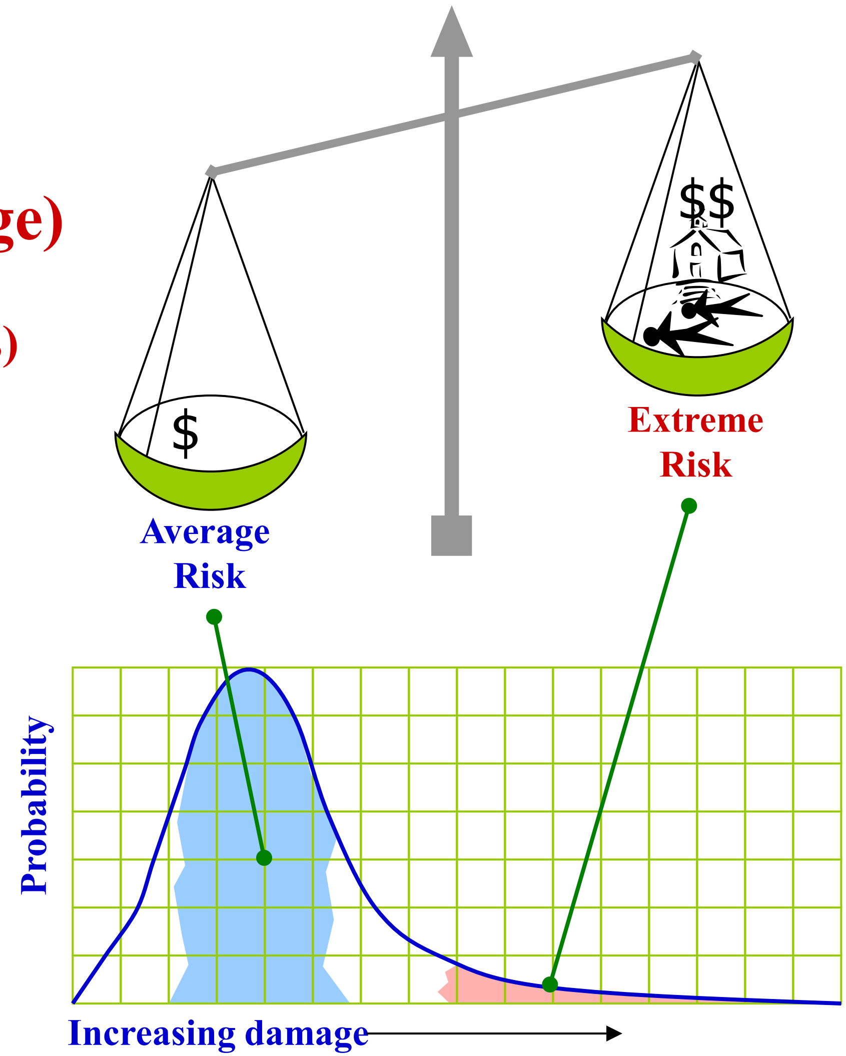
(the expected value of risk and its limitations when it is used as the only metric for risks related to extreme events)

Limitation of Expected Value of Risk

Risk = *f*(Probability, Damage)

or

Risk = *f*(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.

Limitation of Expected Value of Risk

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 :

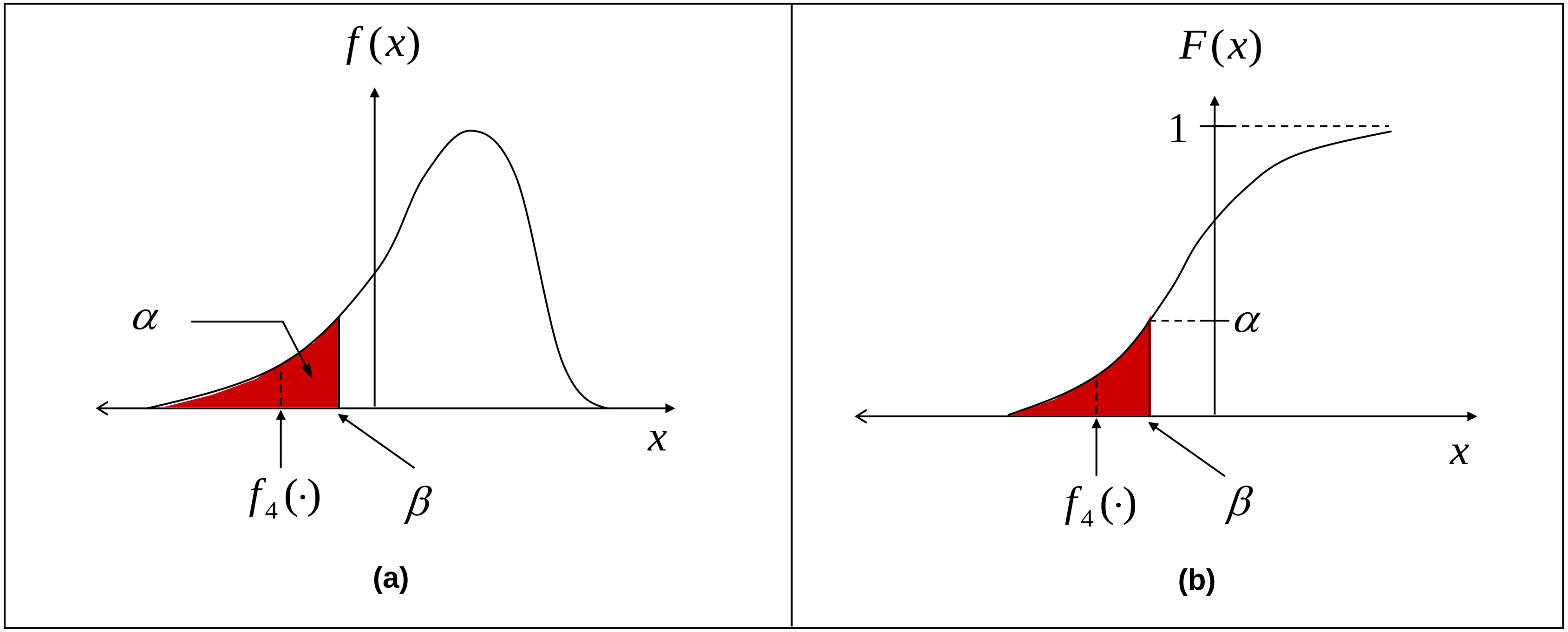
$10^3 \text{ x } 10^{-1} = \$10^2$

$10^7 \text{ x } 10^{-5} = \$10^2$

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.

Partitioned Multiobjective Risk Method (PMRM)

Conditional Expectations



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

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

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

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

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

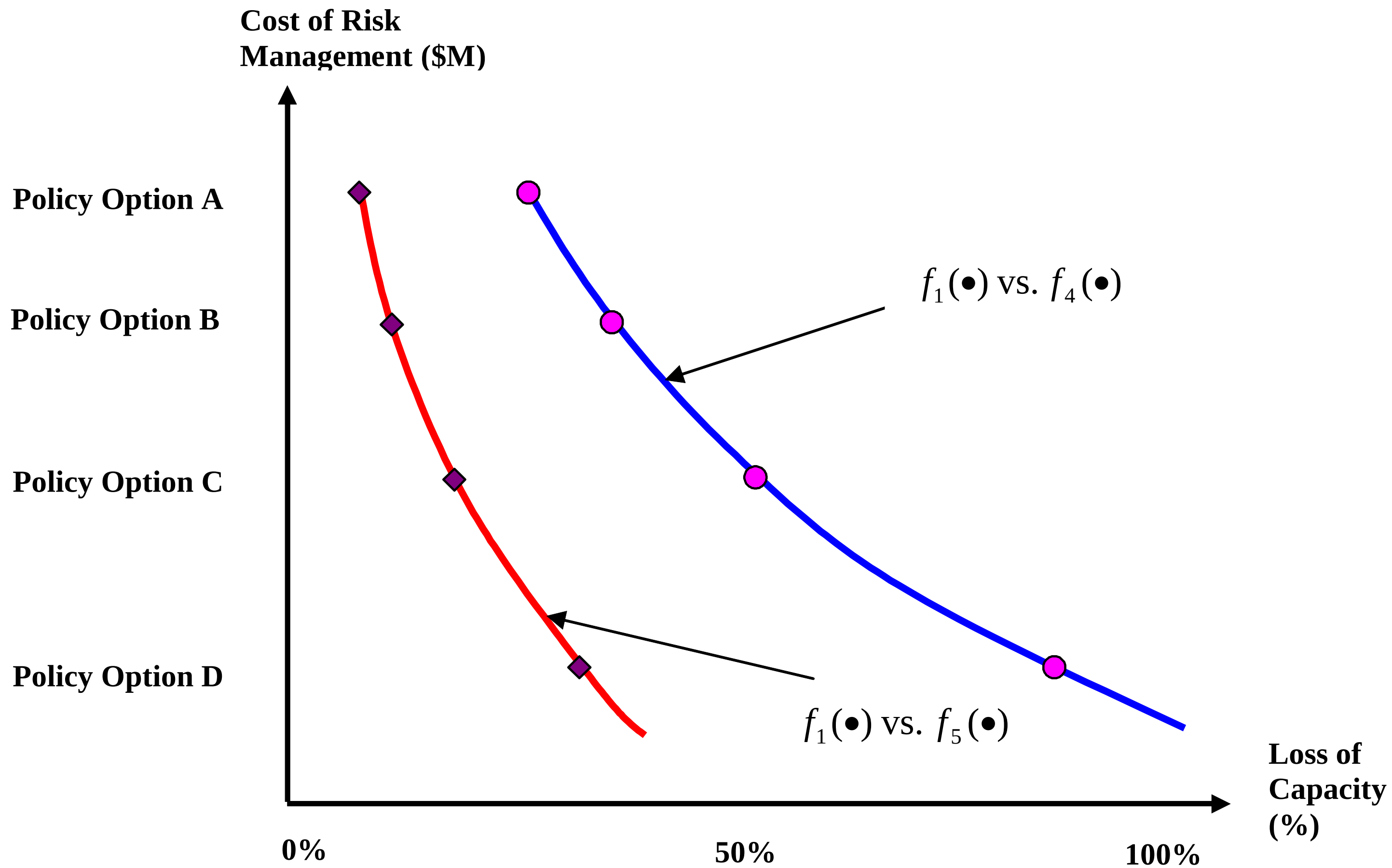
$$f_4(\cdot) = E[X \mid X > \beta_2] = \frac{\int_{\beta_1}^{\infty} xp(x)dx}{\int_{\beta_2}^{\infty} p(x)dx}$$

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

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

$f_5(\cdot)$ represents the unconditional (conventional) expected value of risk.

Multiobjective Trade-off Analysis for Risk of Extreme Events Using PMRM



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

- 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

Inoperability Input-Output Model (IIM)

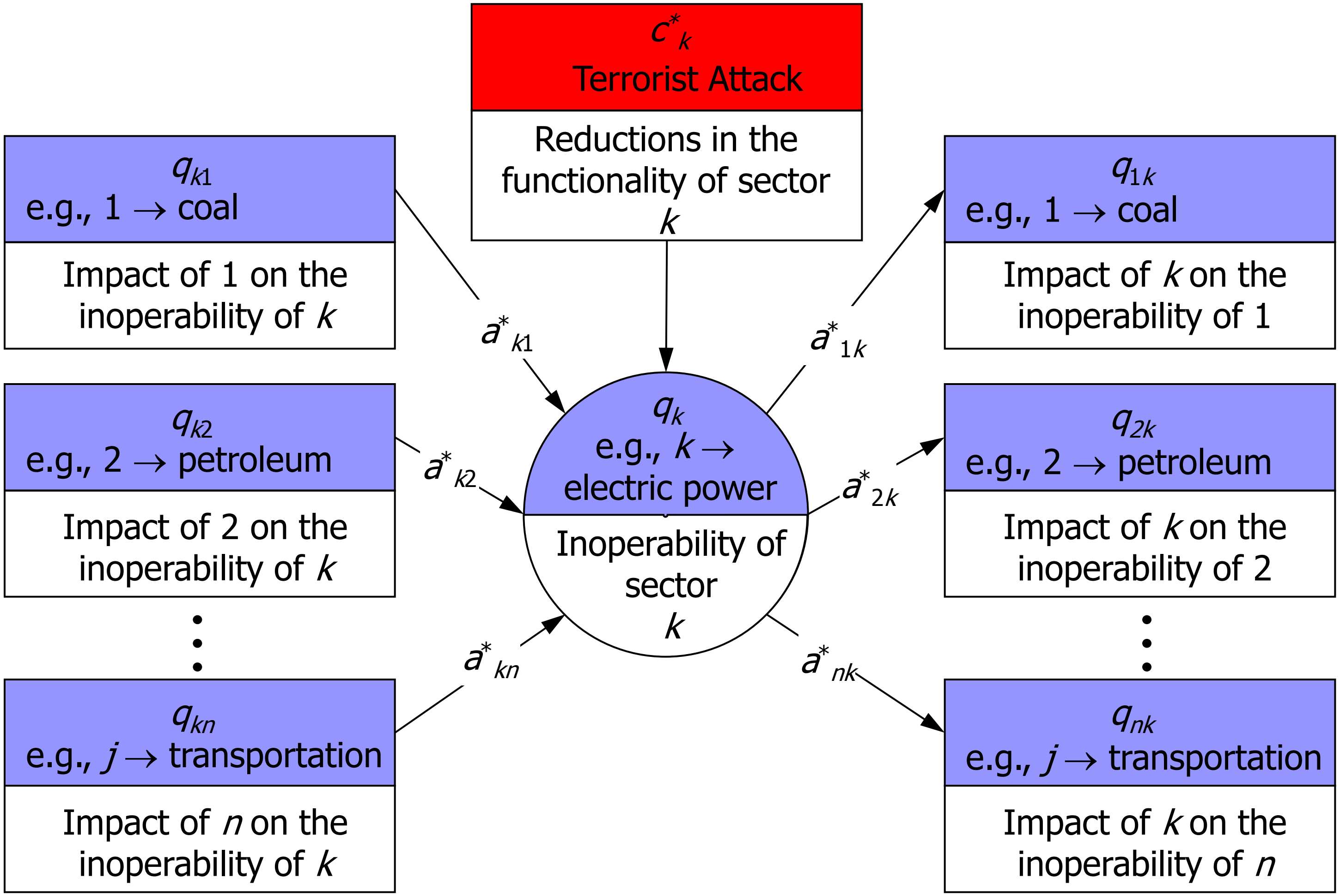
Background

- **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)

University of Virginia

Calculating propagating Effects



Inoperability Input-Output Model (IIM)

Basic Model

$$\mathbf{x} = \mathbf{A}\,\mathbf{x} + \mathbf{f} \Leftrightarrow x_i = \sum_j a_{ij} x_j + f_i$$

- Leontief construct based on industry consumption.
  - **x** is the vector of industry outputs
  - **A** is the technical coefficient matrix
  - **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 Input-Output Model (IIM)

Model Components

Leontief Model

Production
$\mathbf{x}$

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{c}$$

A :=Technical Coefficient Matrix

Consumption
$\mathbf{c}$

Inoperability I-O Model (IIM)

Terrorist Attack
$\mathbf{c}^*$

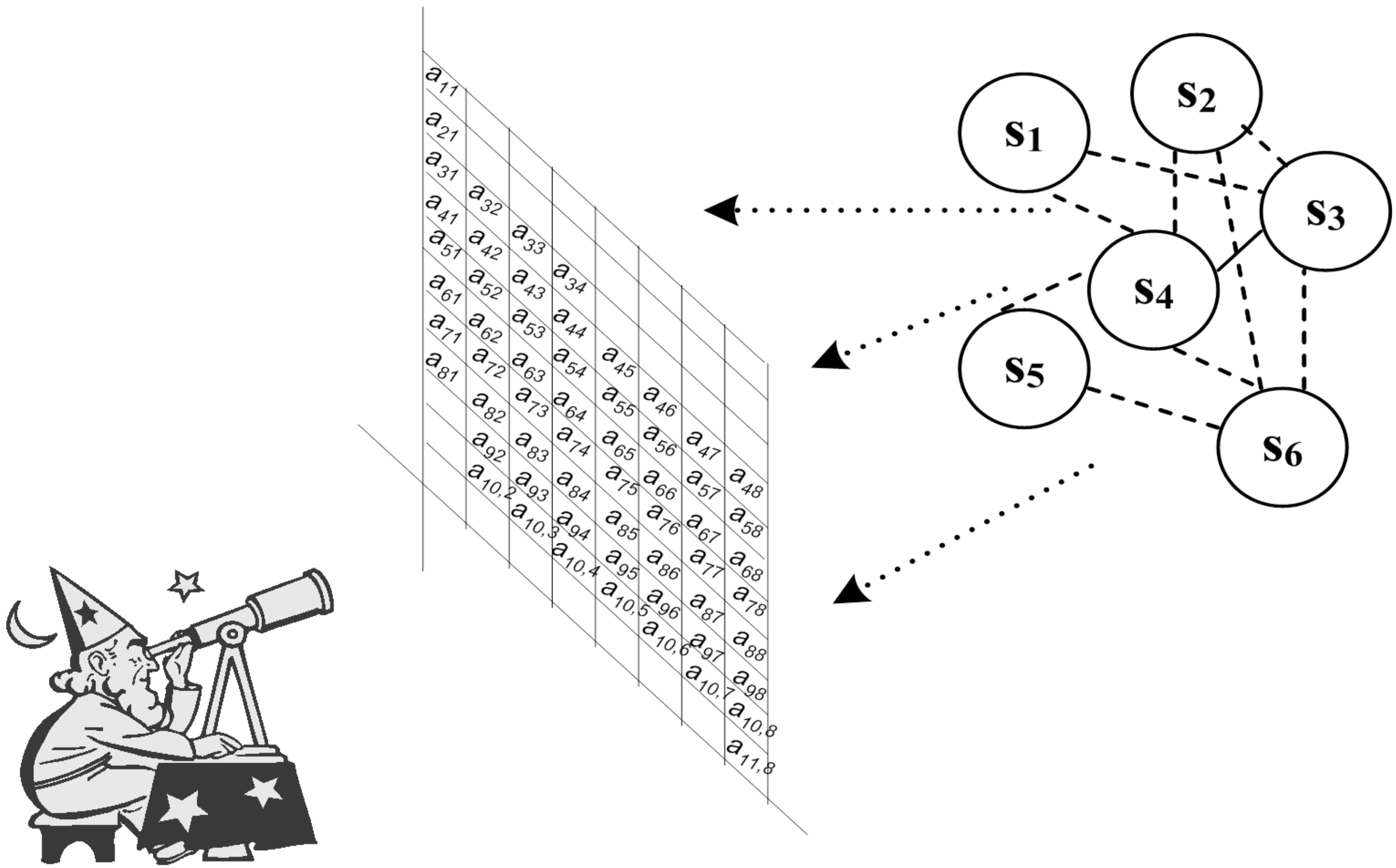
$$\mathbf{q} = \mathbf{A}^* \mathbf{q} + \mathbf{c}^*$$

A* := Interdependency Matrix

Inoperability
$\mathbf{q}$

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

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

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)

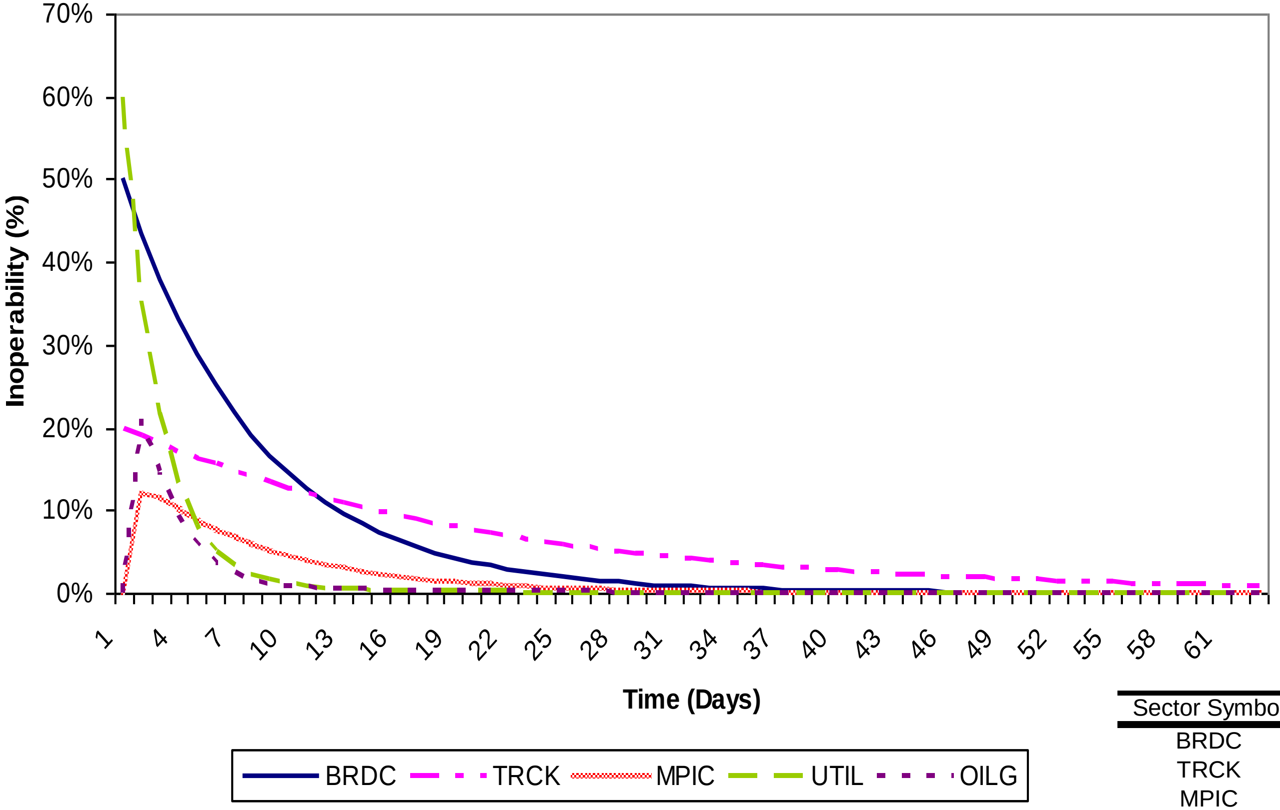
Dynamic IIM (DIIM)

Background and Capabilities

- 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 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

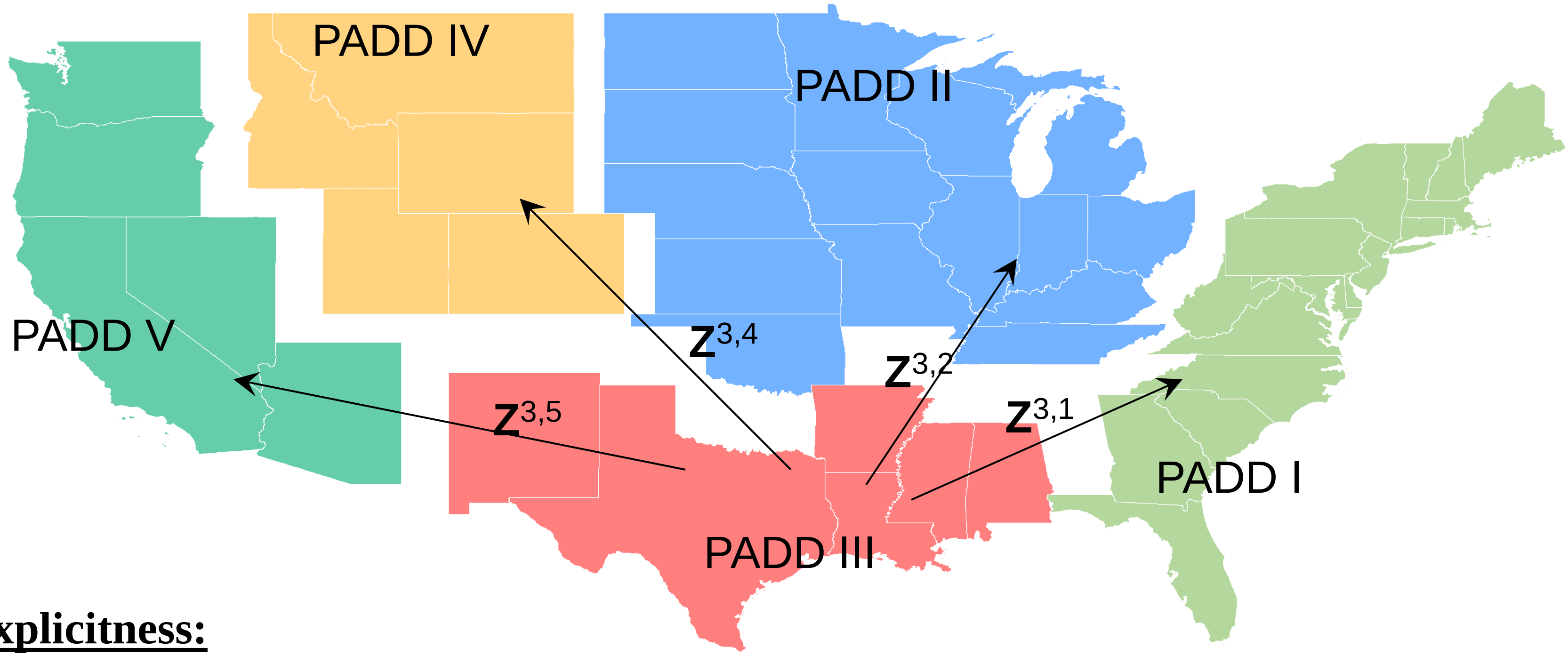
- The lack of spatial explicitness in risk analysis results in only average estimates across geography. Such estimates may lead to overlooking **geographically-concentrated risks** or **significant cross-regional interdependencies**.
- Spatially explicitness is added when the economy is regarded as a **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.

Regional IIM (RE-IIM)

University of Virginia

Example Model

Petroleum Administration and Defense Divisions (PADDS)



Spatial Explicitness:

- Adapt multi-regional formulation [Isard 1998].
- $\mathbf{z}^{RS}$ is a vector of **cross-regional (CR) transactions** from region R to region S.
- $\mathbf{z}^{RS} = \left[z_1^{RS}, \ldots, z_n^{RS}\right]^T$, 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

National Commission on H-EMP

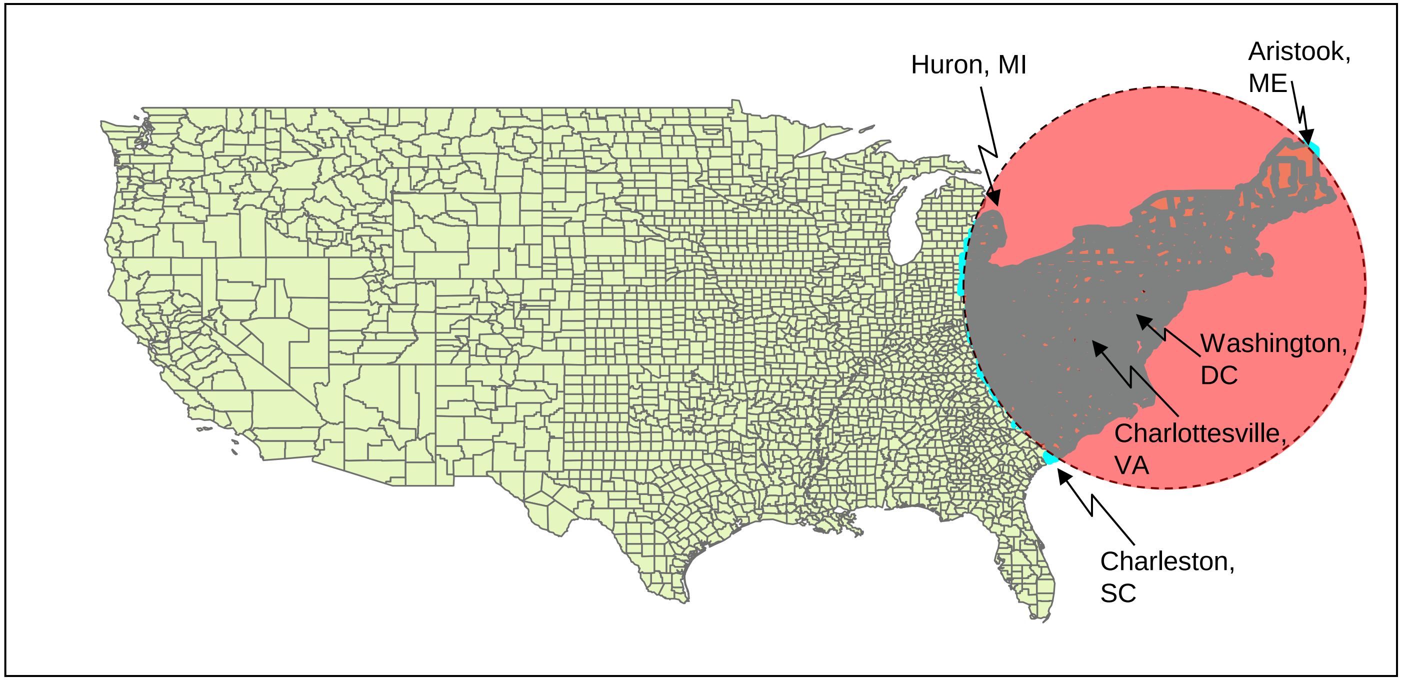
Background

- 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^{o}N Latitude and -75.54^o Longitude**



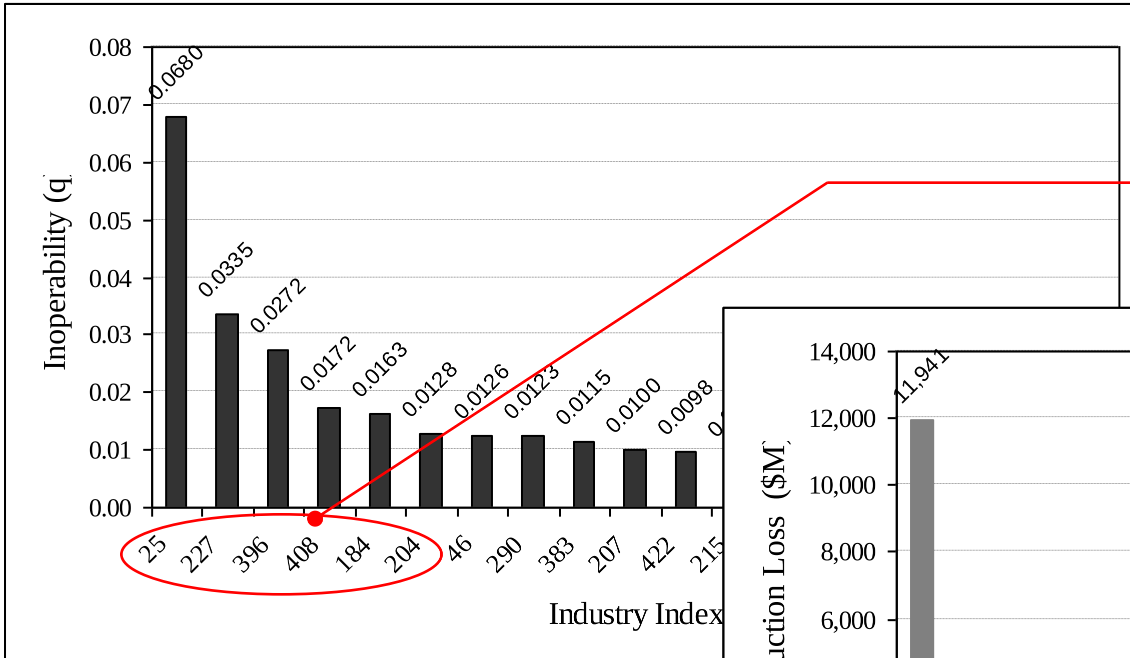
National Commission on H-EMP

IIM Metrics – Inoperability and Economic Loss

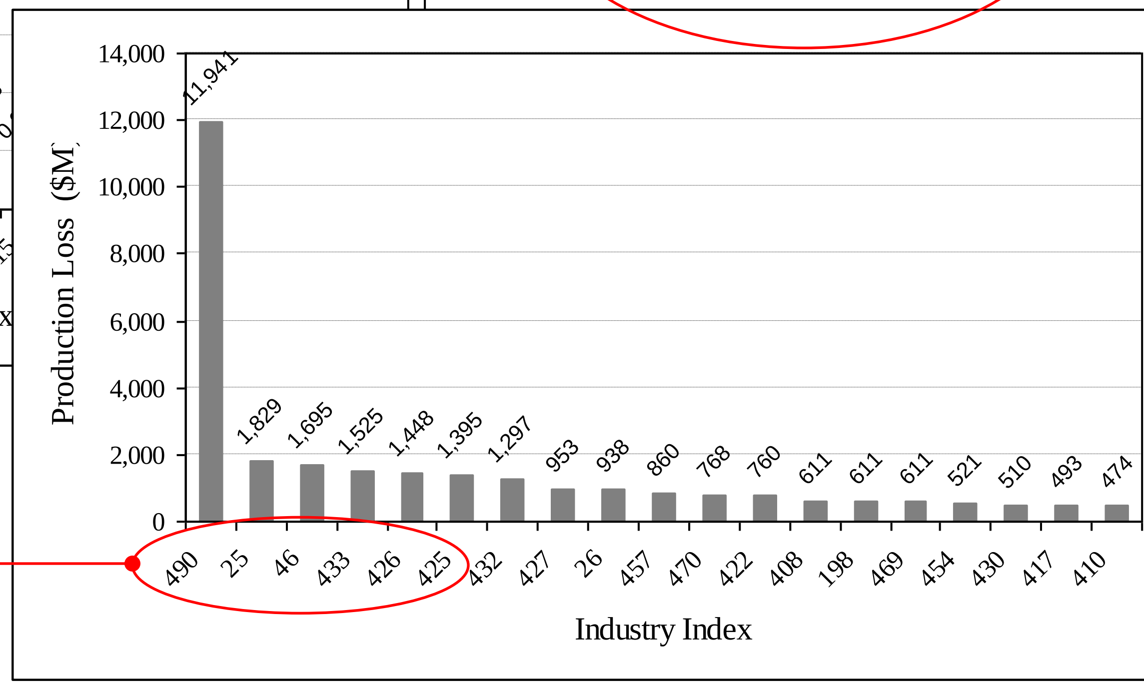
- We assessed perturbations to the availability/functionality of electric power and H-EMP-sensitive equipment for nearly **500 economic sectors**.
- The resulting impacts on users of electric power and H-EMP-sensitive equipment are measured in terms of IIM metrics: inoperability and economic loss.
  - **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

National Commission on H-EMP

University of Virginia

Impact on Workforce

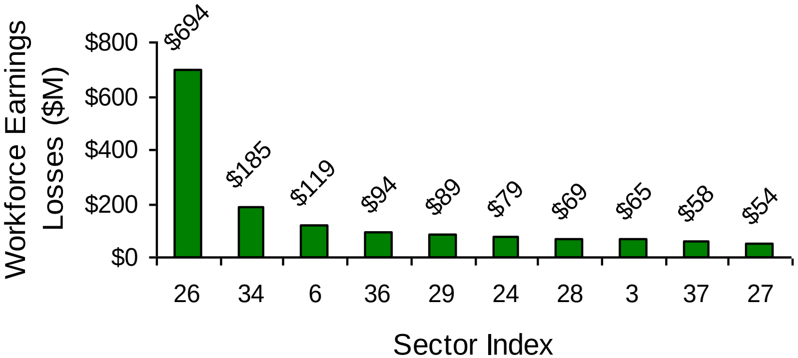
"**Thus, there is a strong need for models more capable of capturing the complex interactions between operational infrastructure and then financial flows that the infrastructure supports**. Similar models would be helpful in understanding the consequences of a pandemic event that made it impossible for **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**."

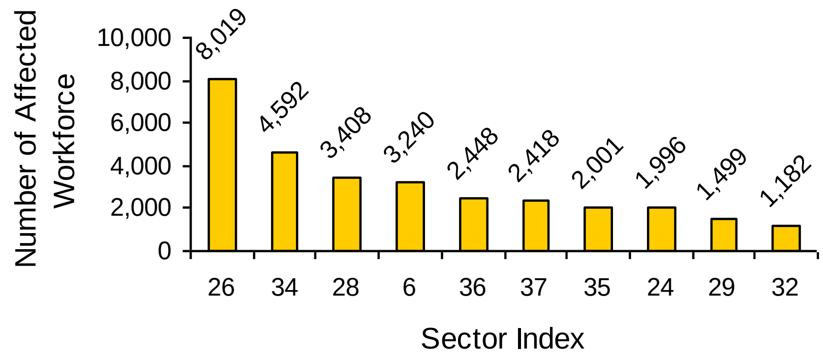
[Systemic Risk and the Financial System: Background Paper: Darryll Hendricks, John Kambhu, and Patricia Mosser, May 2006]

National Commission on H-EMP

University of Virginia

Sample Workforce Impact Analysis Generated from RE-IIM





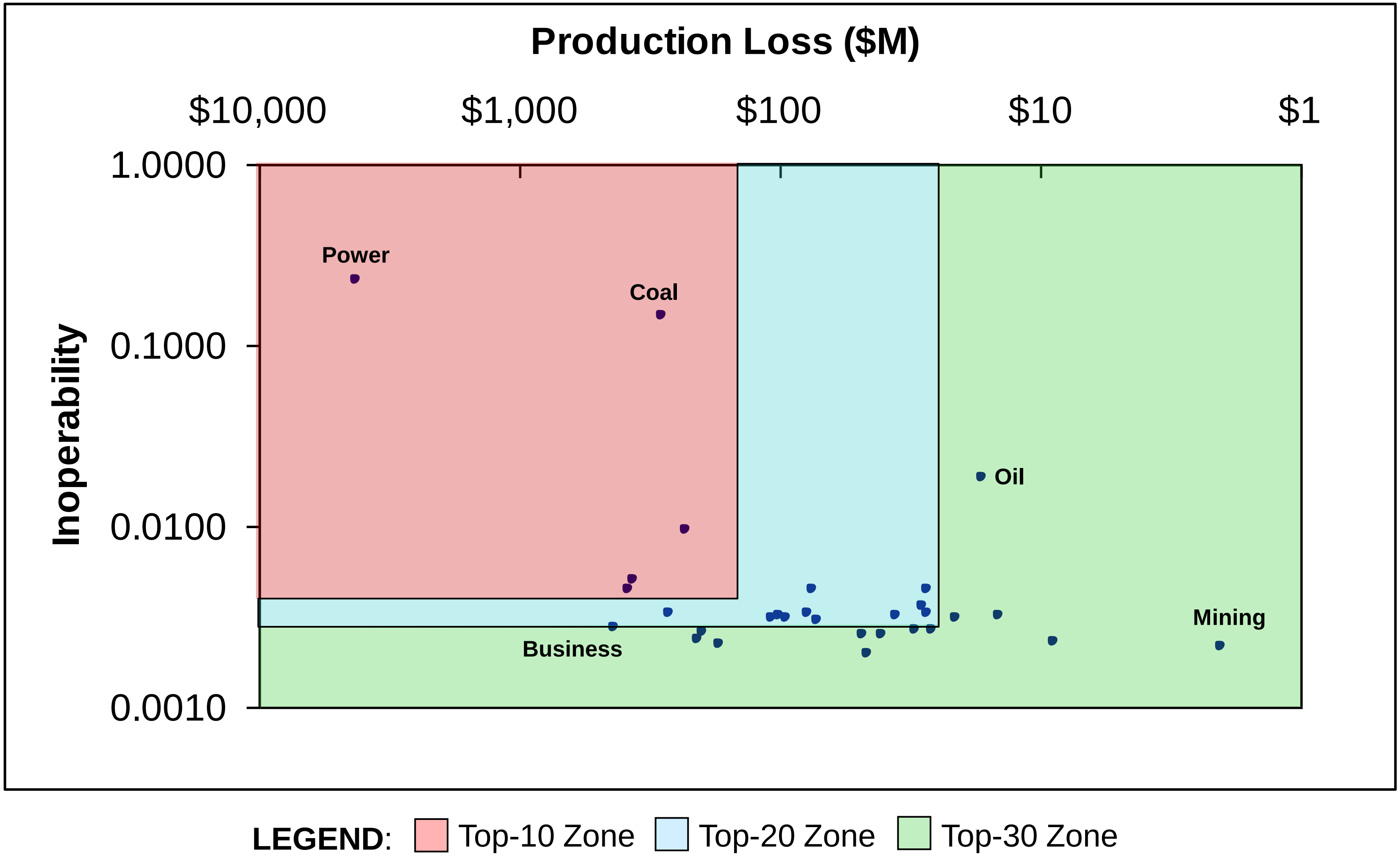
Rank	Index	$M	Sector Description
1	26	694	Electric, gas, and sanitary services
2	34	185	Business services
3	6	119	Construction
4	36	94	Health services
5	29	89	Depository and nondepository institutions and security and commodity brokers
6	24	79	Transportation
7	28	69	Retail trade
8	3	65	Coal mining
9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

Rank	Index	# Affected	Sector Description
1	26	8,019	Electric, gas, and sanitary services
2	34	4,592	Business services
3	28	3,408	Retail trade
4	6	3,240	Construction
5	36	2,448	Health services
6	37	2,418	Miscellaneous services
7	35	2,001	Eating and drinking places
8	24	1,996	Transportation
9	29	1,499	Depository and nondepository institutions and security and commodity brokers
10	32	1,182	Hotels and other lodging places, amusement and recreation services, and motion pictures

National Commission on H-EMP

University of Virginia

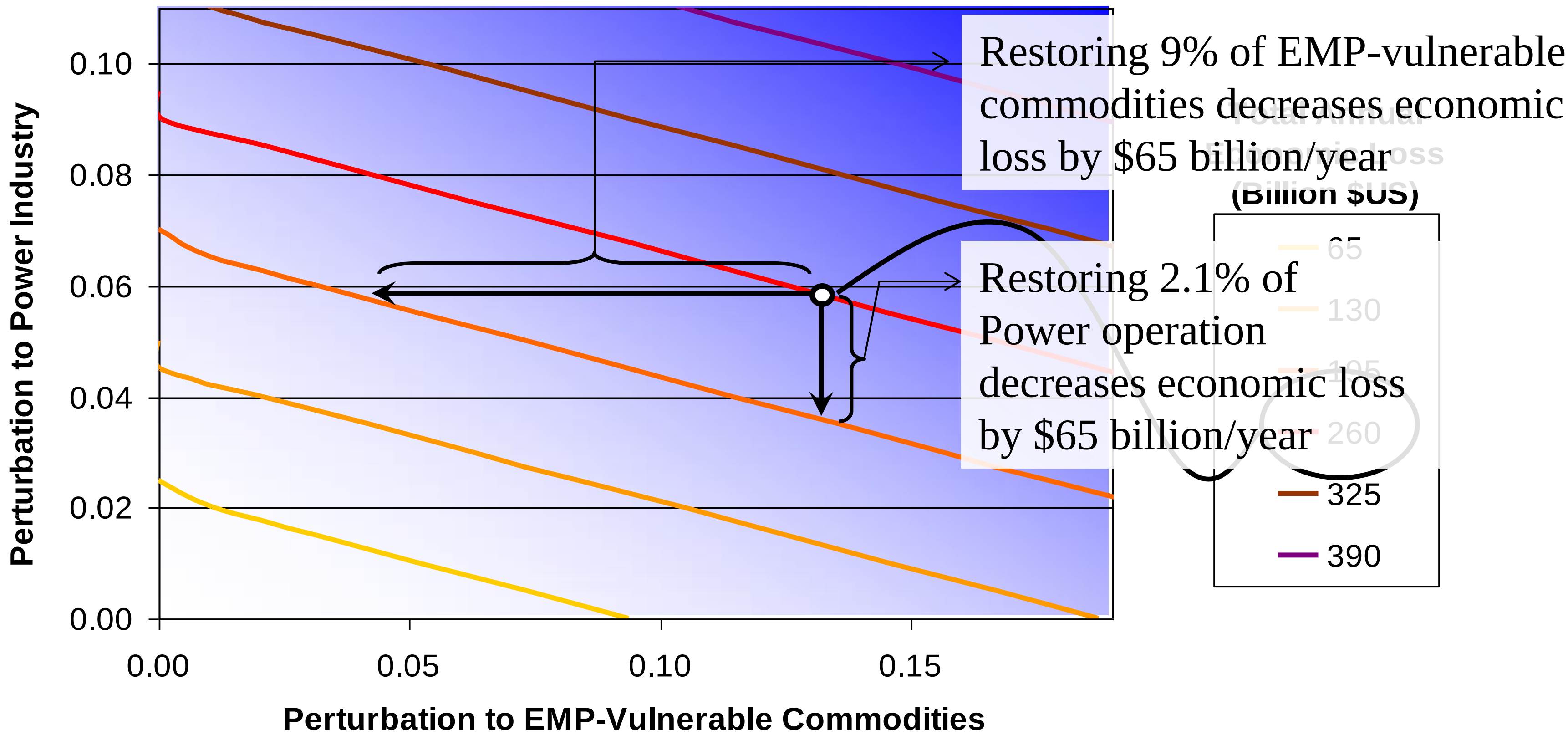
Sample IIM Impact Matrix



National Commission on H-EMP

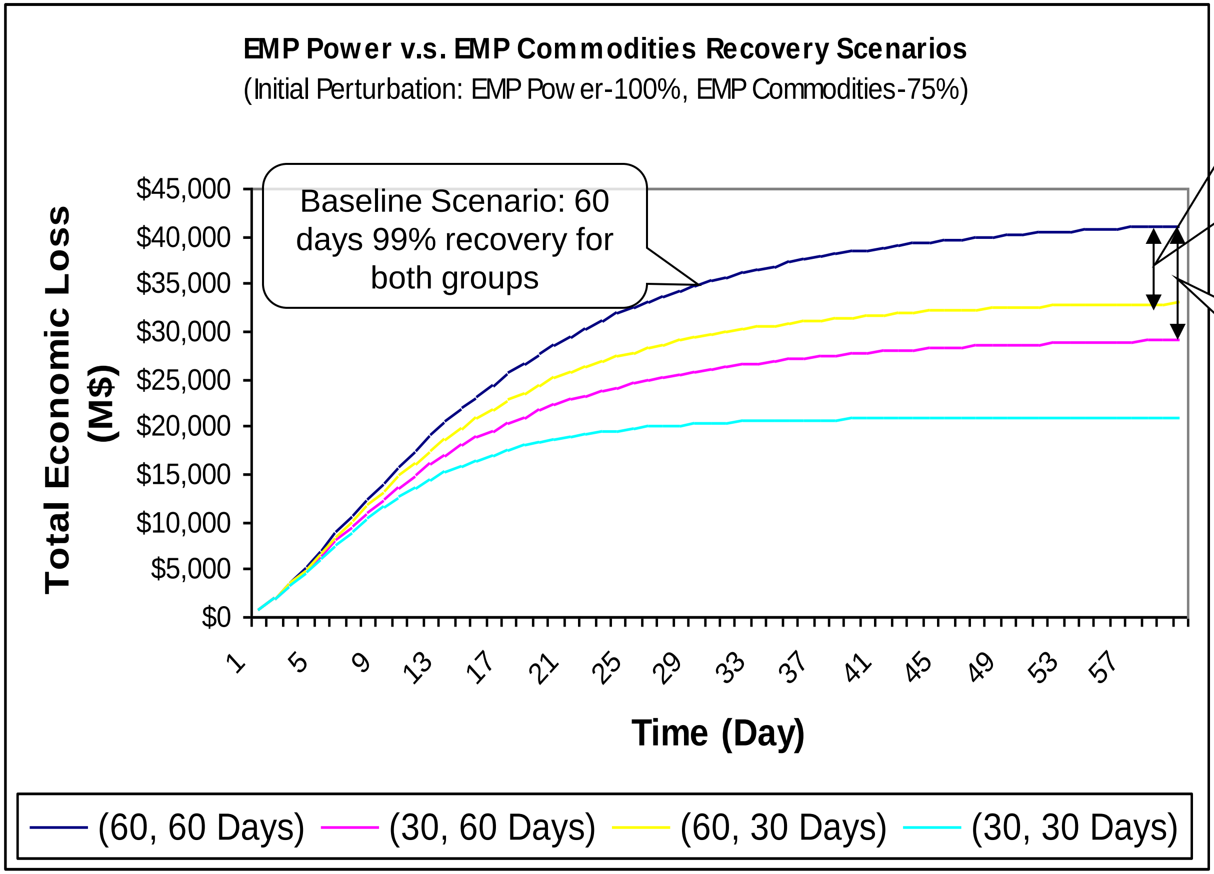
University of Virginia

Trade-off Analysis Example



National Commission on H-EMP

Temporal Trade-off



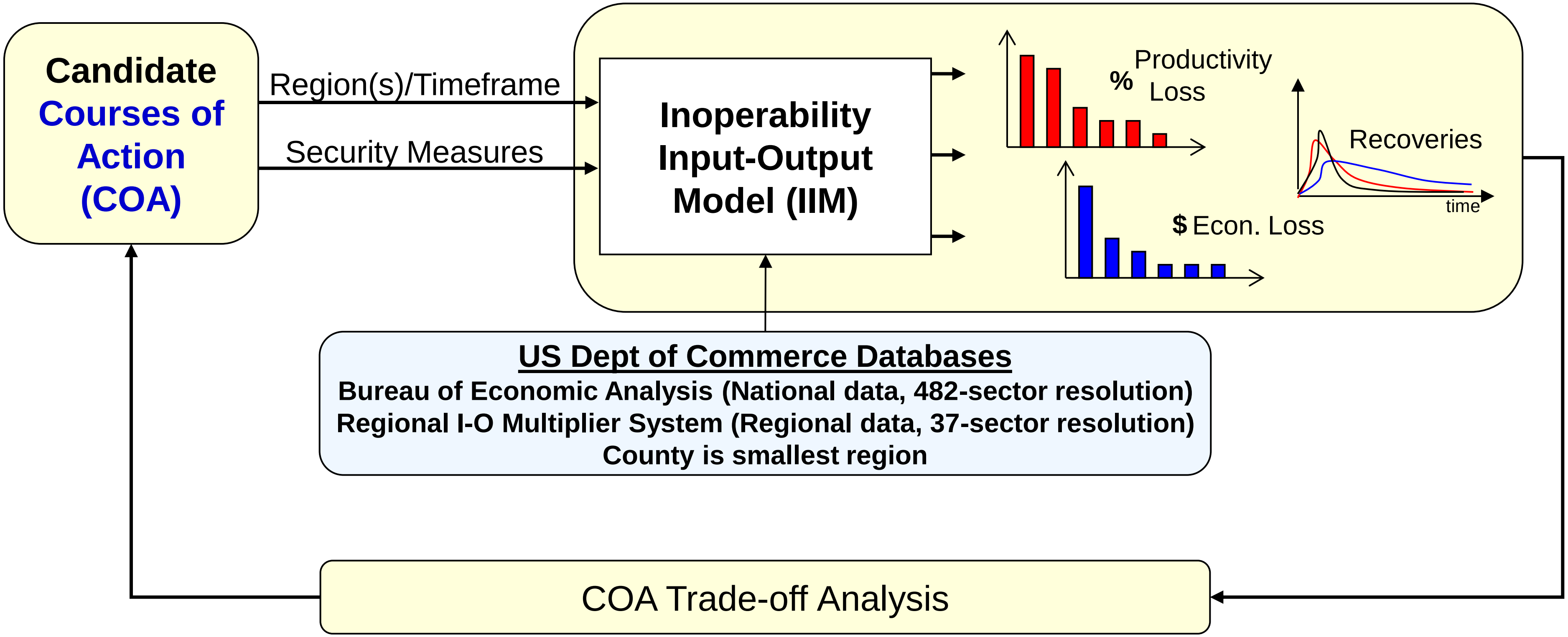
Reducing EMP commodity sectors recovery time from 60 days to 30 days save $8,094 million

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

Interdependency Analysis: Impact Analysis of Issuing Alert Levels By the Department of Homeland Security (DHS)

DHS Alert Levels

Applying the IIM to COA Decisionmaking



DHS Alert Levels

Example: National Guard Impact

- 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.)**

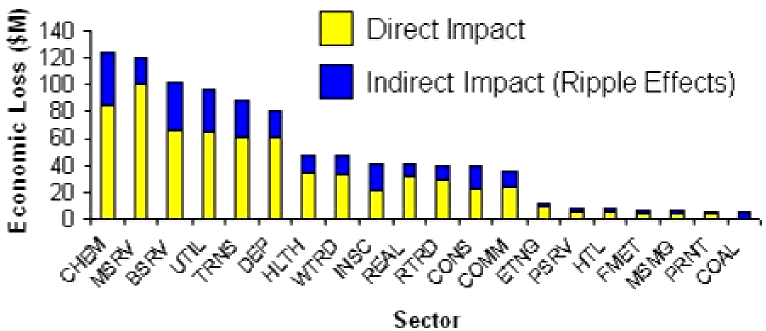
DHS Alert Levels

Example: Newark Red Alert

University of Virginia

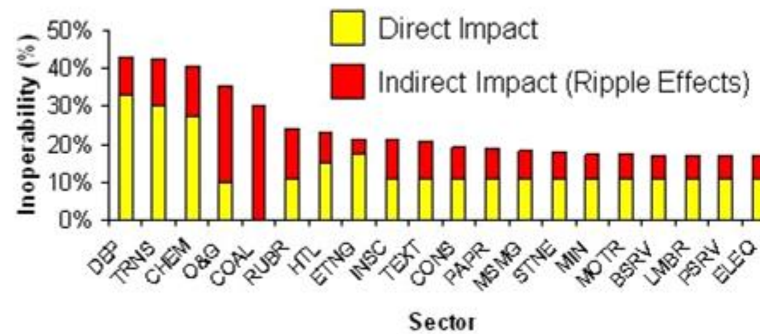
Most Affected Sectors in Terms of Economic Losses

(Newark Area, 1 week at Red)

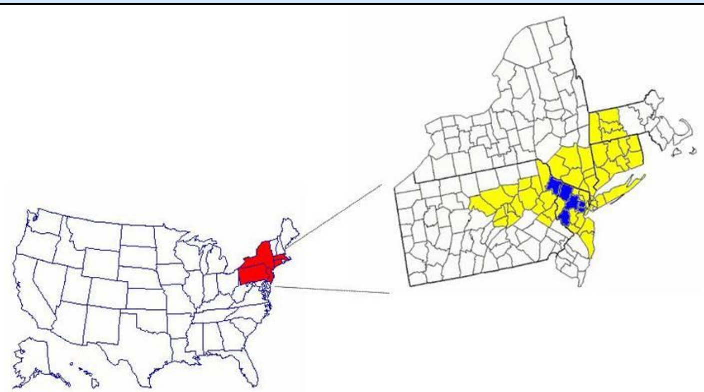


Most Affected Sectors in Terms of Productivity (%)

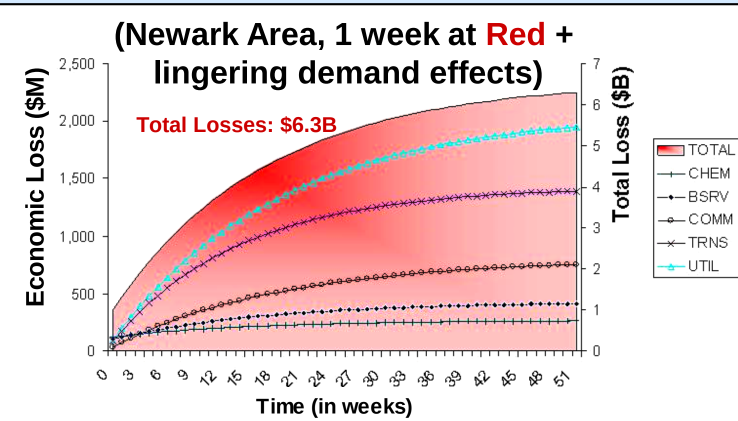
(Newark Area, 1 week at Red)



Geographic Scope of Alert



Identification of Sectors with Sustained Impacts



DHS Alert Levels

Finding from Applying IIM

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.

Particular Security Measures to Affect Impact → 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.

Critical Sectors that may Suffer Sustained Economic Damage → The closures of "Eating and Drinking Places" would cause significant losses to "Fishing and Forestry Products", possibly causing sustained losses of business enterprises.

Interdependency Analysis: Evaluating Interdependencies of James River Crossings For Virginia Department of Transportation (VDOT)

VDOT Interdependency Analysis

University of Virginia

Background Map

VDOT Interdependency Analysis

University of Virginia

Databases

HIGHWAY ASSET FAILURE:	IMPACT:	DATABASES:
Closure	**(1) Workforce Commute** Losses from Delayed/Absent Workers	Journey to Work Data Regional Employment Data Regional Earnings Data
Congestion	**(2) Commodity Flow** Losses from Delayed Commodities	Commodity Flow (CF) Data to Destination CF Data from Origin CF Data through Corridors
Collapse	**(3) Business Accessibility** Losses from Business Demand Reduction	RIMS II Data Geographic Location Data

VDOT Interdependency Analysis

Workforce-IIM: Defining Affected Regions

- 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)

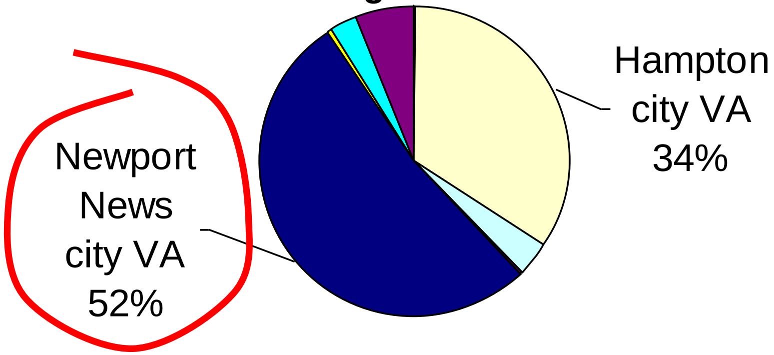
VDOT Interdependency Analysis

University of Virginia

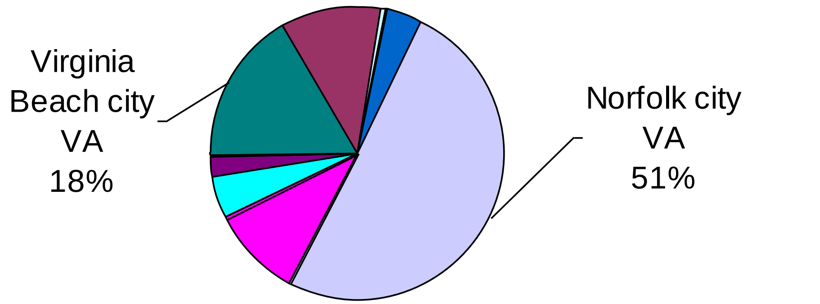
Workforce-IIM: Journey-to-Work Data

From	To NW	To SE	Totals
NW	214,952	22,658	250,705
SE	22,410	534,551	571,822
To Totals	247,348	563,811	3,164,052

Destination of Workers Crossing Bridge from SE



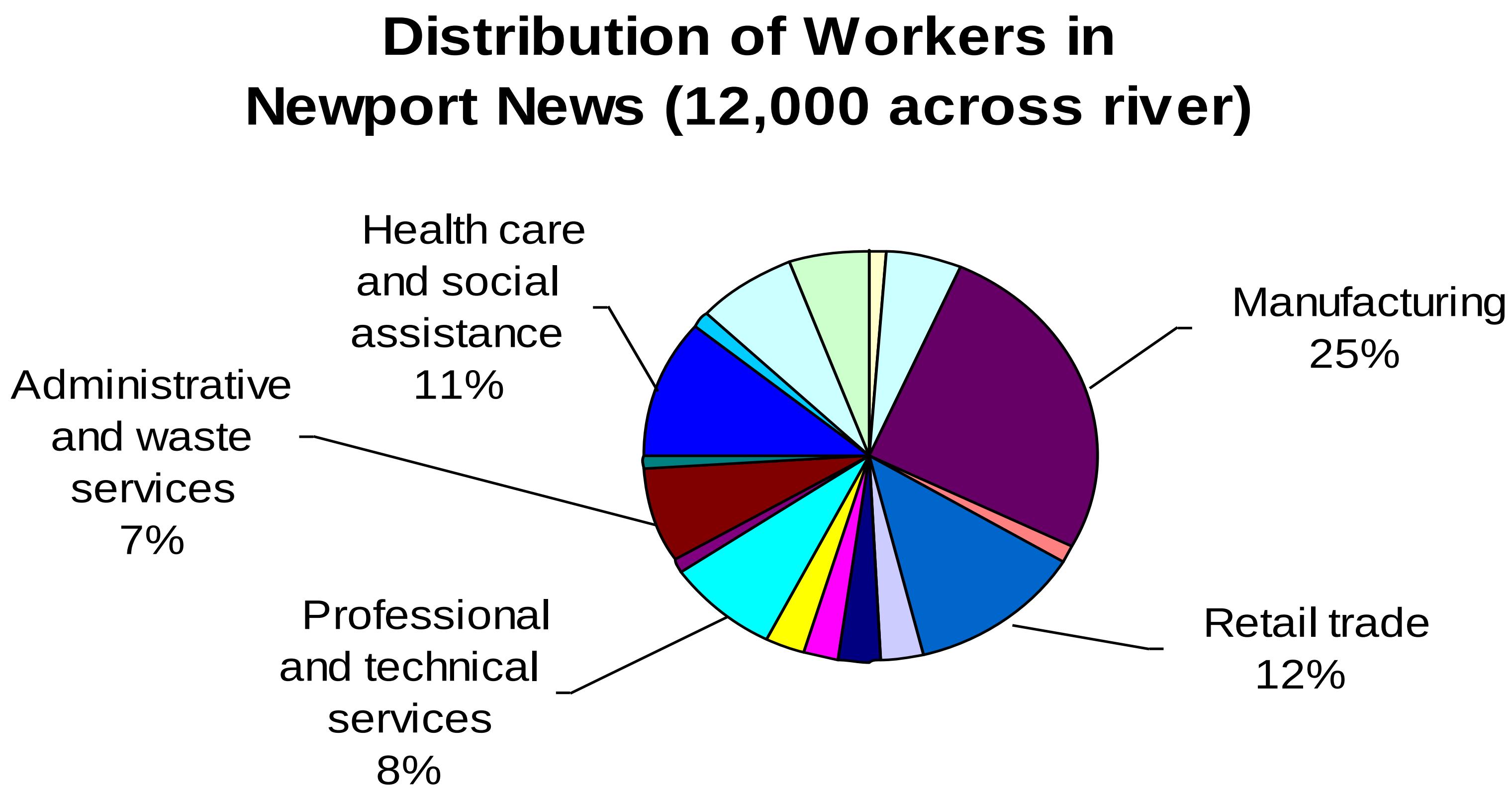
Destination of Workers Crossing Bridge from NW



VDOT Interdependency Analysis

University of Virginia

Workforce-IIM: Using Employment Data



VDOT Interdependency Analysis

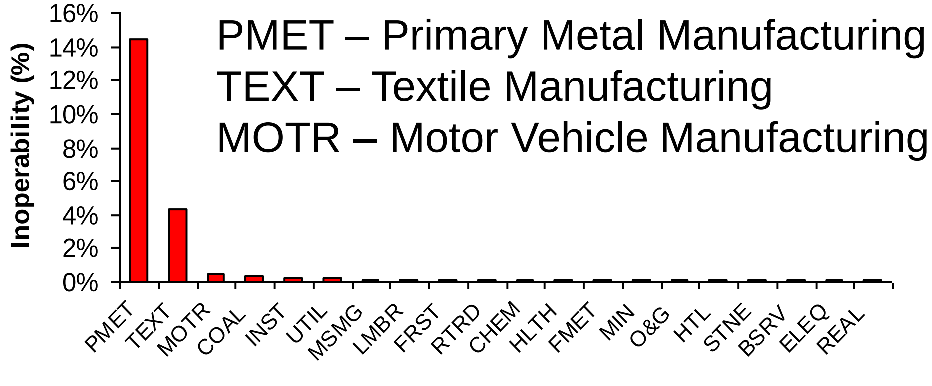
University of Virginia

Workforce-IIM: Economic Loss and Inoperability Rankings

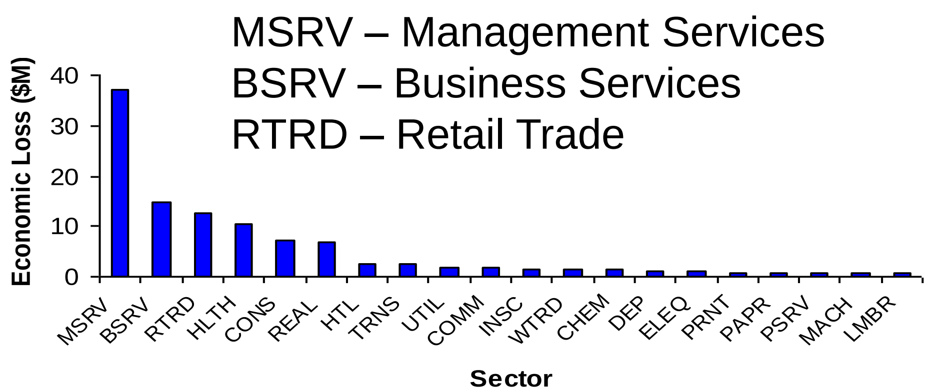
- **Assume travelers are distributed across sectors similar to the workers' distribution across sectors**

- **Given the scenario perturbation, the estimated annual loss is $110 million to the local economy of Southeastern Virginia.**

Top-20 Affected Sectors in Terms of Inoperability



Top-20 Affected Sectors in Terms of Economic

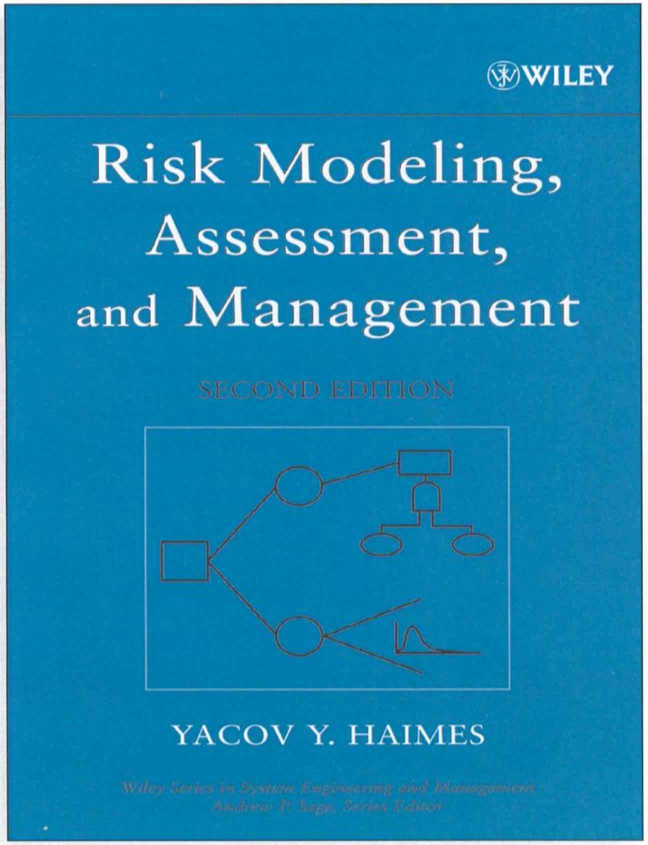


Epilogue

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.

Wiley Series in Systems Engineering and Management, Andrew P. Sage, Series Editor



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.

ISBN 0-471-48048-7 • 2004 • 864 pp. • $126.50

Haimes, Y. Y., *Risk Modeling, Assessment, and Management*, Wiley & Sons, NY. First Edition, 1998.

- Haimes, Y. Y., *Risk Modeling, Assessment, and Management*, Wiley & Sons, NY, Second Edition, 2004.
- Haimes, Yacov Y., and Barry M. Horowitz, “Adaptive Two-Player Hierarchical Holographic Modeling Game for Counterterrorism Intelligence Analysis,” submitted for publication in *Systems Engineering*, 2004.
- Longstaff, T. A., C. Chittister, R. Pethia, and Y. Y. Haimes, “Are We Forgetting the Risks of Information Technology?” *IEEE Computer: Innovative Technology for Computer Professionals*, December 2000, pp. 43-51.
- National Research Council, *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism*. Washington, DC: The National Academies Press, 2002.
- National Research Council, *Preparing for the Revolution: Information Technology and the Future of the research University.* Washington, DC: The National Academies Press, 2002.
- National Science Board, *Science and Engineering Indicators 2002,* www.nsf.gov/sbe/srs/sein.pdf, viewed December 1, 2003.
- U.S. Department of Transportation, *The Changing Face of Transportation,* Washington DC, 2000.

- Y.Y. Haimes, “On the Definition of Vulnerabilities in Measuring Risks to Infrastructures,” *Risk Analysis*, Vol.26, No. 2, pp. 293-206, 2006.
- J.F.R. Fellows, Y. Y. Haimes, B. A. Jackson, J. H. Lambert, and N. C. Matalas, “ Reducing the Vulnerability of Water Supply Systems to Attack,” *Journal of Infrastructure Systems*, Vol. 4, No. 4, pp. 164-177, Dec. 1998.
- Y.Y. Haimes, “Roadmap for Modeling Risks of Terrorism to the Homeland.” *Journal of Infrastructure Systems*, Vol. 8, No. 2, pp. 35-41, 2002.
- Y.Y. Haimes, “Strategic Responses to Risks of Terrorism to Water Resources.” *Journal of Water Resources Planning and Management*, Vol. 128, No. 6, pp. 383-389, 2002.
- Y.Y. Haimes, & B. M. Horowitz, “Risk-Based Methodology for Scenario Tracking, Intelligence Gathering, and Analysis for Countering Terrorism.” *Systems Engineering*, vol. 6, No. 3, pp.152-169.
- Y.Y. Haimes, M.F. Leung, & J.R. Santos, “Risk Modeling, Assessment and Management of Lahar Flow Threat.” *Risk Analysis*, Vol. 23, No. 6, pp. 1323-1335, 2003.
- Y.Y. Haimes, & P. Jiang, “Risk Management for Leontief-Based Interdependent Systems.” *Risk Analysis*, Vol. 24, No. 5, pp.1215-1229, 2004.
- Y.Y. Haimes, & J.R. Santos, “Applying the Partitioned Multiobjective Risk Method (PMRM) to Portfolio Selection.” *Risk Analysis*, Vol. 24, No. 3, pp. 697-713, 2004.
- Y.Y. Haimes, & J.R. Santos, “Modeling the Demand-Reduction Input-Output (I-O) Inoperability Due to Terrorism of Interconnected Infrastructures.” *Risk Analysis*, Vol. 24, No. 6, pp. 1437-1451, 2004.

- Y.Y. Haimes, & B.M. Horowitz, “Modeling Interdependent Infrastructures for Sustainable Counterterrorism.” *Journal of Infrastructure Systems*, Vol. 10, No. 2:33-42, 2005.
- Y.Y. Haimes, & B.M. Horowitz, “Adaptive Two-Player Hierarchical Holographic Modeling Game for Counterterrorism Intelligence Analysis.” *Journal of Homeland Security and Emergency Management*, Vol. 1, No. 3, pp. 1-20, 2004.
- C.G. Chittester, & Y.Y. Haimes, “Risks of Terrorism to Information Technology and to Critical Interdependent Infrastructures.” *Journal of Homeland Security and Emergency Management*, Vol. 1, No. 4, pp. 1-21, 2004.
- Y.Y. Haimes, B.M. Horowitz, J.H. Lambert, J.R. Santos, C. Lian & K.G. Crowther “Inoperability Input-Output Model (IIM) for Interdependent Infrastructure Sectors. I: Theory and Methodology.” *Journal of Infrastructure Systems,* Vol. 11, No. 2:67-79, 2005.
- Y.Y. Haimes, B.M. Horowitz, J.H. Lambert, & J.R. Santos, K.G. Crowther & C. Lian “Inoperability Input-Output Model (IIM) for Interdependent Infrastructure Sectors. II: Case Studies.” *Journal of Infrastructure Systems,* Vol. 11, No. 2:80-92, 2005.
- C.G. Chittister, & Y.Y. Haimes, “A roadmap for quantifying the efficacy of risk management of information security and interdependent SCADA Systems.” *Journal of Homeland Security and Emergency Management,* Vol. 2, No. 2, Article 12, 2005.
- K.G. Crowther, & Y. Y. Haimes, “Application of the Inoperability Input-Output Model (IIM) for Risk Assessment and Management of Interdependent infrastructures.” *Systems Engineering*, Vol. 8, No. 4, 2005.

- Y. Y. Haimes, “Infrastructure Interdependencies and Homeland Security.” *Journal of Infrastructure Systems*, ©ASCE: 65-66, 2005.
- Y.Y. Haimes, & J. R. Santos, “Portfolio Risk Partitioning with Leontief-type Diversification.” *Finance Letters*, Vol. 3, No. 1:117-123, 2005.
- 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*

•P. Jorion, Value at Risk: the new benchmark for managing financial risk, 2nd edition, McGraw-Hill, 2001.

•R. T. Rockafellar and S. Uryasev, Optimization of conditional Value-at-Risk, Journal of Risk, 2(2000).