Risk and Resilience: Past and Future

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Risk and Decision Science Focus
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Global Risks
World Econ. Forum
2014

Emerging Global Risks
Global Risks Before: Plague

Origin and Spread of the Black Death in Asia

Origins and Dates of Breakout:
- 1338-1339
- 1346

Map showing the spread of the Black Death in Asia, including key cities and trade routes.
By 1348, following trade routes, plague had sparked epidemics in most of western Europe. Victims developed inflamed lymph nodes, most died within a few days of onset of symptoms. Significant population decline, “Black Death”.

- In 1347 Italian merchants fled the plague-infected Black Sea ports and unwittingly spread the disease to the Mediterranean Basin.
Risk Assessment Formulation

What can happen (go wrong)?

What are the consequences?

How likely is it?

Kaplan & Garrick 1981
Plague Risk Assessment & Management
(Venice, 1348)

Threat: God
Management: Praying, Flagellants

Threat: Skin
Management: Metals

Threat: Vampire
Management: Brick in Mouth
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Top-Down
Resilience/Decision & Network Analysis
- Goal Identification and Problem Framing
  What are the goals, alternatives, and constraints?
- Decision Model
  What are the criteria and metrics, How do we measure decision-maker values
- Metrics Generation and Alternative Scoring
  How does each alternative score along our identified criteria and metrics?

Bottom-Up
Risk Assessment
- Risk Characterization
  What are the risks relative to a threshold? How do they compare to other alternatives?
- Physical/Statistical Model
  What is the hazard? What is exposure?
- Data Collection
  What are fundamental properties/mechanisms associated with each alternative?

Management
Modeling
Data Collection

Linkov et al., 2014
Outline

- From Physics to Social Science
  - Seeing the Wood Despite the Trees
  - Model Uncertainty and Choices Made by Modelers
  - Using our Brain to Develop Better Policy
- From Risk to Resilience
  - Risk
    - Conceptualization
    - Risk Assessment Case Studies
    - Problems with Risk-based Approaches
  - Resilience
    - Conceptualization
    - Resilience Matrix Approach and Jamaica Bay Case
    - Network Science Approach
- Discussion
Serendipity and Looking for an Edge

"Scientific Convergence: Dealing with the Elephant in the Room"
Linkov et al., Environmental Science and Technology (in press)
Radioactive Contamination of Natural Ecosystems: Seeing the Wood Despite the Trees

Shoji Hashimoto,* † Igor Linkov,‡ George Shaw,§ and Shinji Kaneko †

IAEA Model Intercomparisons (1997-2002)

FORESTPATH (1993-1995)
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Perspectives on Modeling

Linkov and Keisler (2014)

Reliance on empirical data

- Rarely used methods
- Used in most environmental areas

Decision maker - Value
Bayesian Expert - subjective
Statistical – data
Mechanistic - model

Judgment

MCDA – 2% of ALL Environmental Paper
Decision Analysis

Decision Analytical Frameworks
- Agency-relevant/Stakeholder-selected
- Currently available software
- Variety of structuring techniques
- Iteration/reflection encouraged
- Identify areas for discussion/compromise

Decision-Maker(s)

Tool Integration
- Risk Analysis
- Modeling / Monitoring
- Cost
- Stakeholders’ Opinion

Decision Integration

Sharing Data, Concepts and Opinions

Innovative solutions for a safer, better world
Mental Modeling

Perspective

Using Our Brains to Develop Better Policy

Igor Linkov,1,• Susan Cormier,2 Joshua Gold,3 F. Kyle Satterstrom,4

Flood Risk Management: US Army Corps of Engineers and Layperson Perceptions

Matthew Wood,1 Daniel Kovacs,2 Ann Bostrom,3 Todd Bridges,1 and Igor Linkov1,•

Climate change risk management: a Mental Modeling application

Todd S. Bridges · Daniel Kovacs · Matthew D. Wood · Kelsie Baker · Gordon Butte · Sarah Thorne · Igor Linkov
Scientific Convergence: Dealing with the Elephant in the Room
Risk Management Challenges

- Risk = Threat $\times$ Vulnerability $\times$ Consequence

- Requires specific knowledge and quantification of all three components
- No temporal component
- Modern system complexity and threat uncertainty make risk management difficult and expensive.
400,000 in Toledo, Ohio, water scare await test results

By Susanna Capelouto and Mark Morgenstein, CNN
updated 9:15 PM EDT, Sun August 3, 2014

ACE can manage HABs by altering water flow

Natural Stressors

Water resource management is an important factor for HABs

Organic matter/Metals/Nutrient inputs

Irradiance

Physical Stressors

Flushing

Bloom formation

Bloom stages

pH

Resting stage

Turbulence

Growing stage

Salinity

Linkov et al., 2007

ACE can generate turbulence and mixing by altering water intake regimes and decreasing HABs.
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Added alerts

http://www.springer.com/cda/content/image/cda_displayimage.jpg?

Journal of Zhejiang University SCIENCE A

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Collier, Linkov 2014
Ebola Hearing Details Real Risks Of Deadly Disease Hitting U.S.

Patient tested in California for possible Ebola exposure

By Laura Ly, CNN
updated 6:53 AM EDT, Wed August 20, 2014
Risk Assessment is one part of Resilience

After Linkov et al, Nature Climate Change 2014
Resilience Quantification – Background

Cutter et al., 2010
Learning from Military

A highly networked system is governed by *domains of warfare* that organize system components and establish a basis for measurement.

**Physical:** system performance in space and time.

**Information:** creation, manipulation and sharing information.

**Cognitive:** translating, sharing, and acting upon information to enable system management.

**Social:** interaction, collaboration and self-synchronization between individuals and entities.
Resilience: Matrix Approach

Resilience Matrix:
Analyze the functionality of each **domain** of the system across each **stage** of the event timeline

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<th>Prepare</th>
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<th>Recover</th>
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- Uses general metrics for measuring relative system resilience
- Different from vulnerability assessment – threats unknown
- Useful for identifying weak areas and prioritizing investment to improve overall resilience
# General Form of Resilience Matrix

<table>
<thead>
<tr>
<th>Time</th>
<th>Previous Cycle</th>
<th>Plan/Prepare</th>
<th>Absorb</th>
<th>Recover</th>
<th>Adapt</th>
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<tbody>
<tr>
<td>Adverse Event</td>
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## Physical
- State and capability of equipment and personnel, network structure
- Event recognition and system performance to maintain function
- System changes to recover previous functionality
- Changes to improve system resilience

## Information
- Data preparation, presentation, analysis, and storage
- Real-time assessment of functionality, anticipation of cascading losses and event closure
- Data use to track recovery progress and anticipate recovery scenarios
- Creation and improvement of data storage and use protocols

## Cognitive
- System design and operation decisions, with anticipation of adverse events
- Contingency protocols and proactive event management
- Recovery decision-making and communication
- Design of new system configurations, objectives, and decision criteria

## Social
- Social network, social capital, institutional and cultural norms, and training
- Resourceful and accessible personnel and social institutions for event response
- Teamwork and knowledge sharing to enhance system recovery
- Addition of or changes to institutions, policies, training programs, and culture

From Linkov et al, Env. Sci. & Tech 2013
Use developed resilience metrics to comparatively assess the costs and benefits of different courses of action.
Resilience Matrix: Jamaica Bay Case Study

Superstorm Sandy Flood Depths
- < 3 ft
- 3-6 ft
- 6-12 ft
- >12 ft
- Wave Action & Water Movement

Legend:
- More than $82,000
- $68,001 to $82,000
- $53,001 to $68,000
- $39,001 to $53,000 (US median: $50,157)
- $24,001 to $39,000
- $24,000 or less
- No households
Project Evaluation

- Baseline assessment can be used to evaluate proposed projects

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<td>45</td>
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<tr>
<td>Cognitive</td>
<td>90</td>
<td>49</td>
<td>38</td>
<td>27</td>
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<td>Social</td>
<td>82</td>
<td>54</td>
<td>12</td>
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<tr>
<td>Social</td>
<td>85</td>
<td>54</td>
<td>24</td>
<td>73</td>
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*Projects may have (+) or (-) in other matrices*
Network Science

We quantify resilience by using network science approach by considering the different domains as interdependent multiplex networks.

Resilience and Network Science

A simple illustration of the model, in which a city depends on Power, Mobile Communication and Water services, the latter of which are in turn dependent on Electrical power.

Here:
- **Power Plant**: supplier
- **City**: demander
- **Cell, Water**: both suppliers and demanders
Approach to Quantifying Resilience
Preliminary Results

Instant switching

Next step switching

No additional links: $P_{\text{multiple}} = 0$

Additional links enabled: $P_{\text{multiple}} = 0.1$
Resilience and Epidemic Spread

The resilience is defined as a competition process between commuters and disease spreading in a metapopulation system.

Three Behavioral Disease models

1. Local Information
2. Global Information
3. Local, belief-based spread of the fear of the disease
Preliminary Results

MODEL 1

MODEL 2

MODEL 3
Resilience in Venice?
What Happened in Venice?

Linkov et al., 2014
References

Call for Papers: Springer’s Environment, Systems and Decisions

ESD provides a catalyst for research and innovation in cross-disciplinary and trans-disciplinary methods of decision analysis, systems analysis, risk assessment, risk management, risk communication, policy analysis, environmental analysis, economic analysis, engineering, and the social sciences.
The Society for Risk Analysis invites you to join us to the
World Congress on Risk 2015 in Singapore –
Risk Analysis for Sustainable Innovation.

In 2003, the International Society for Risk Analysis (SRA) launched a series of World Congresses on Risk, in partnership with other scientific societies, professional organizations, governments, corporations, and foundations. SRA hosted the first World Congress on Risk in Brussels, Belgium, in 2003, and has held two subsequent World Congresses since that time.

SRA will hold the fourth in the series of World Congresses on Risk from the 19th to 23rd of July 2015 in Singapore. The theme of the World Congress on Risk 2015 is: “Risk Analysis for Sustainable Innovation.” By selecting this theme, SRA hopes to focus attention on risks of importance to global development with specific attention to the experiences of developing countries, in such domains as:
Executive Order: "resilience" means the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.
Jamaica Bay Demonstration

Goal
- Quantitative, comprehensive assessment of community resilience to inform project prioritization efforts.

Motivation
- Provide context to traditional risk-based engineering

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<thead>
<tr>
<th>Report</th>
<th>Pages</th>
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<tr>
<td>NY Rising, Jamaica Bay Communities</td>
<td>743 pgs</td>
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<td>NYC Special Initiative for Rebuilding and Resilience</td>
<td>34 pgs</td>
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<tr>
<td>Building Resiliency Task Force</td>
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<td>Structure of Coastal Resilience, Jamaica Bay</td>
<td>52 pgs</td>
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<tr>
<td>2100 Commission</td>
<td>206 pgs</td>
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Outline

1. Define System and Threats
2. Identify Critical Functions of the System
3. Performance Indicators
4. Performance Scores
5. Prioritize Efforts
6. Critical Function Weights
7. Project Evaluation
1. System and Threats

System

Jamaica Bay Wildlife Refuge and Surrounding Communities

Threats

Coastal storms (hurricanes, tropical storms, nor’easters)

Corps Missions:
coastal protection, ecological restoration
2. Identify Critical Functions

- **Identify critical functions of the communities:**
  - Transportation
  - Sanitation
  - Access to Food and Water
  - Housing/Shelter
  - Support Commerce
  - Recreation/Community
  - Electrical Power
  - Health Services

- **Identify critical functions of the bay:**
  - Wildlife Habitat
  - Recreation/Education
3. Performance Indicators

- Experts identify indicators of performance for each cell of the matrix for each critical function.
- Based on resilience properties:
  - Redundancy
  - Flexibility
  - Modularity
  - Robustness
  - Resourcefulness
  - Distributed
  - etc.

### Housing

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### Transportation

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### Wildlife Habitat

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4. Performance Scores

- Identify specific metrics (qualitative or quantitative) or proxies for the capability of the system to perform in each cell of the matrix.

- Examples:

<table>
<thead>
<tr>
<th>Raw Value</th>
<th>Normalized Score</th>
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<tr>
<td>Participation in Notify NYC Alert System:</td>
<td>48%</td>
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<tr>
<td>Existing dunes/berms:</td>
<td>8’</td>
</tr>
<tr>
<td>Access to debris removal equipment:</td>
<td>med-low</td>
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5. Prioritize Efforts

- Use matrix form to identify weaknesses in resilience.
- Ex:

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<td>90%</td>
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<td>10%</td>
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<tr>
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<td>80%</td>
<td>19%</td>
<td>23%</td>
<td>75%</td>
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<tr>
<td>Cognitive</td>
<td>68%</td>
<td>95%</td>
<td>22%</td>
<td>40%</td>
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<tr>
<td>Social</td>
<td>76%</td>
<td>88%</td>
<td>92%</td>
<td>34%</td>
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(Hypothetical Values)
6. Critical Function Weights

- The matrix approach is broadly applicable but can be tailored to specific management goals.

Ex: USACE is budgeted/mandated to protect people and property and support ecosystem health. Therefore, apply weights to critical functions:

- Housing 30%
- Transportation 20%
- Wildlife Habitat 20%
- Recreation 10%
- Electrical Power 10%
- Health Services 10% ...
7. Project Evaluation

Baseline Resilience Score used to...

- Compare mutually exclusive projects
- Develop portfolio of projects
- Identify system gaps not addressed by any projects

... but full matrix provides best information to guide resilience management.
Risk (or Consequence) Quantification

Benchmarks – Reflection of “Acceptable” Risk

\[
HQ = \frac{\text{Media Concentration}}{\text{Benchmark}}
\]

Hazard Quotient (Threat-Specific)

\[
HI = \sum_{i} HQ_i
\]

Hazard Index (Cumulative)

No benchmarks for Emerging Threats!
Traditional Risk Assessment

• Example: Drinking contaminated water
• RA Goal: Will exposure to a contaminant cause adverse health effects?
• Quantification of Hazard and Exposure (or Threat and Vulnerability) based on data (often limited and imprecise) regarding toxic effects of materials on people and animals
• State-of-the-science hazard and exposure assessment is not very far advanced
  – Two general bodies of data
    ◆ Toxicity studies in animals
    ◆ Epidemiologic studies in humans
    ◆ Exposure Scenarios
  – Uncertainties can be tremendously large
Risk Management Challenges

- \( \text{Risk} = \text{Threat} \times \text{Vulnerability} \times \text{Consequence} \)

- Requires specific knowledge and quantification of all three components
- No temporal component
- Modern system complexity and threat uncertainty make risk management difficult and expensive.
Traditional risk management focuses on planning and reducing vulnerabilities. Resilience management puts additional emphasis on speeding recovery and facilitating adaptation.
Innovative solutions for a safer, better world

BUILDING STRONG®

Mental Modeling

Linkov and Keisler (2014)