Infrastructure Interdependency, Consequence Effects and Engineering

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Policy and Decision Analytics Dept.
The Problem Space is Broad

CASoS Engineering
There are different decision and analysis lifecycles

Consequence Effects Management

Intentional
- Terrorist (IED, CBRN)
- Significant decision rollout

Accidental

Natural
- Hurricane
- Earthquake
- Flooding …

Pre-event Planning

Crisis or Action Management

System Restoration/Recovery/Evolution

Event Impacts on
- Missions
- Functions
- Infrastructures
- Assets
- Population
- Economy
- Resources/Environment

Event/Response

Planning

Recovery/Improvements

Interdependencies

Formulate Systemic Understanding
Predicting Unforeseen Consequences
Informing Policy
Decision Made
Improve Methods to Enact Decisions
Decision Implementation Support
Successful Policy

Sandia National Laboratories
There are a range of data, modeling and analysis capabilities needed for this class of problems

<table>
<thead>
<tr>
<th>System Mapping</th>
<th>Quantitative Modeling</th>
<th>Hypothesis Testing</th>
<th>Uncertainty Analysis</th>
<th>Forecasting and Optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualitative Inductive</td>
<td>Quantitative Descriptive</td>
<td>Quantitative Deductive</td>
<td>Quantitative Exploratory</td>
<td>Quantitative Predictive</td>
</tr>
<tr>
<td>Provides situational awareness of relationships, potentially causal relationships, linkages and interdependencies</td>
<td>Formulation and simulation requires specification of rules and governing relationships to represent and track consequences</td>
<td>Problem focused, statement of hypothesis of system behavior. Goal is to improve understanding of system under specified conditions.</td>
<td>Examines behavioral and quantitative sensitivity, allows testing of model robustness and hypotheses, quantification of risks and identification of leverage points</td>
<td>Identification of future system behavior, optimal or robust solutions.</td>
</tr>
</tbody>
</table>

Disaster Planning: understanding and quantifying interdependency effects to improve protection &/or response

Example – Hurricane Impacts on Petrochemical Supplies

For more information see the following websites:
http://www.sandia.gov/CasosEngineering
http://www.sandia.gov/nisac/chemical.html
Disaster Planning: understanding and quantifying infrastructure impacts and adaptation to improve risk management

Example – Earthquake impacts on Transportation Fuels

Petroleum Pipelines concentrated in central portion of US

Scenario Earthquake – Ground Motion

National Fuels Network Model (with crude oil production and import points, refineries and refined product terminals)

For more information see the following website:
http://www.sandia.gov/CasosEngineering
Or contact Tom Corbet (tfcorbe@sandia.gov)

Changes in Fuel Production and Flows
Food Defense: stochastic mapping to prioritize pathways for intervention
**Backward Tracing of Contamination Conditional Probabilities:** the probability contamination exists at a sprout company if detected at a retail location


<table>
<thead>
<tr>
<th></th>
<th>Sprout Co 1</th>
<th>Sprout Co 7</th>
<th>Sprout Co 2</th>
<th>Sprout Co 4</th>
<th>Sprout Co 10</th>
<th>Sprout Co 8</th>
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</thead>
<tbody>
<tr>
<td>Large Grocery Chain 1</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
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<td>0.27</td>
<td>0.18</td>
<td>0.09</td>
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<td>Sprout Co 7 Customers</td>
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<td>0.53</td>
<td>0.20</td>
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<td>0.14</td>
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<td>0.10</td>
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<tr>
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<td>0.00</td>
<td>0.25</td>
<td>0.38</td>
<td>0.50</td>
<td>0.06</td>
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<tr>
<td>Large Grocery Chain 2</td>
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<td>0.38</td>
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<tr>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Distributor 5 Customers</td>
<td>0.00</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
<td>1.00</td>
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<tr>
<td>Grocery Chain 6 Retail</td>
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<td>1.00</td>
<td>0.00</td>
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</tr>
<tr>
<td>Grocery Chain 5 Retail</td>
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<td>0.53</td>
<td>0.20</td>
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<td>Unconditional Probability</td>
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</table>
Policy Design:
Pandemic Influenza Containment Strategy

Example: Designing an Effective Strategy for Containing a Novel, Pandemic Influenza Strain until a Vaccine can be Developed

Constraints
- Antiviral Stockpile
- Compliance with Containment Policy
- Hospital/Treatment Capacities
- Detection, Decision and Action Timelines
- Vaccine Development Timeline

Is There a Way to Effectively Contain Spread through Social Contact Networks?

For Details see:
- Targeted Social Distancing Design for Pandemic Influenza, RJ Glass, LM Glass, WE Beyeler, and HJ Min, Emerging Infectious Diseases, November, 2006.
- Rescinding Community Mitigation Strategies in an Influenza Pandemic, VJ Davey and RJ Glass, Emerging Infectious Diseases, March, 2008.
Policy Design: Robustness to Uncertainty

- The best-performing composite intervention strategies include school closure.
- Child and teen social distancing is the next most important component.
- Quarantine and antiviral treatment appear to be effective in strategies reliant on few interventions.
- Prophylactic interventions (contact tracing-based antiviral prophylaxis) requires more interventions.

For Details See: Integrating Uncertainty Analysis into Complex-System Modeling for Effective Public Policy I: Preliminary Findings. P. Finley et al., 8th International Conference on Complex Systems, June 2011, Quincy, MA (Proceedings available for download)
Sandia’s resilience assessment framework is especially effective at providing comprehensive assessments because of its flexibility and explicit evaluation of resources, recovery costs, and feedback loops between recovery activities and system performance.

For more details see:


NISAC Program Capabilities

- **Interdependencies and System Modeling**
  - The interdependencies and system modeling capability provides the foundation for all NISAC products including asset prioritization, earthquake planning scenario, and other impact analyses.

- **Economic and Human Consequences**
  - NISAC uses a mixture of proprietary commercial software and in-house modeling and simulation capability to provide first-in-class estimates of population and economic impacts.

- **Asset and Facility Operations Modeling**
  - Infrastructure operators interact with infrastructure systems by making decisions based on constraints and opportunities. Modeling these interactions allows prediction of likely infrastructure operator responses to external events and the possible infrastructure impacts caused by those decisions.

- **Fast Integrated Hazards Analysis**
  - NISAC uses a common integrated simulation environment to provide consistent consequence estimates across event analyses and to expand event scenarios to multiple cascading events. This capability significantly improves NISAC’s ability to provide timely and cost-effective analysis of event implications during a real event.

- **Integrating Architecture**
  - Integrating architecture supports systems analyses, fast turnaround analyses for events of national concern, and exercise support. NISAC’s integrating architecture also improves coordination with other stakeholders in infrastructure protection including sector-specific agencies, FEMA, and state agencies.

http://www.sandia.gov/nisac/
Past and current work with problem owners spans a variety of problems:

- Global Financial System Risks (DHS-Federal Reserve)
- Global Energy System Risks (DOE)
- Health Care System Operations (DVA)
- Infrastructure Risks and Mitigation Design (DOE-DHS)
- Food Defense (DHS)
- Public Health (FDA)
The NISAC program funded us to identify risks in the banking and finance infrastructure.

We worked with the Federal Reserve Bank of NY to develop an agent-based network modeling approach to evaluate Fedwire, the large transaction clearing system and with the Bank of Finland to develop a model of interacting global monetary systems.

This work identified key parameters and conditions that increase congestion in payment systems and a monetary policy implementation strategy that minimizes cascading effects in monetary systems.
Understanding Congestion and Cascades in Payment Systems

For Details see:


We are working with the VA Veterans Health Administration, Office of Public Health and Environmental Hazards to analyze threats to the VA that can affect veterans’ care.

We are developing and utilizing large-scale agent based simulation environment to evaluate the potential effects on healthcare operations:

- Results: Ongoing research, 3 conference presentations, 4 papers in progress,
- Significance: Innovative contributions to health care modeling.
Evaluating Threats and Designing Mitigation Strategies for the Veterans Health Administration

- Medical Physics
  - Diseases and treatments
  - Labor, resources
- Organizational Physics
  - Distinction between MSUs
    - Capacities
    - Capabilities
    - Resources
  - Resource allocation policies
    - Initial
    - Dynamic
- Social Physics
  - Mood contagion in social networks
  - Social components of lifestyle associated diseases
  - Dissemination of practice

The Effect of Healthcare Environments on a Pandemic Influenza Outbreak, Victoria J. Davey (Veterans Health Administration Office of Public Health and Environmental Hazards), Daniel C. Cannon and Robert J. Glass (Sandia National Laboratories) (Dec 2010)

Loki-Infect 3: A Portable Networked Agent Model for Designing Community-Level Containment Strategies, Jacob A. Hobbs, Daniel C. Cannon, Leland B. Evans (Sandia National Laboratories), Victoria J. Davey (Department of Veterans Affairs), Robert J. Glass (Sandia National Laboratories) (Dec 2010)

A Complex Adaptive Systems Modeling Framework for Public Health Action Exemplified by the Veterans Affairs Modeling Object Oriented Simulation Environment, Thomas W. Moore, John M. Linebarger, Patrick D. Finley, Roger Mitchell, Walter E. Beyeler (Sandia National Laboratories), Victoria J. Davey (Department of Veterans Affairs), Robert J. Glass (Sandia National Laboratories) (Dec 2010)

Defining & Evaluating Threats and Designing Mitigation Strategies for VA Healthcare, Robert Glass, Thomas Moore, Walter Beyeler, Arlo Ames, Louise Maffitt, Patrick Finley (Sandia National Laboratories); Ronald Norby (Veterans Health Administration 10N/VISN 22); Victoria Davey (Veterans Health Administration Office of Public Health and Environmental Hazards) (May 2010)
Application: Tobacco Control Policy Impacts on Population Health

Opinion Dynamics Modeling: impacts on smoking behavior
Goal/Aspiration: Identify key uncertainties and dynamics in order to design and develop a CASoS engineering approach for reducing climate risks.

Method: risk analysis approach that accounts for the full range of potential outcomes by explicitly including uncertainty, design validation strategy and identify modeling needs. Interacting nation state transaction modeling.
Global Security Focus

- Global socio-economic interdependent CASoS
- System Stability in context Perturbations and Stressors (e.g., climate)
- Design policy that enhances system resilience
Example Results: Entity and Global Health in context of finite energy shocks

Small Shock

Configuration is perfectly symmetrical, but many realizations show spontaneous differentiation in which resources are produced at different rates and health differs across classes.

Removal of some resource A causes a disruption that can have large and long-term consequences even if it is very brief.

Large Shock

Disruptions beyond a certain severity are fatal to the system.
Complex Adaptive System of Systems (CASoS) Engineering
http://www.sandia.gov/CasosEngineering/

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