SAND2013-1784C

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Managing Space Weather Risk : A Wicked Problem

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Ottawa, Canada

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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High Consequence Problems

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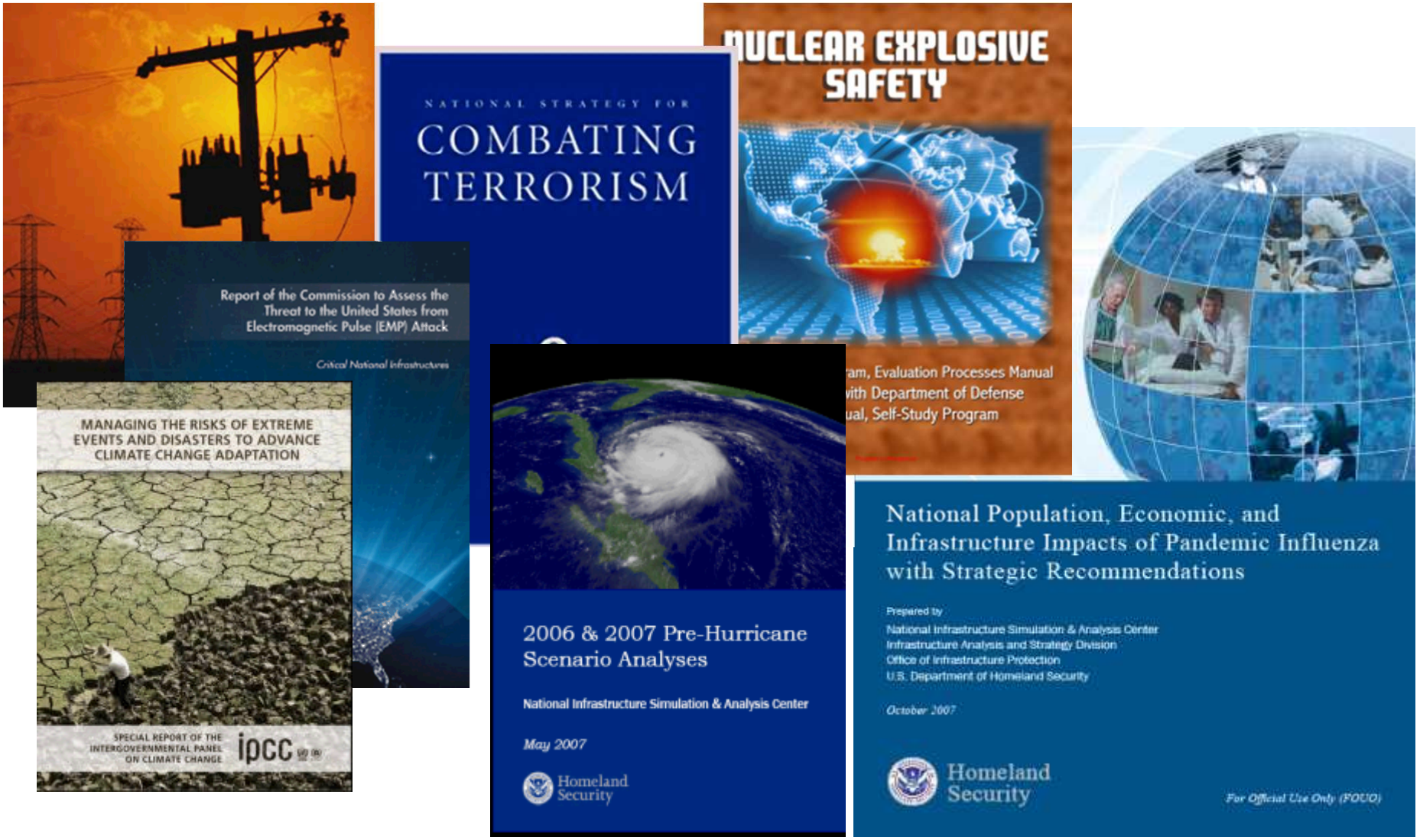
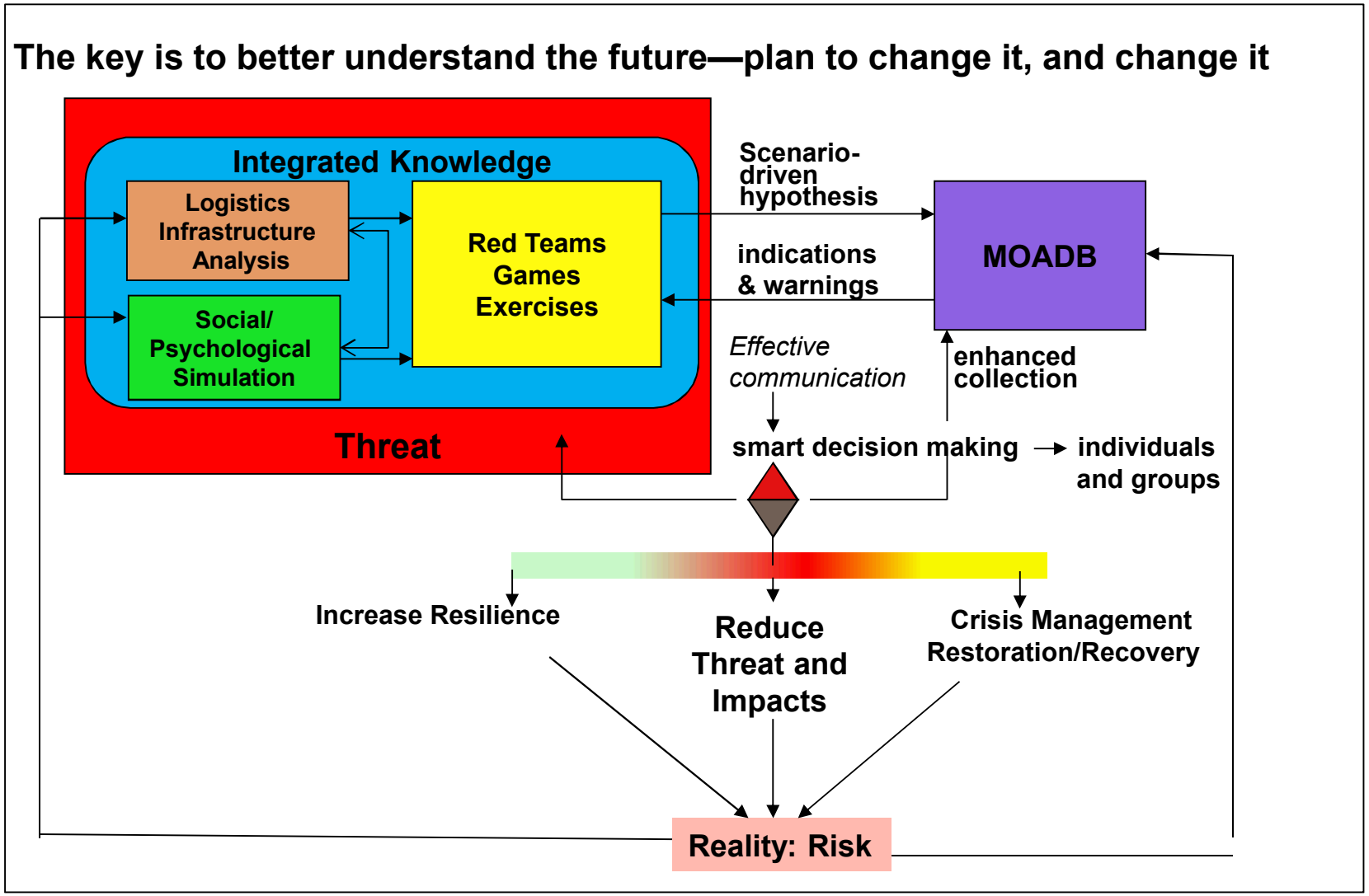
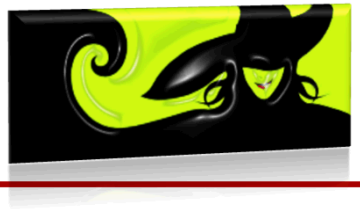


Managing High Consequence, Low Frequency Disruptive Events





Wicked Problems

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1. *There is no definitive formulation of the problem.*
2. *There is no end to the problem.*
3. *Solutions are not true-or-false, but good-or-bad.*
4. *There is no immediate and no ultimate test of a solution to the problem.*
5. *Every solution to the problem is a "one-shot operation" -- there is no opportunity to learn by trial-and-error, every attempt counts significantly.*
6. *There is not an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into a plan.*
7. *Every instantiation of the problem is essentially unique.*
8. *The problem is actually a symptom of another problem.*
9. *The existence of discrepancies when representing the problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.*
10. *The planner has no right to be wrong.*

Complexity

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Principle Characteristics

I. Complex systems are wholes with irreducible properties that emerge from the interaction and interdependence among its parts: EMERGENCE

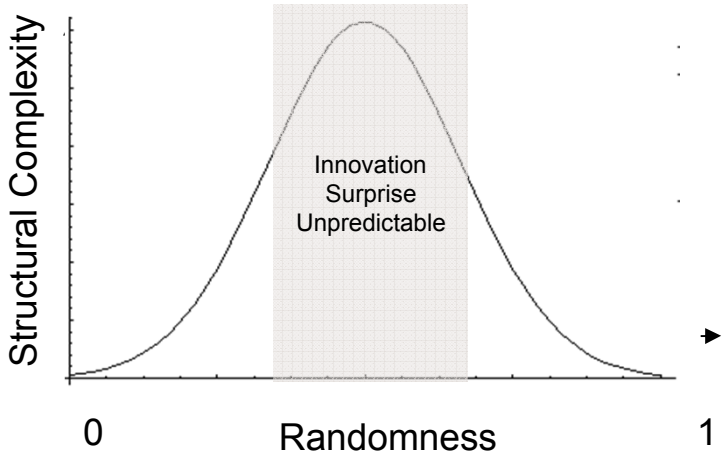
II. Complex systems that are purposeful are capable of maintaining themselves and initiating action to achieve goals in a changing environment: ADAPTIVE

III. Purposeful complex systems create themselves in response to self-creativity in other systems: INNOVATION, TRANSFORMATION

IV. Complex systems are coordinating interfaces in Nature's holarchy: SYSTEM of SYSTEMS

Measuring Complexity

varying degrees of organization – or structure, regularity, symmetry and intricacy – in a systems' behavior or its architecture.



Lessons Learned:
Risk Management of Natural Disasters*

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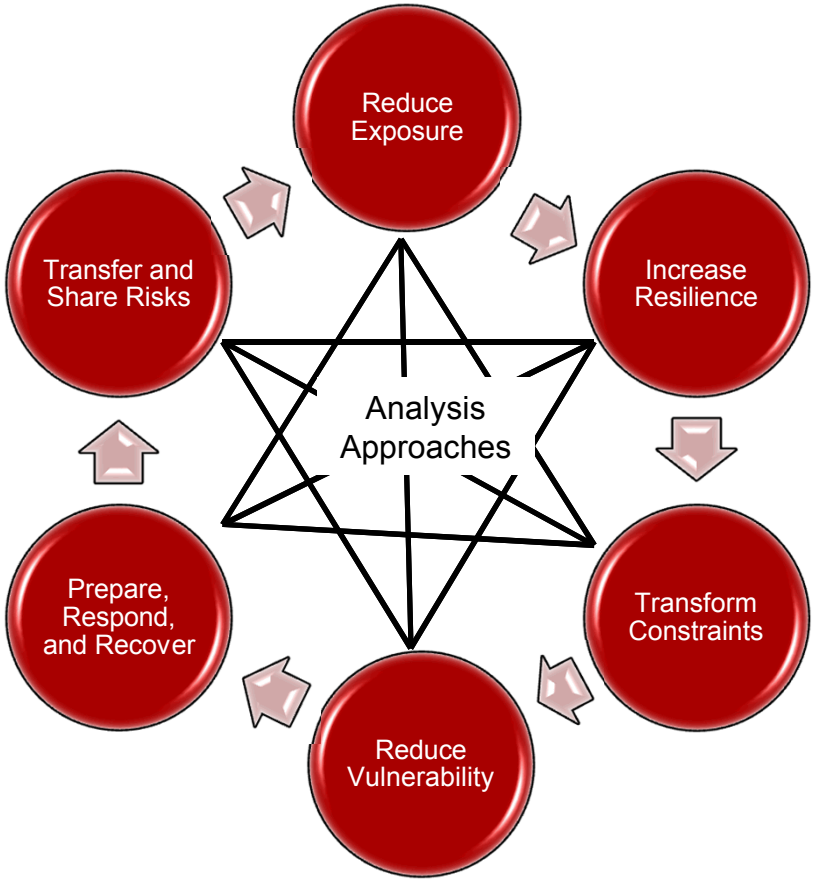
Severity impact ***exposure*** ***vulnerability*** *extremes dynamic temporal spatial scales economic social geographic demographic cultural institutional governance environmental future vulnerability* ***resilience*** *coping adaptive capacity* ***Data*** *lacking* ***local level*** ***Inequalities*** *constraints*



Framework driven primarily by normative perspectives

*"Managing the Risks of Extreme Events and Disasters To Advance Climate Change Adaptation,", United Nations Environmental Program and World Meteorological Organization, 2012

Infrastructure Resilience Framework

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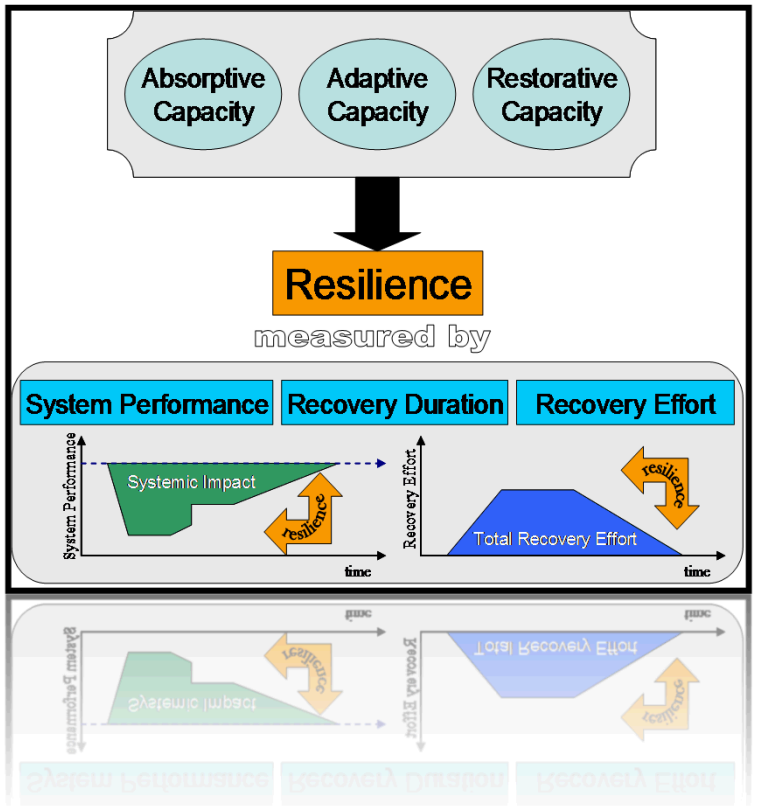

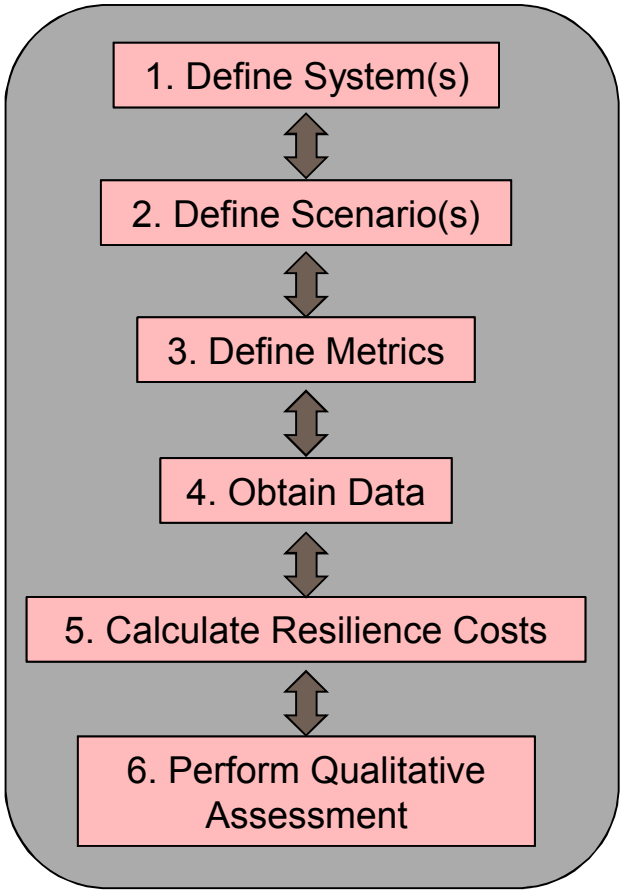

Framework driven primarily by economic perspectives

Flow of National Assets

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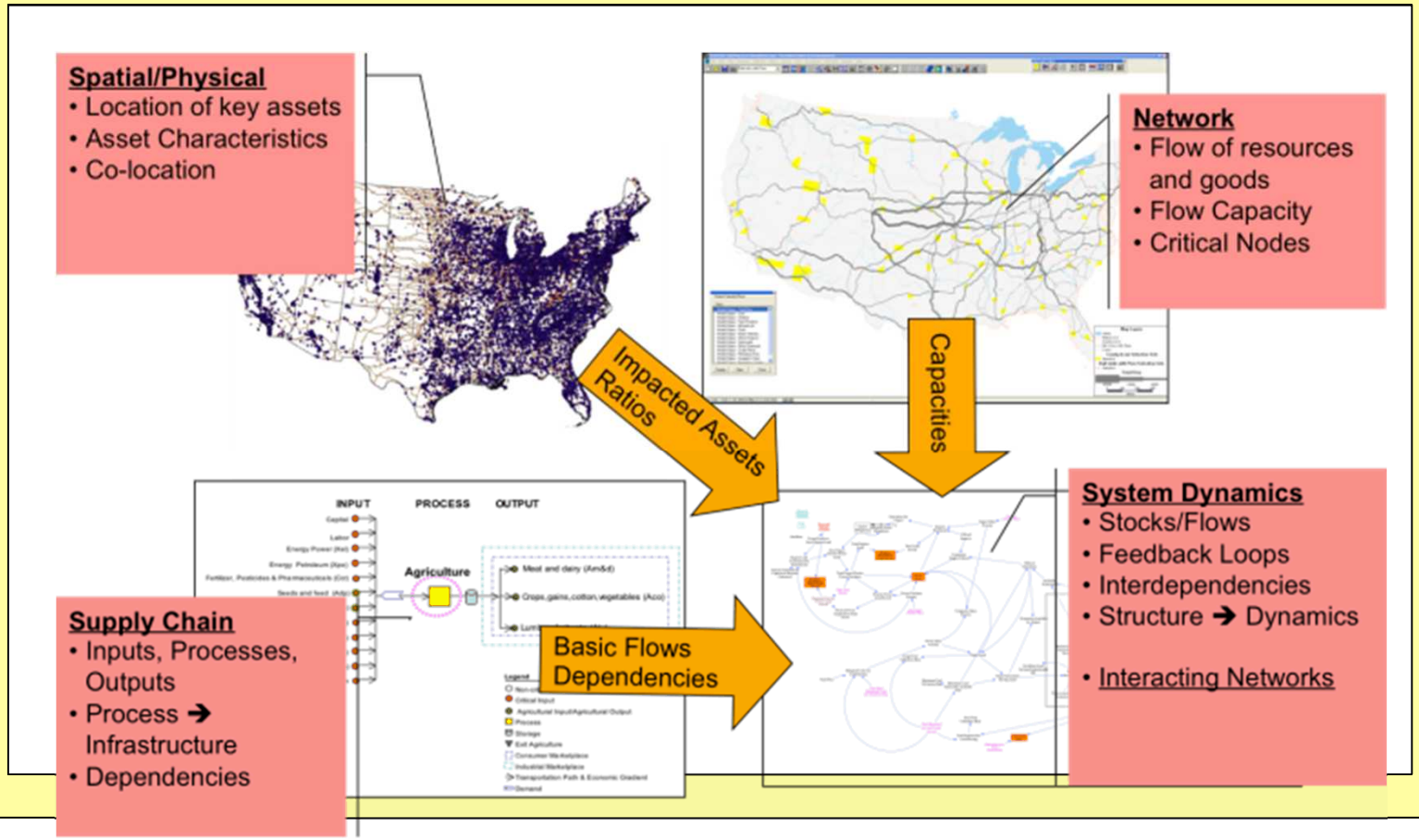
Uncertainty Quantification



Framework driven primarily by regulatory perspectives

What are the metrics? How much data do we have to work with? Who needs the answer, when? What level of confidence is required? What is the cost of getting it wrong?

Slide 8

1 need to beef up this slide and include other methods.
Hayden, Nancy Kay, 2/27/2013

Waterfalls and Fragmentation Preclude Taming of Wicked Problems

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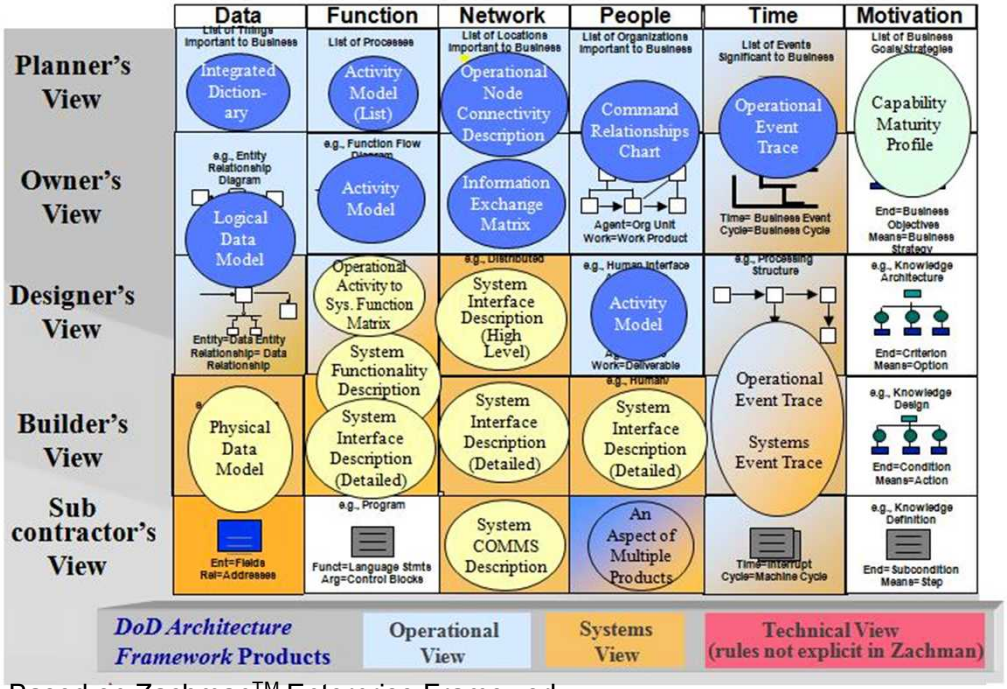
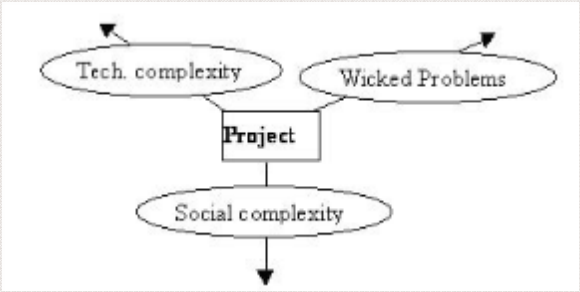
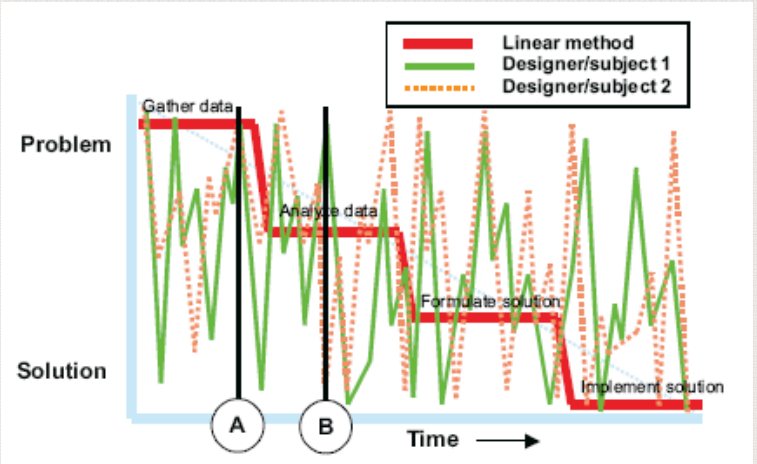
Solutions require collective intelligence (coherence) integrated horizontally and transformed vertically across diverse enterprise perspectives



Based on Zachman™ Enterprise Framework

Sources of Incoherence

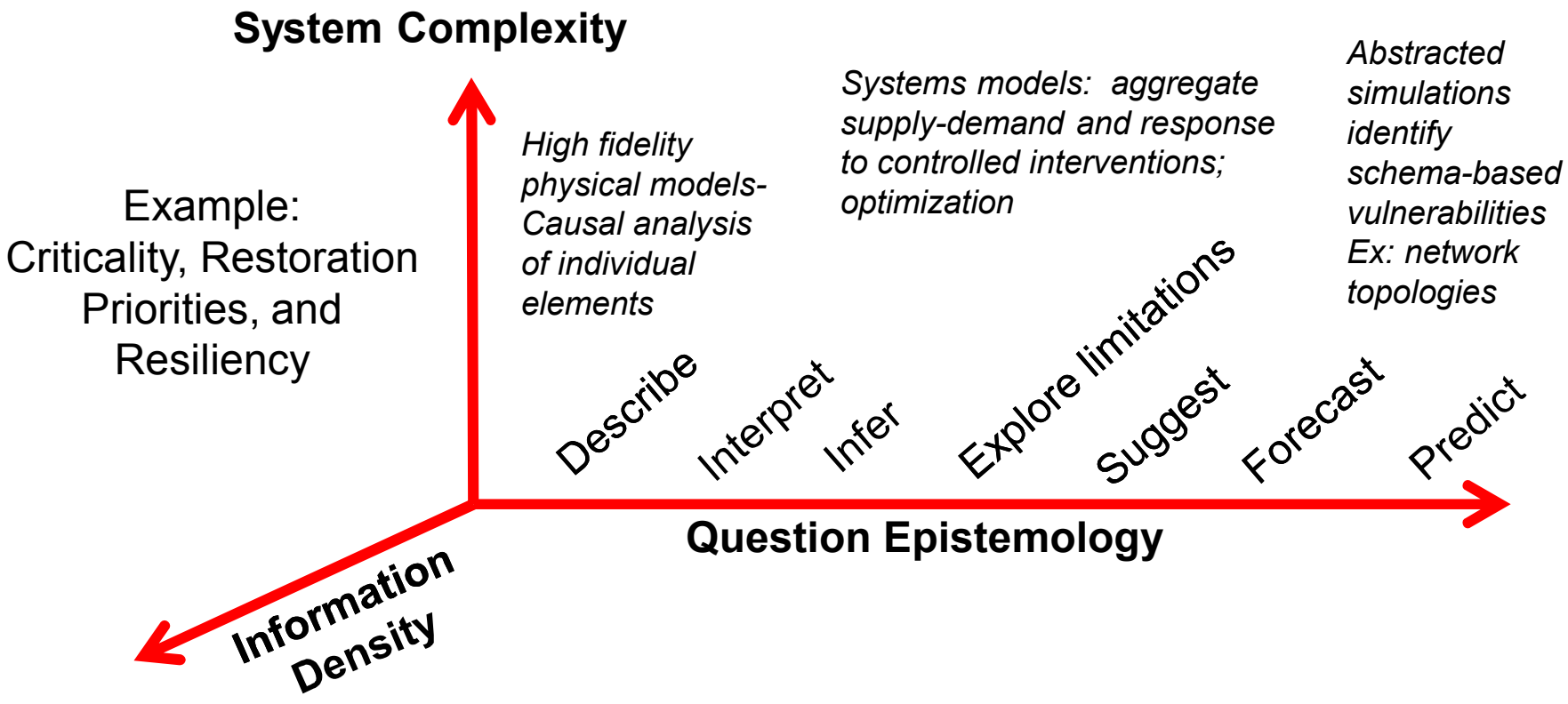




Framework driven primarily by organizational perspectives

Putting It All Together: Frame the Problem

Analysis approach depends on what question is being asked, what fidelity is required, in what timeframe



Risk-Based Policy Analysis at Sandia

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- Physics-Based Studies
  - Identify and reduce vulnerabilities of national security systems to EMP
- Operations Research and Computational Analysis (ORCA) Optimization studies
  - Integrated stockpile optimization under resource constrained enterprise with uncertainty
- NISAC policy studies
  - Improve understanding, preparation, and mitigation of consequences of infrastructure disruption
  - Provide a common, comprehensive view of US infrastructure and response to disruptions
    - Describe vulnerabilities of critical infrastructure
    - Predict policy options to prevent cascades
    - Explore cascading impacts of power outage
    - Predict economics of infrastructure recovery
- International Security Studies
  - Explore impacts of climate change on migration
  - Explore organizational learning and innovation
  - Predict emergence of leaders
- Integrated Cognitive Systems
  - Behavior Influence Assessments

Physics-Based Understanding to Reduce Vulnerability

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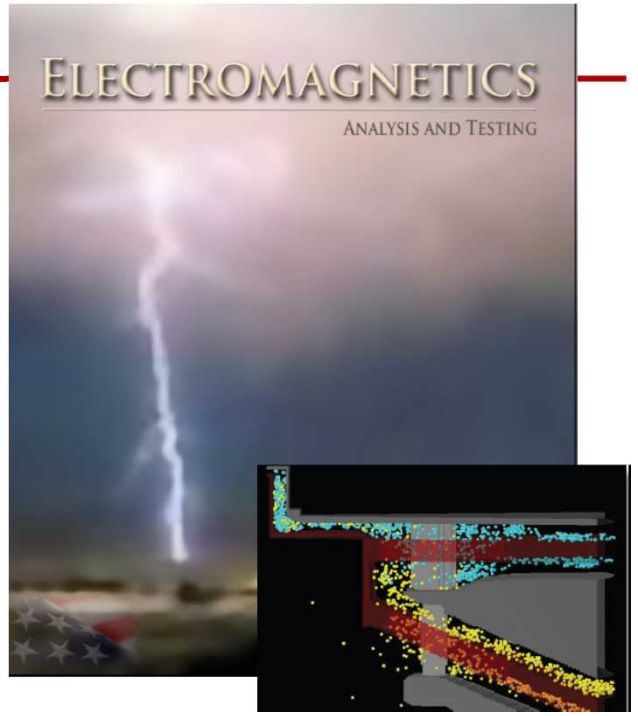
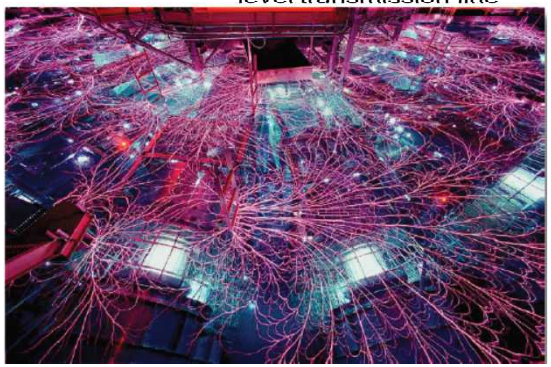
Long History of Research

- **Integrated EM Effects Test and Analysis**
- **Joint Voltage from Lightning Currents**
  - Stockpile surety
- **Protecting the Planet**
  - Asteroid threats
  - System level effects of exo-atmospheric EMP
- **First Principles Simulation of EMP at High Altitude**
  - Radiation hardening of military systems microelectronics
- **Novel designs for improved, GPS-satellite based, radiofrequency monitoring for EMP emissions**
  - Results can be applied to early warning systems



Electron flow in a Terawatt level transmission line



Sandia's Z accelerator for high-energy density physics research

Potential EMP Effects on US Infrastructure

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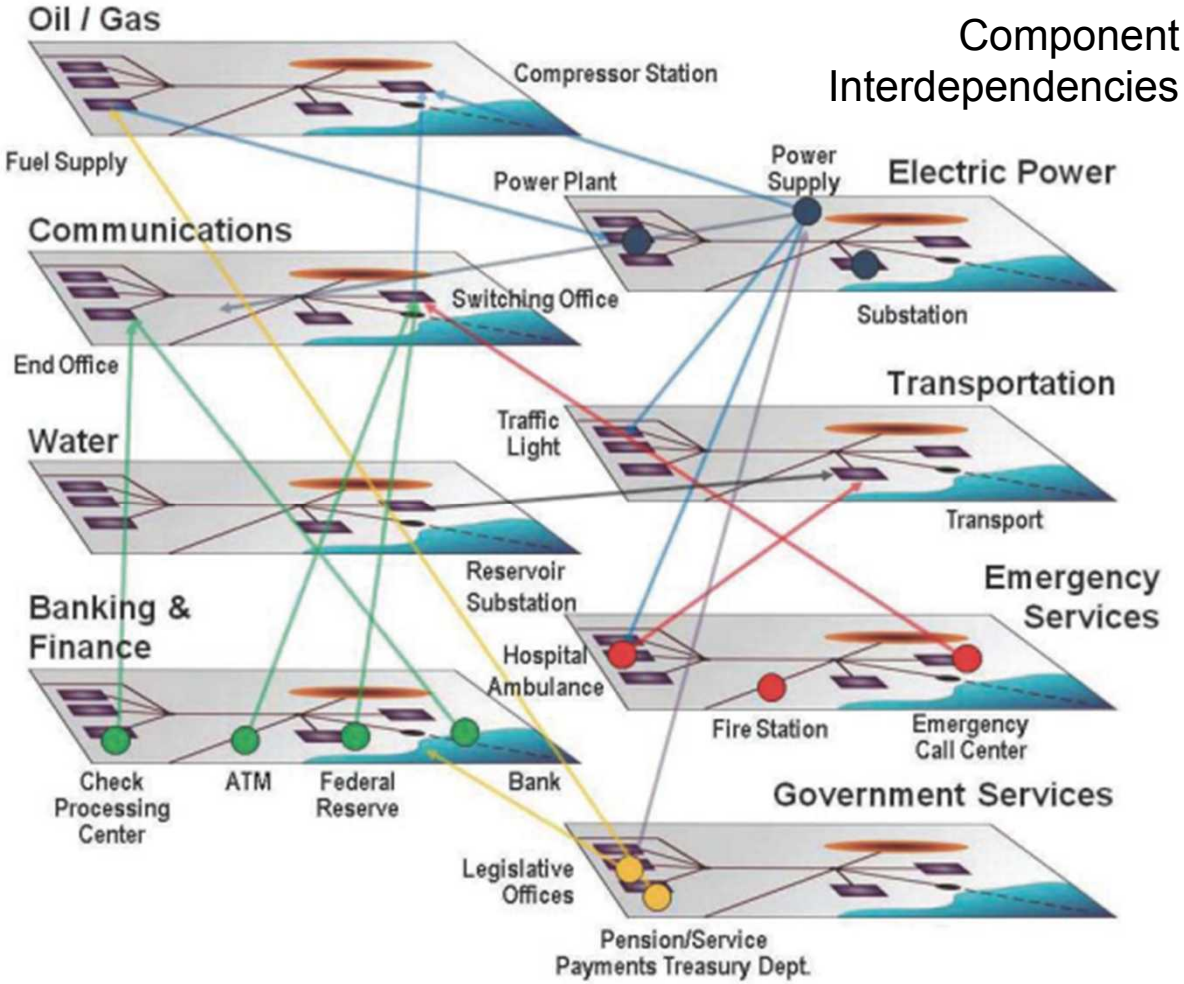
HITRAC/DHS Request 2012
KEY FINDINGS

- Electric power systems are resilient and would likely be able to shift power distribution to backup configurations to accommodate local disruptions.
- Component repairs would likely require 1 day to complete except for the loss of a large power transformer which requires in excess of 6 months to replace.
- A solar storm could affect radio communications, such as satellite communication, commercial airliners, radio, TV, cellular and high-frequency communications signals.

Component Interdependencies



Hypothetical Interdependency Framework, EMP Commission Report 2008

Hurricane Planning and Response

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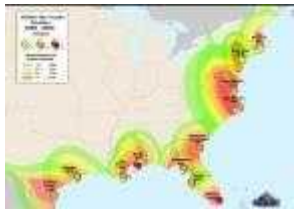
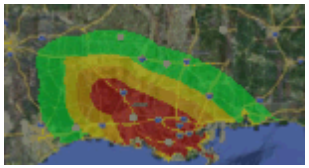
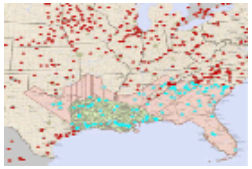
- Planning Scenarios

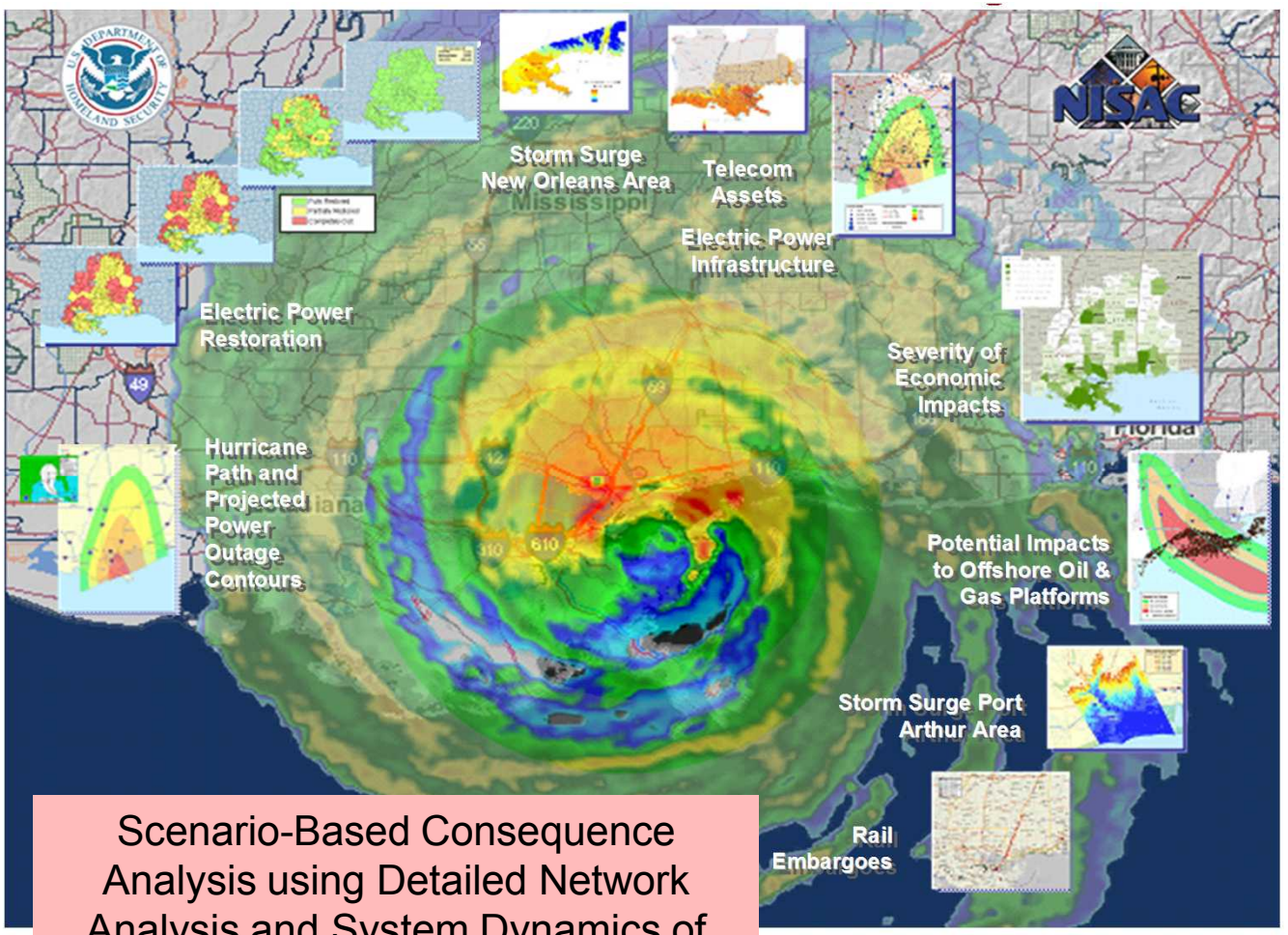


- Pre-Landfall Infrastructure & Population Impacts



- Post-Landfall Response & Recovery Issues





Earthquake planning and Response

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Earthquake Response & Recovery planning

- Multiple scenarios
- Quantify regional and national impacts on population, critical infrastructure, economy

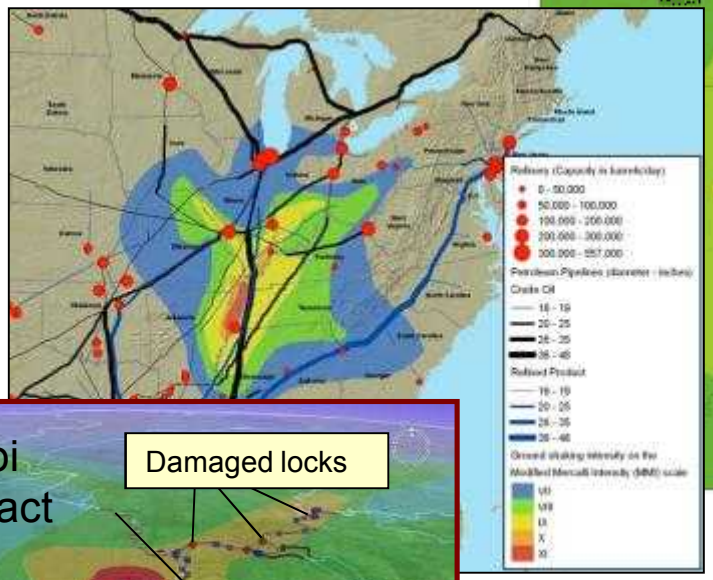
NG & petroleum pipelines break in areas of strongest shaking:

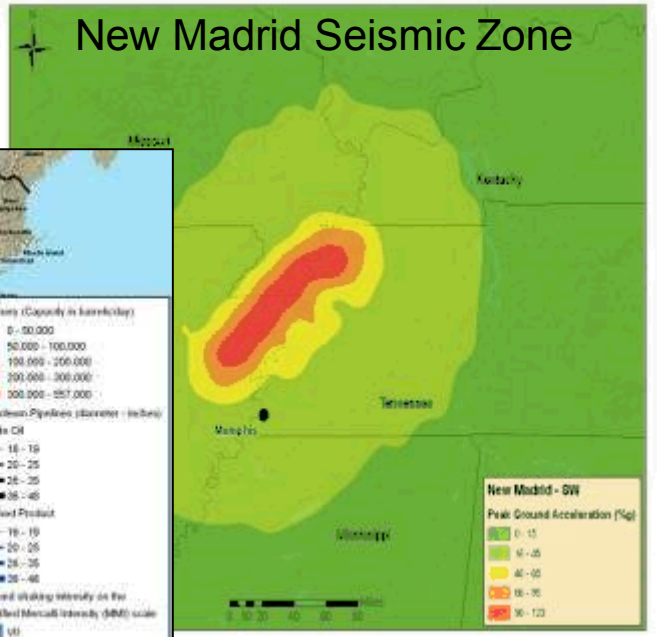
- Midwest loses 25% of supply
- 60% after 3 weeks

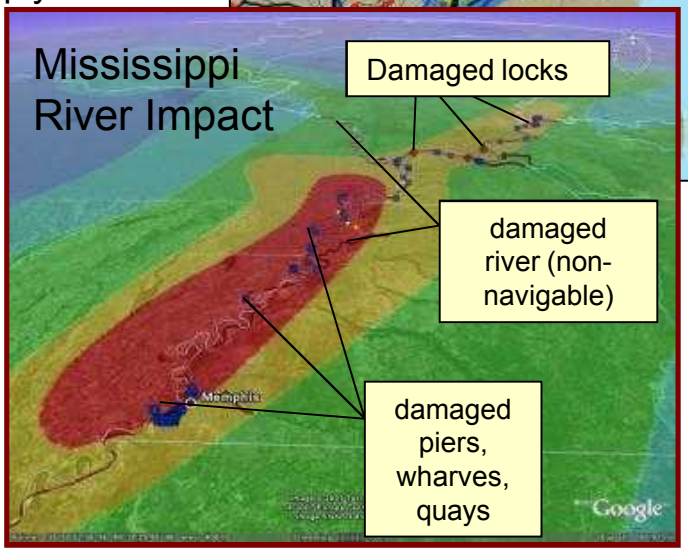
Long-term effects:

- Mississippi River water transportation may be disrupted for months
- Significant disruption to transportation of bulk agricultural products, coals, minerals

Natural Gas & Petroleum Pipelines







Scenario-Based Consequence Analysis using Detailed Network Analysis, System Dynamics with Sensitivity Analysis to prioritize recovery actions a priori and “think outside box” for adaptive capacity

Planning for H5N1 Pandemic Influenza

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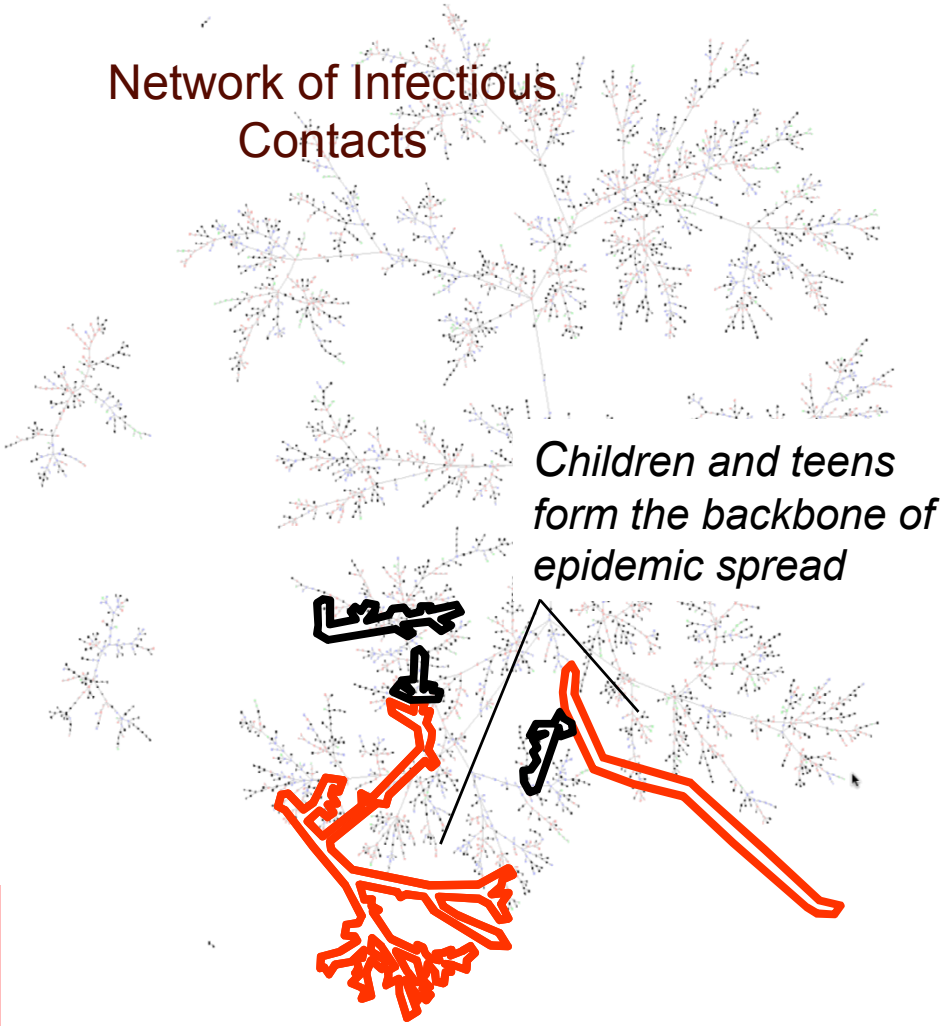
Modeling & Analysis:

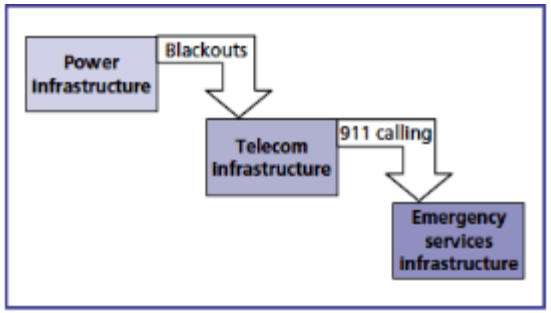
- Community interactions (schools, workplace networks)
- Assessed effectiveness of response strategies
  - social distancing
  - Vaccination
- High-performance computing used to run 10's of millions of scenarios
- Discovered social distancing best minimized disease spread, especially closing schools

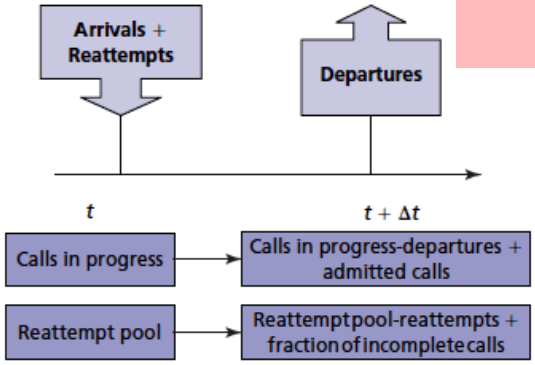
Abstracted Agent Based Modeling, Derived Network Analysis, Stochastic Uncertainty Analysis

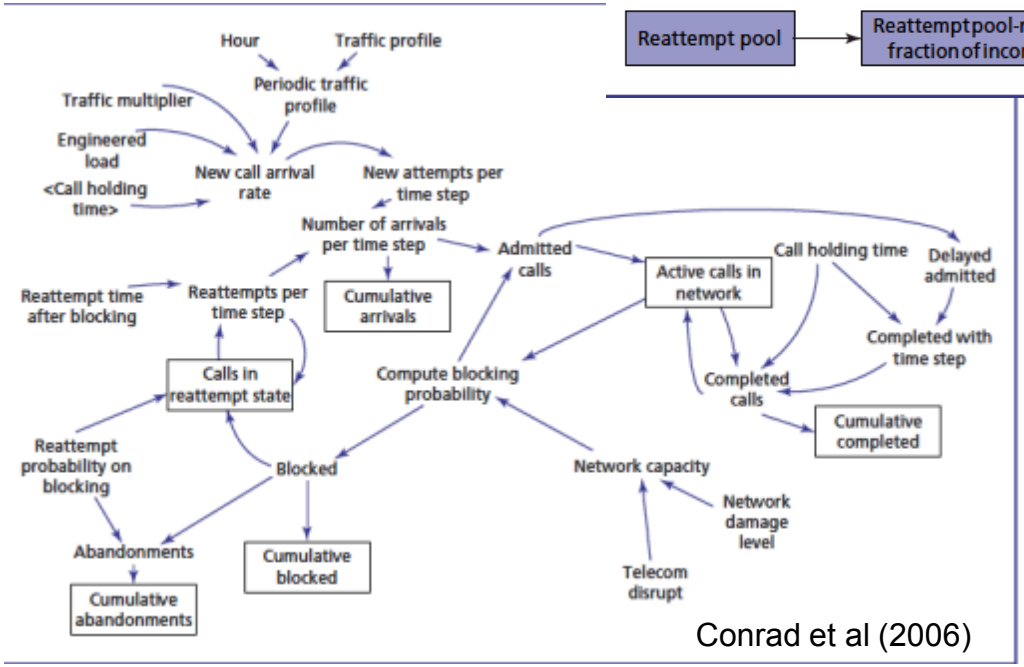


Power Outage: Cascading Impact on Telcom Systems and Emergency Services

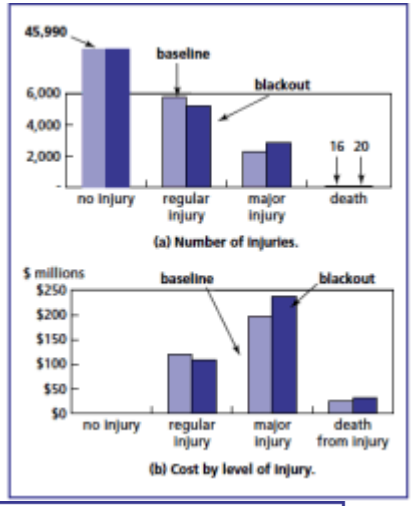
Scenario-Based Consequence Analysis using System Dynamics with Sensitivity Analysis to Plan Adaptive Emergency Response Capabilities

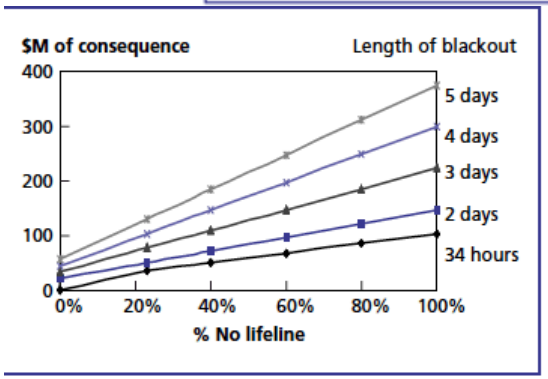






Conrad et al (2006)





Behavioral Influence Assessment (BIA)

Informs High Consequence Decisions

- Better understand and anticipate the interplay between specific political/social organizations and general society (including its infrastructure) in response to potential event or actions

Structure

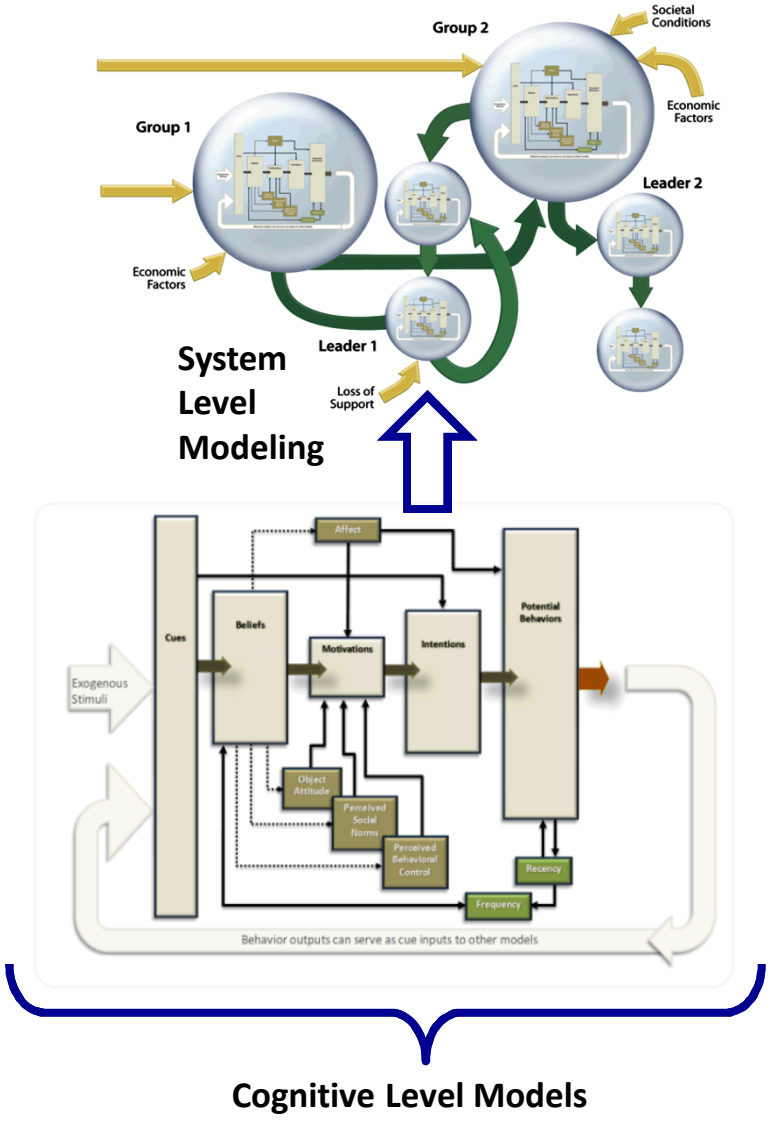
- Synthesizes a set of of decision theories into a cognitive-system dynamic framework that captures the dynamics of individuals interacting within groups and societies over time

Features

- Multi-scale and transparent assessment with quantifiable uncertainty based on data, expert information, and decision theories

Impacts

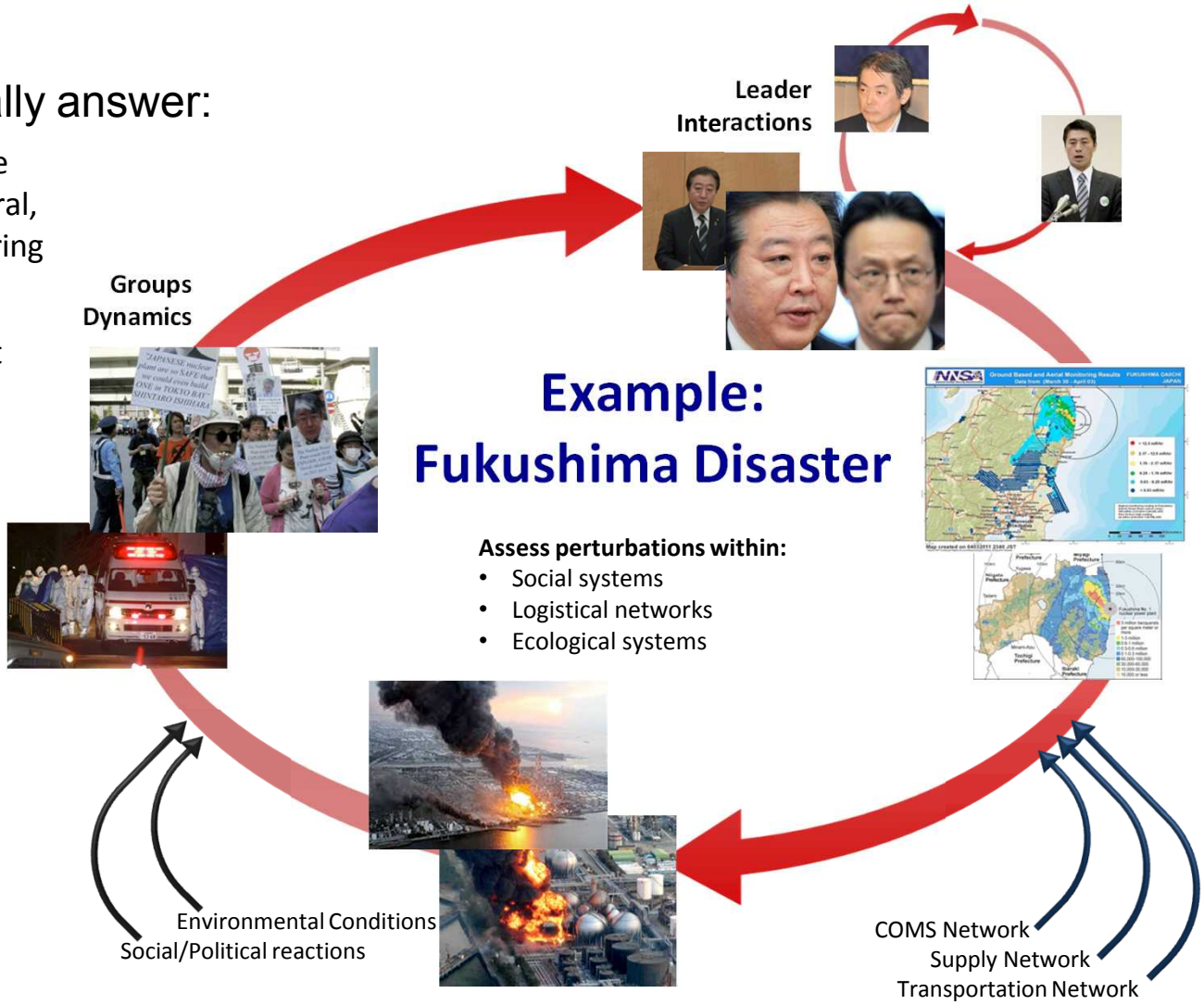
- Enables analysts to assess higher-order (cascading) influences and reactions to events, as well as determine the uncertainty that the event will produce the desired results over time



BIA Tool Can be Integrated With Others

Assessments to potentially answer:

- What are the expected response behaviors within different cultural, social, and economic groups during and after a natural disaster?
- What are the tipping points that drive people to respond in counter-productive ways during natural disasters?
- How could energy security concerns affect behaviors?
- What are the long-term effects of a natural disaster on groups?



Lessons Learned from Policy Analysis

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Wicked Problems Are Hard, But Can Be "Tamed"

- Conduct right analysis for different perspectives, data, timescales
  - Decide on question and risk metrics
  - Simplify to essential components
  - Abstract up to multiple simultaneous scales and resolutions
  - Plan how to communicate results clearly and timely - *not optional*
- Quantify/qualify interactions of political, health, social, economic and technical systems including uncertainties
- Couple socio-systems (power networks, societies, etc.) to physical systems (space weather, other climate phenomena, geology)
- Develop methods to handle data issues up front (large, complex; data poor environments)
- Analysis approaches include calibration, verification, validation
- Capture non-local, non-intuitive and interdependency effects
- Operationalize confidence and trust in decision support
- Always include Sense-Making in the process

Summary:
Taming Wicked Problems Requires a CASoS

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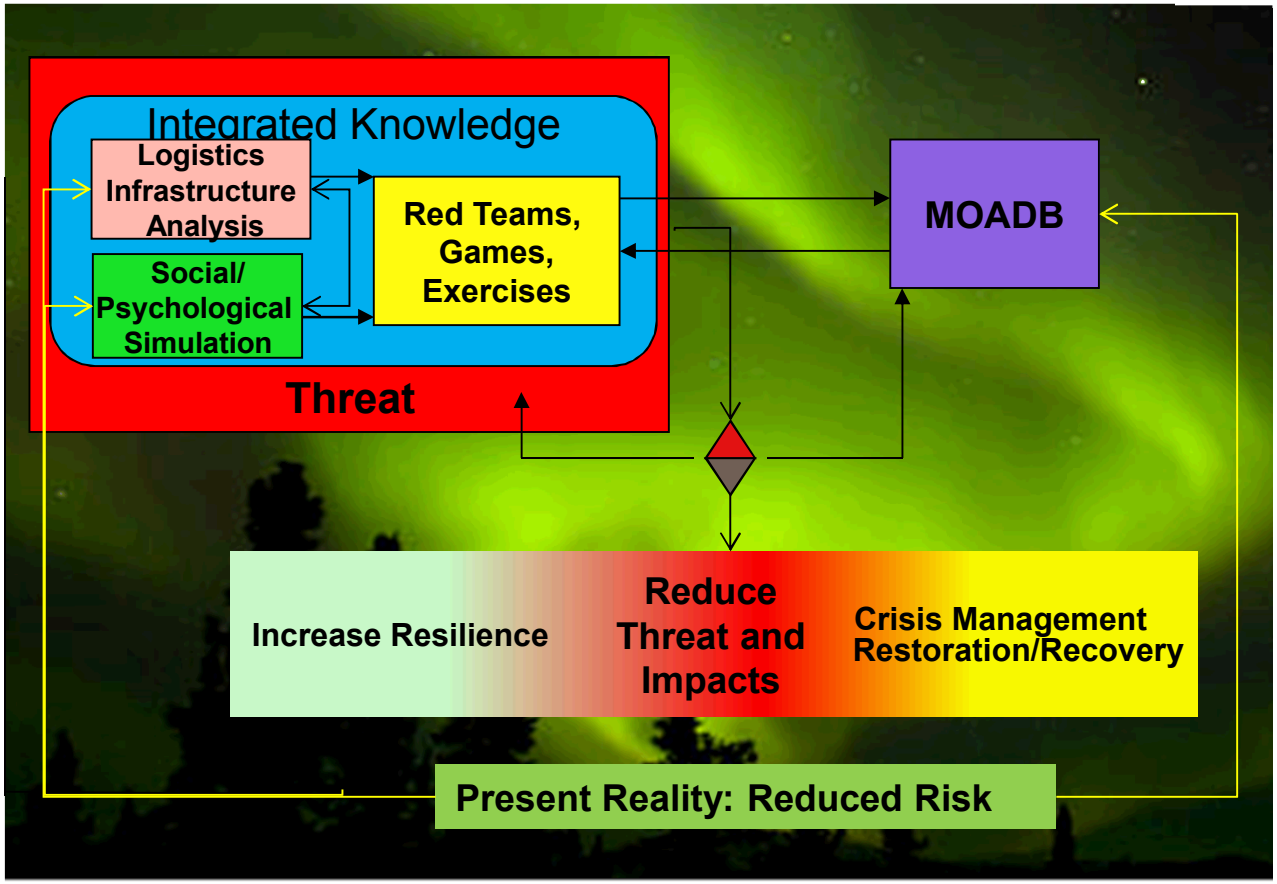
Descriptive/prescriptive experimentation and analysis to reduce vulnerability

Forecasting analysis to reduce likelihood of exposure

Cost/Benefit design analysis to improve system robustness

Exploratory analysis to increase latent and adaptive capacities



Predictive analysis for minimizing cascading effects while enabling system recovery

Optimization analysis to radically improve system performance