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Assessing the Resilience of Infrastructure with Economic Modeling

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Outline

- Introductions
- Economics at Sandia National Laboratory
- Decision and analysis lifecycles
- Background and history of resilience
- Our contribution to resilience
- Economics and resilience
  - The intersection of engineered and human systems

National Infrastructure Simulation & Analysis Center

- **2001 Patriot Act identified NISAC as center for Critical Infrastructure Interdependency Modeling, Simulation, and Analysis**
- **A common, comprehensive view of US infrastructure, its response to disruptions, and impacts**
- **Operationally-tested rapid-response capability**
  - Crisis action analysis 24/7
  - Sandia and Los Alamos National Laboratories, joint execution
- **Types of analyses**
  - Hurricanes
  - Earthquakes
  - Other acute events

NISAC

Los Alamos

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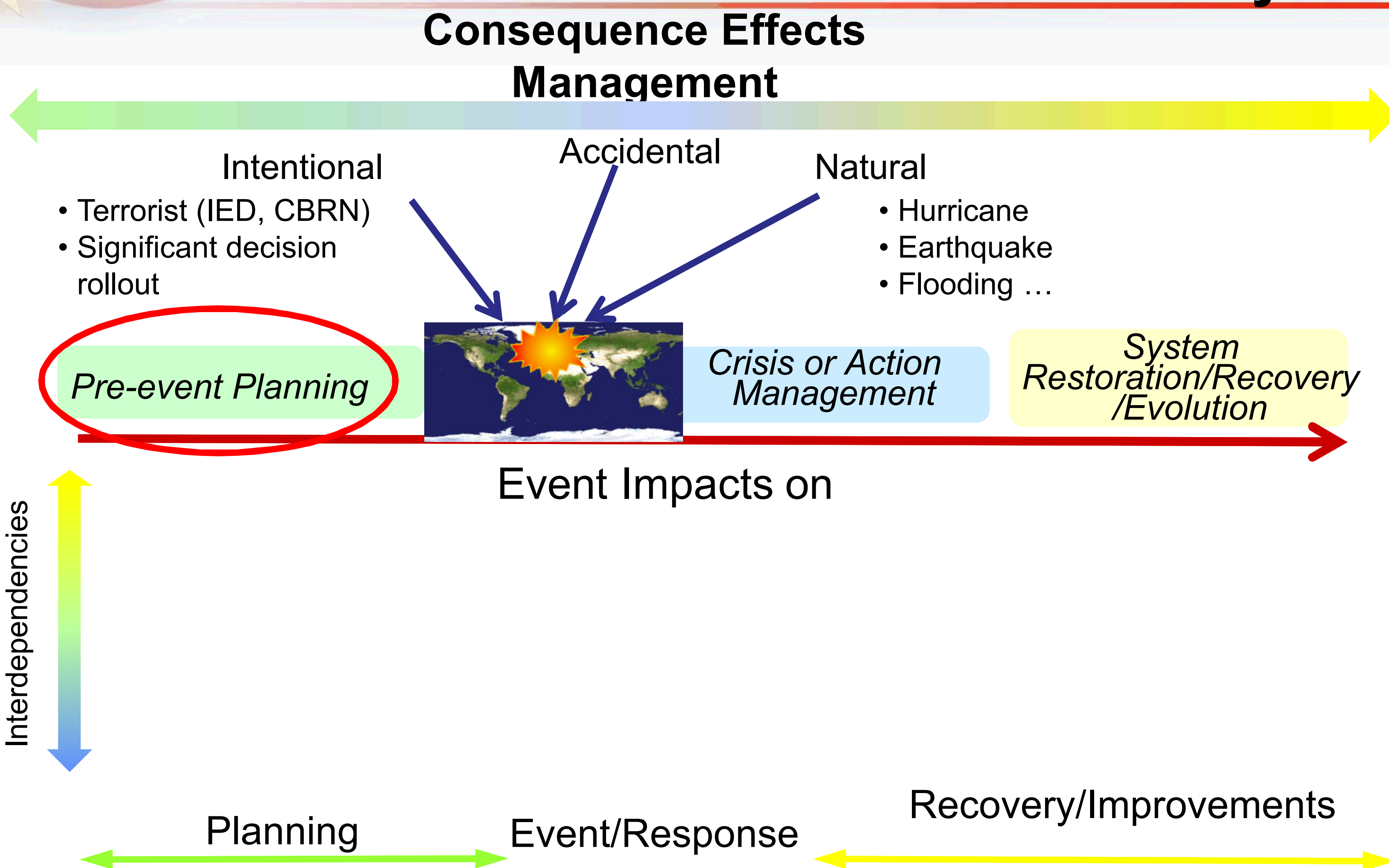
What we do

- Critical infrastructure consequence analysis and prioritization
- Critical infrastructure expertise, modeling and simulation capability, and interagency partnerships developed over the past 7 years
- Includes operational and strategic analysis of incidents and emerging risks
- Supports interagency, intergovernmental, international, and private sector partners with risk and consequence analysis

There are different decision and analysis lifecycles



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Definitions: many options, no consensus

- **Many definitions exist**

- **Common concepts include:**
  - Withstand changes from external force
  - Absorb impact
  - Adaptation
  - Rate of recovery

- **Literature highlights two major definition types**
  - Ecological resilience: measured by magnitude of disturbance required to move system to new "stability domain"
  - Engineering resilience: ability to return to a steady state following a disturbance

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What is resilience?

- **System Resilience** (Vugrin et al., 2010)
  - Ability of a system to efficiently reduce the **magnitude** and **duration** of the deviation from targeted system-performance levels in response to some event
  - Emphasizes combination of the impact of event and time and cost required for system to recover
  - Pertains to both economic and infrastructure systems

- **3 Properties:**
  1. Absorptive Capacity
     - Ability of system to absorb disruptive event
  2. Adaptive Capacity
     - Ability of system to adapt to disruptive event
  3. Restorative Capacity
     - Ability of system to recover
     - Includes most definitions of *economic resilience*

Ex-Post Quantitative Assessment of Critical Infrastructure Resilience

- **Infrastructure Resilience Analysis Methodology (IRAM) (Biringer, Vugrin, and Warren, 2013)**
  - “Hybrid” methodology focusing on performance-metrics and attribute analysis
  - Explicitly considers resource utilization and constraints during post-disruption recovery activities

- **The IRAM method – 7-Step process:**
  1. Define infrastructure
  2. Define disruption scenario or event
  3. Define metrics
  4. Obtain system performance and recovery data
  5. Calculate resilience costs
  6. Perform structural assessment
  7. Identify resilience enhancement features

Ex-Ante Quantitative Assessment of Critical Infrastructure Resilience

- **The IRAM framework can also be applied to ex-ante evaluations of critical infrastructures**
  - Requires quantitative metrics of critical infrastructures

- **3 of the 7-Step process can be conducted ex-ante**

1. Define infrastructure
   - Limited to infrastructures where data are available (e.g., publicly-funded infrastructure)

3. Define metrics
   - Metrics limited by specific data gathered
   - Must be useful for allocating resources and prioritizing response (i.e., must be able to scale across entire affected region to provide meaningful comparisons)

4. Obtain system performance and recovery data

Motivating Questions

- How resilient is the current system?
- What are the costs associated with resilience?
- What system features limit resilience and how can they be improved?
- Which investment strategies enhance the system resilience?
- What are the resource requirements and costs associated with those strategies?
- In an uncertain environment, how can one effectively invest in resilience?

Why pursue operational economic resilience for infrastructure systems?

- **Contributing factors to variations in economic impact:**
  - Magnitude and duration of disruption
  - Geographic characteristics
  - Size and specialization of regional economy
  - Publicly-funded (or regulated) infrastructure (e.g., roads, telecom., etc)
- **Resilient system metrics useful in understanding economic resiliency of a geography or community**
- **Proposed metrics should be operationally available to policymakers tasked with allocating resources and prioritizing disaster response**
- **Qualitative assessments not ideal**
  - Often rely on individual stakeholder input
  - Although stakeholders may be incentivized to improve their own resilience, may not be an incentive to signal resilience to decision-makers

Signaling resilience to decision-makers allocating resources and prioritizing disaster response is not currently incentivized.

Example Study: Resilience Certification

- **Objective: support development of first-ever resilience certification program for buildings**

- **Activities:**
  - Conceptual certification process
  - Cost/benefit method
  - Stakeholder survey

- **Results:**
  - Program participation linked closely to ROI demonstration
  - Green buildings are potential analogue for benefit evaluation
  - Insurance sector grasped concept most quickly

Pilot launched in 2013. For more info, see http://www.dhs.gov/blog/2014/09/23/dhs-issues-first-ever-resilience-startm-designations-homeowners

Quantitative Assessment of Infrastructure Resilience

- **Estimating resilience based on supply data alone may not be adequate:**
  - May produce simultaneity bias (i.e., more cars results in more roads and vice-versa)
- **Hypothesis: Resilience of publicly-funded infrastructure likely correlated with both quality and supply**
- **Analysis:**
  - **If** the resilience of an infrastructure can also be defined of as the invariance of infrastructure performance
  - **And** variance of infrastructure performance is highly-correlated with the variance of (publicly-funded) infrastructure revenues
  - **Then** variance of revenues which support infrastructure may act as a reasonable proxy for infrastructure resilience

Potential solution: proxy for quality, standardized data on quality is difficult to obtain and often does not scale sufficiently.

Quantitative Assessment of Infrastructure Resilience

- **Objective: novel approaches to evaluating infrastructure quality at the state and local level → quantity is not equivalent to quality**

- **Activities:**
  - Volatility model based on portfolio theory to compare actual road infrastructure revenue portfolios to variance-minimizing revenue portfolios
  - Based on Garret (2006) who extends Markowitz (1952) volatility-based Portfolio Theory to examine variability in state revenue sources
- **Results:**
  - Minimizing infrastructure revenue variance while maximizing supply of infrastructure may provide a useful metric for comparing across distinct geographical areas

New Orleans Grid Resilience

- Coordinated effort with the City of New Orleans, Rockefeller Foundation, and SNL

- Hypothesis: Improved modernization of electric power grid will improve the resilience of the local community

- Analysis: Inform the volatility model based on portfolio theory with local data and use in conjunction with required benefit cost analysis

- Coordinated effort with local government, infrastructure owner/operators, and resilience experts

Supply Chain Networks

- Demonstrate inherent resilience for specific firm types
- Hypothesis: Linkage characteristics determine how firms and industries protect inventories, find work-a-rounds, and assist in quick re-start of production lines
- Analysis: Model inter-industry network connectivity to examine if/how shocks propagate from the micro-level to the macro-level

- Allow differing impacts to firm types within the same industry in an affected geography

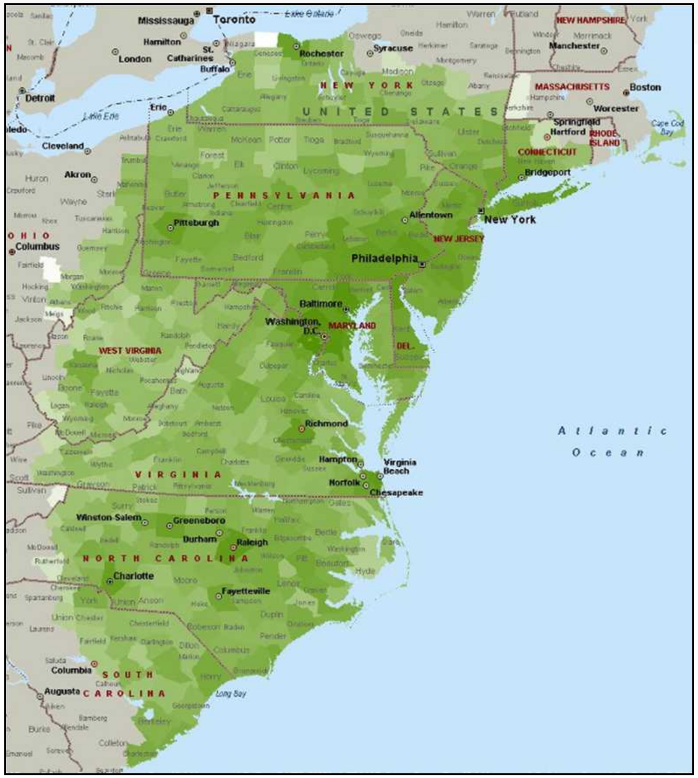
Represents next phase of research to be able to ID and evaluate specific internal an external network structures.

Resilience and Policy Insight +

- **A common reporting metric is necessary for communication and acceptance – GDP**

- **Provides a consistent model application across different geographic regions and time periods**

- **Provide technically consistent estimates of economic impacts from applying resilience-improving engineering to local infrastructure**



Take micro-level changes in investment that directly address improvements to infrastructure resilience and scale to macroeconomic impacts.

Summary

- **Resilience is not a new concept**
  - Lots of work but little consensus

- **Resilience has recently emerged as a national and homeland security priority**
  - Several efforts in progress at the local infrastructure and national supply chain level

- **The IRAM with the inclusion of economic modeling provides an opportunity to address:**
  - Science, tools, and policy implications for improvements in regional and local infrastructure

Thank you

For more information please visit:

http://www.sandia.gov/casosengineering/

http://www.sandia.gov/cities/

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