COMPLEX SYSTEM ANALYTICS

IMPACT

Complex Systems Approaches for Better Understanding Of Health Behavior And Outcomes

Policy impacts on individual behavior and population health

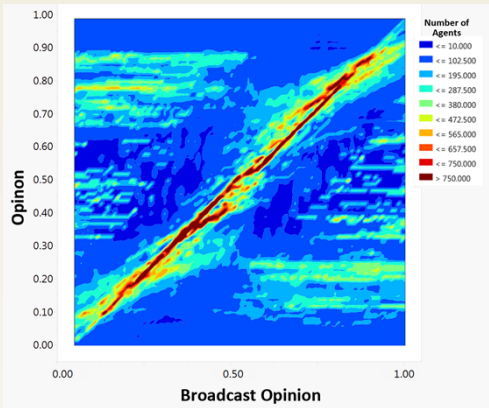
Potential emergent system states (e.g., smoking prevalence, obesity) due to individual behavior and influences (incentives, warnings, education, ads)

SnapDragon for near-term policy effects

Population dynamic models (agent-based/dynamical systems) for population health impacts

ISSUE

Supporting Heath Policy Design



SnapDragon uses software agents to represent a population of individuals with an initial Opinion and a Tolerance

At each time step, agents adjust their opinion based on opinions of neighboring agents, messaging and their own tolerance

Agent behavior is a function of their opinion

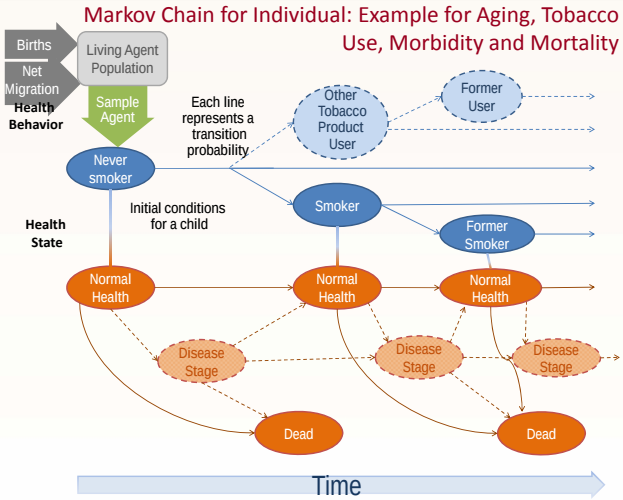
SYSTEM

Multi-Modeling Population Dynamics & Opinion-driven Behavior (SnapDragon) Models

Population dynamics model: agent-based version simulates life span and health states for individuals (more than 300M agents for U.S.), and dynamical systems version simulates mean behavior of aggregate sub-populations by various demographics combinations (more than 1M sub-populations for U.S.)

- demographics of the entire U.S. population (by age, gender, and smoking status)
- health behavior (e.g., smoking, quit smoking, dual use)
- births, immigration, and deaths
- health state

Markov Chain for Individual: Example for Aging, Tobacco Use, Morbidity and Mortality



SUMMARY

- **SnapDragon – near-term changes in health behavior due to interventions and innovations**
- **Population models – population health and mortality dynamics due to changes in population, behaviors and healthcare.**
- **Applied to tobacco control policy, healthcare planning, and obesity interventions**

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COMPLEX SYSTEM ANALYTICS

IMPACT

Rapid and Efficient Disaster Recovery

ISSUE

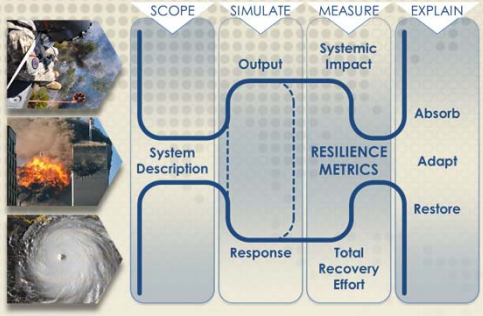
Resilience Analysis and Design

SYSTEM

Infrastructures

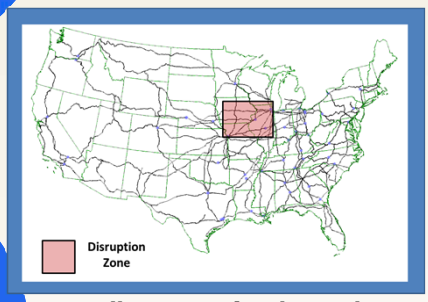
Sandia's resilience modeling and analysis capabilities

- Leverage multidisciplinary foundation
- Provide quantitative basis for assessment and design
- Identify optimal recovery and adaptation strategies
- Inform cost-benefit decisions for resilience design and investment



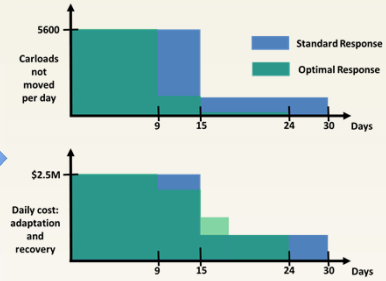
Infrastructure Resilience Analysis Methodology

Resilience Certification

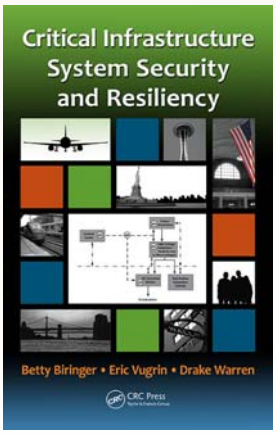


Rail Network Disruption

System-Focused Responses Optimize Resilience



Smaller Impact; Faster, Less Costly Recovery



SUMMARY

- Sandia's infrastructure modeling capabilities enables performance-based resilience analysis.
- Sandia's suite of capabilities enable quantitative, science-informed decision-making for resilience issues.

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IMPACT

Decision Maker Confidence in Analyses and Recommendations

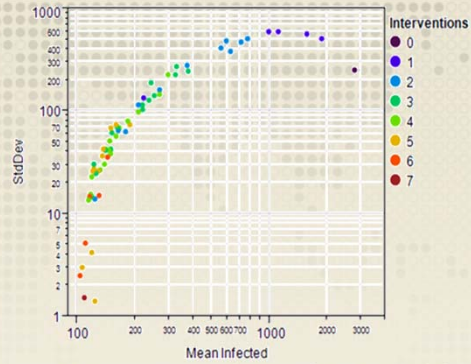
Complex system's non-linear, emergent behaviors are difficult to predict and control

Models that are similar in structure and behavior of complex systems are key to improving understanding and for experiments

Multiple, competing theories can be modeled and compared

Modeling for understanding can improve interventions

No single test is sufficient for CS model validation

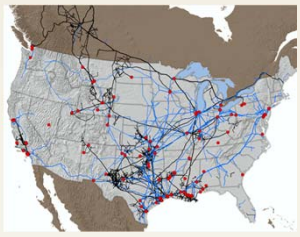


Comparative analysis with UQ reveals better options for achieving desired outcomes

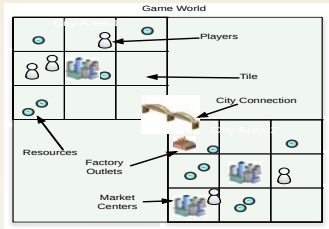
ISSUE

Complex Systems Model Validation

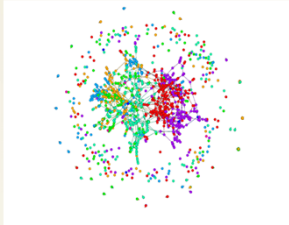
Realistic Network Structures and Interactions/Behaviors



Petroleum Pipelines



Player Behaviors in Online Games

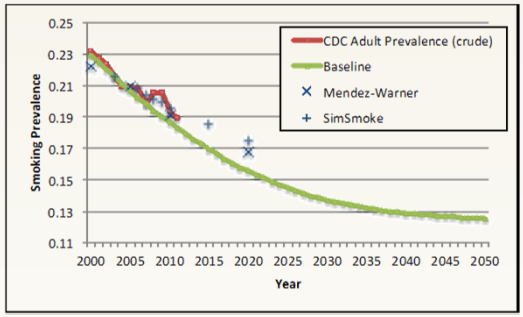


Adolescent Health Survey Example Social Networks

SYSTEM

Agent-based, Optimization, Network, Individual and System Models

History matching of conditions and behaviors and comparison of projections to other models is expected



Model Validation Activities:

- Parameter assessment
- Model behavior assessment
  - Basic-behaviors reproduction
  - Endogenous behavior-reproduction
  - Boundary adequacy
  - Hypothesis testing
- Uncertainty analysis
  - Behavior sensitivity analysis
  - Policy sensitivity analysis
- Forecasting/Behavior prediction
- History matching
- Analog behavior matching
- Peer review

SUMMARY

- **Defense in depth required for models used to design policy**
- **CS models are most useful for exploring conditions that have not existed previously**
- **Validation provides bounded confidence**

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COMPLEX SYSTEM ANALYTICS

IMPACT

Rapid and Efficient Disaster Recovery

ISSUE

Pandemic Planning

SYSTEM

Epidemiological Model (Modified SEIR)

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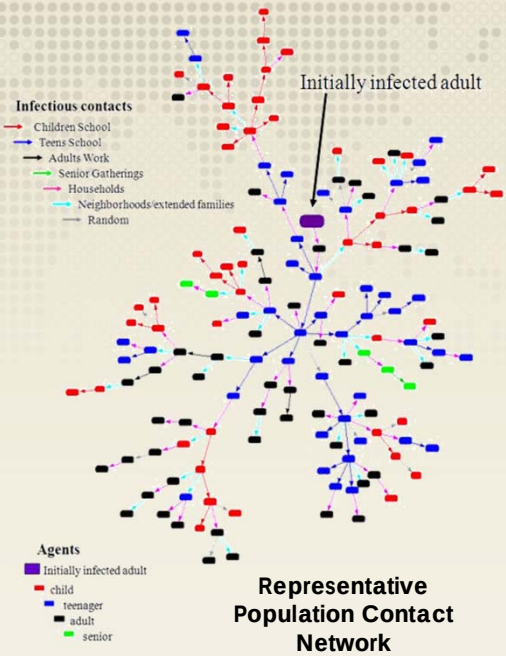
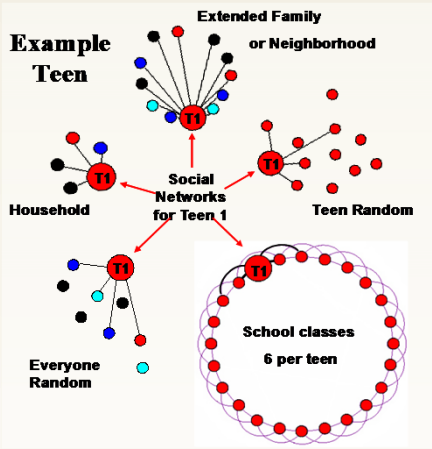
Modeling and analysis processes that account for the dynamics of human-technical-natural systems

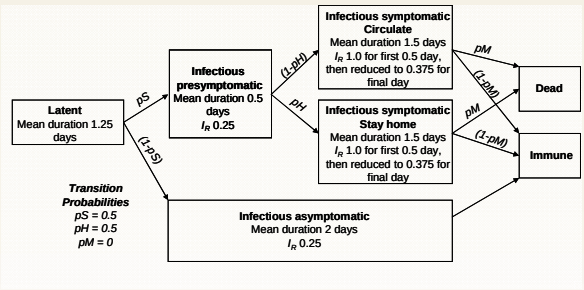
- Explicitly represent and account for uncertainties
- Explicitly represent and account for risk reduction strategies
- Comparative analysis to identify solutions that are robust to uncertainty
- Decision maker confidence in the analysis and ability to implement the engineered solution
- Evaluation and improvement



Representative Population Contact Network



Individuals Interact in Multiple Social Networks



Epidemiological Model (Modified SEIR)

SUMMARY

- The best-performing intervention strategies include school closure early in the outbreak
- Child and teen social distancing is the next most important component (with school closure it reduces mean to 124 cases and the standard deviation to 14)

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COMPLEX SYSTEM ANALYTICS

IMPACT

Improved management of interdependent energy & water systems

Water and energy are critical and interdependent resources

Their availability directly or indirectly touches every other sector.

Managing these resources requires understanding the dynamics uncertainty and complexity

Energy

Water

Agriculture and Food

Chemical

Commercial Facilities

Critical Manufacturing

Defense Industrial Base

Dams / Storage

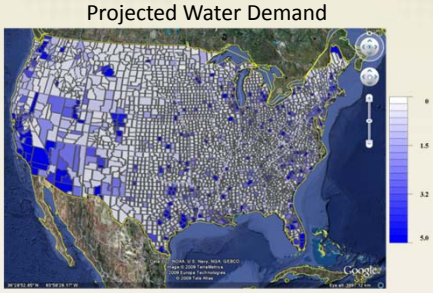
Nuclear Reactors, Materials and Waste

Transportation Systems

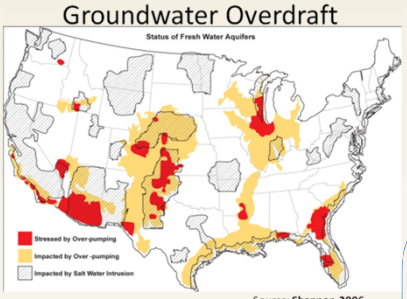
ISSUE

Water and Energy impact every sector

Projected Water Demand



Groundwater Overdraft

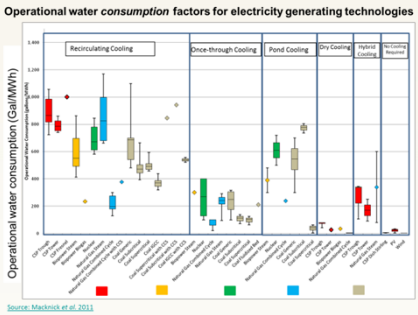


Source: Shannon 2006

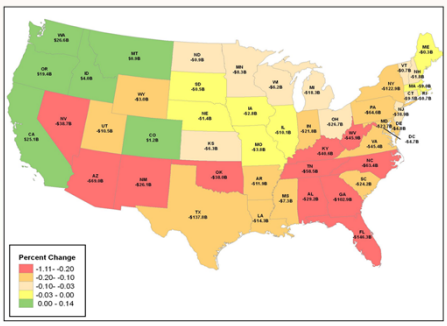
SYSTEM

Hydrologic & System Models

Power Plant Water Use



Source: Macknick et al. 2011



GDP Risk By State 2010 – 2050 due to Climate Change

SUMMARY

- CS approach represents dynamics of climate, population, economics, policy and other events
- Explicit representation of uncertainty and decision feedback are key
- Used to assess:
  - water stress impact on power generation and transmission expansion
  - near-term risk of climate uncertainty
  - conflicting and competing interests and values and compromises
  - risk mitigation options and system resiliency

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