Infrastructure Interdependency, Consequence Effects and Engineering

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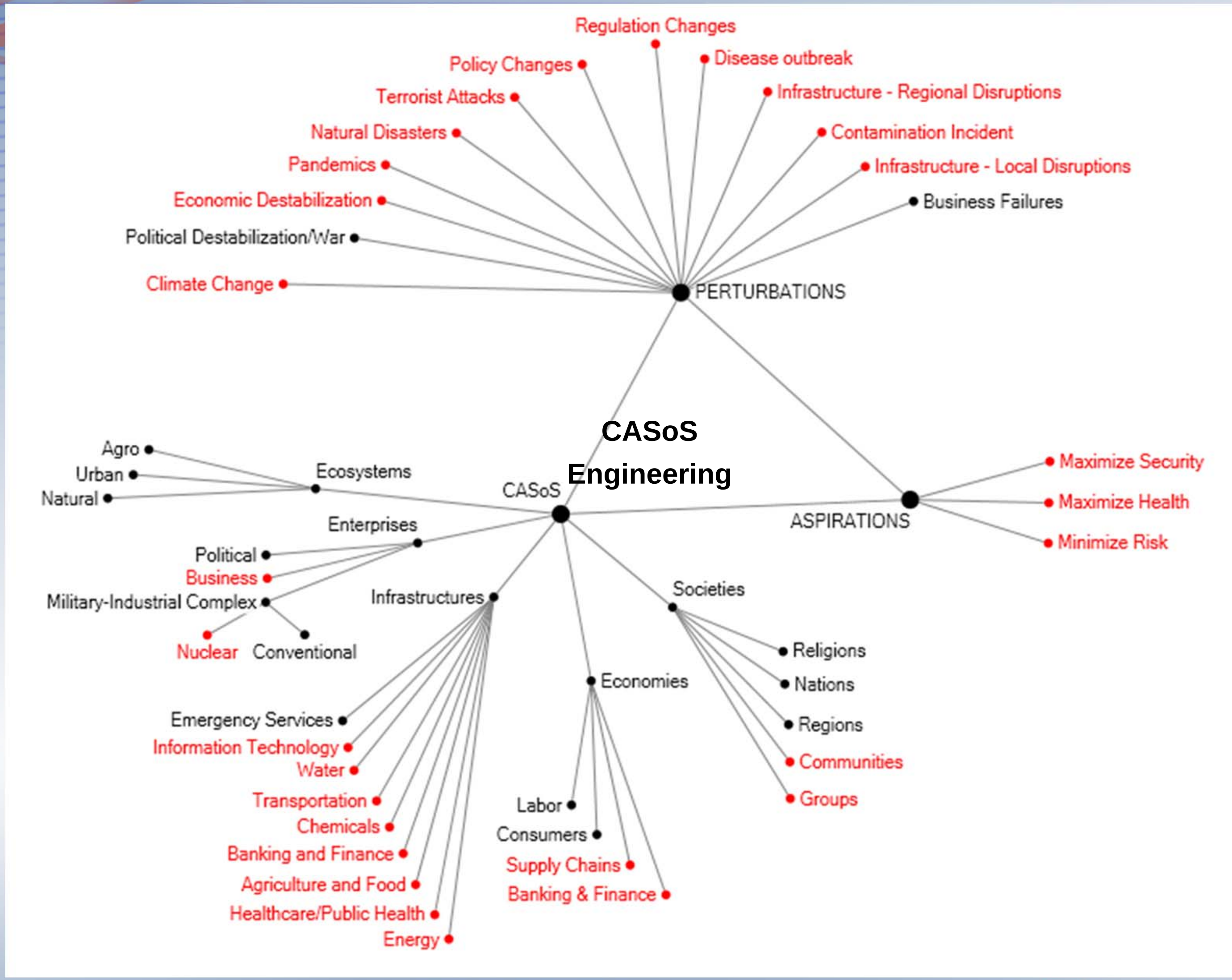
The Problem Space is Broad



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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

Interdependencies

Planning

Recovery/Improvements

Event/Response

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

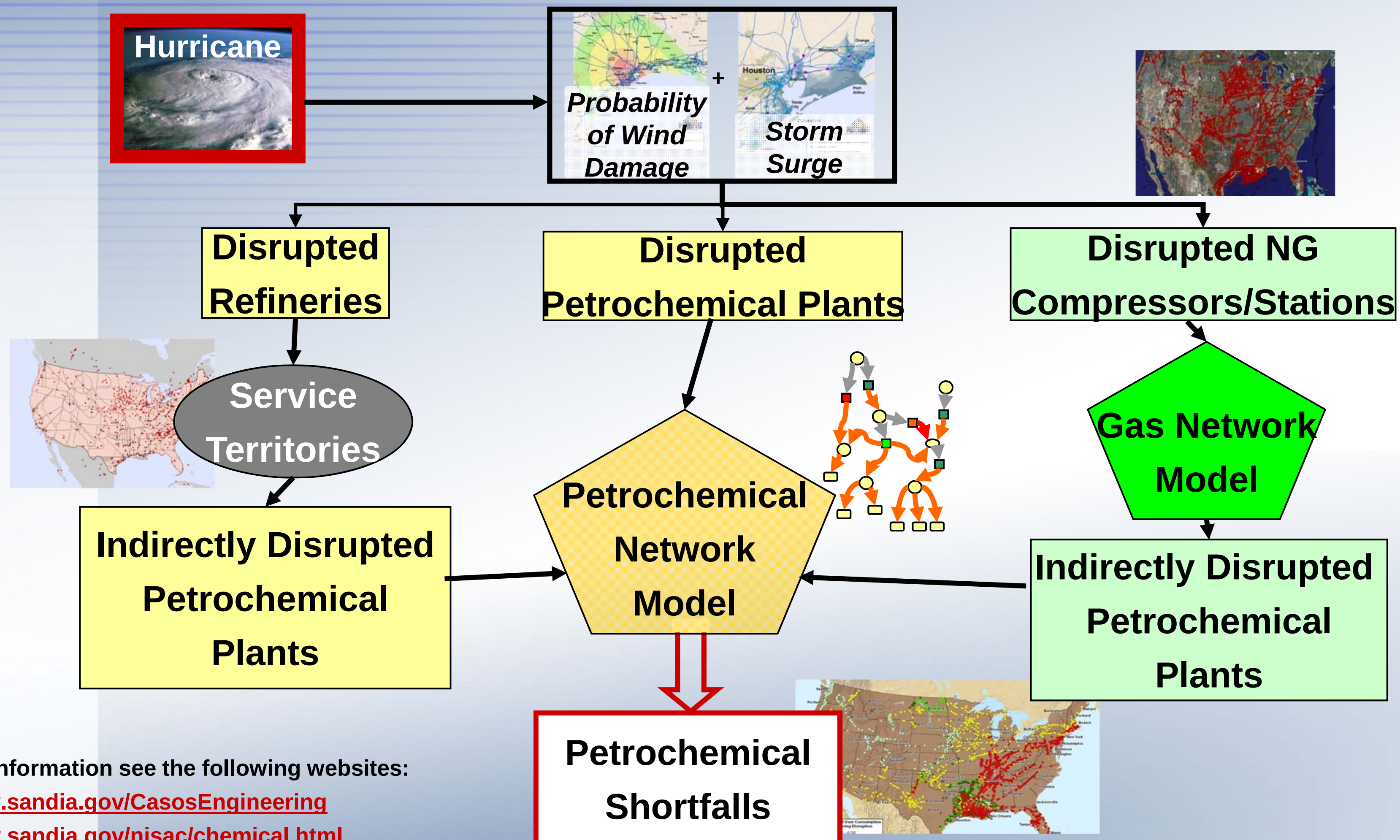
There are a range of data, modeling and analysis capabilities needed for this class of problems

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

Table based on : “Levels of Confidence in System Dynamics Modeling: A Pragmatic Approach to Assessment of Dynamic Models” by Aldo A. Zagonel and Thomas F. Corbet, CI Modeling and Simulation Department, Published in the International System Dynamics Conference Proceedings, 2006.

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

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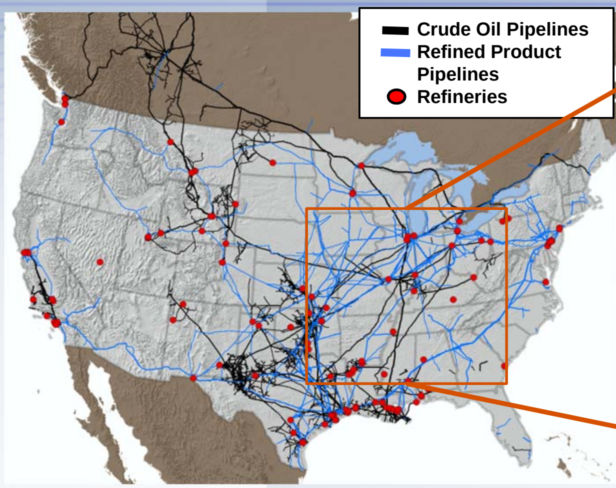
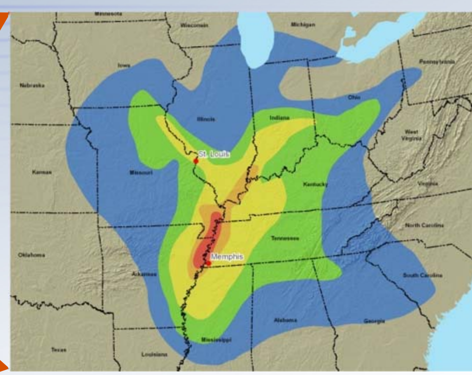
Disaster Planning: understanding and quantifying infrastructure impacts and adaptation to improve risk management

Example – Earthquake impacts on Transportation Fuels

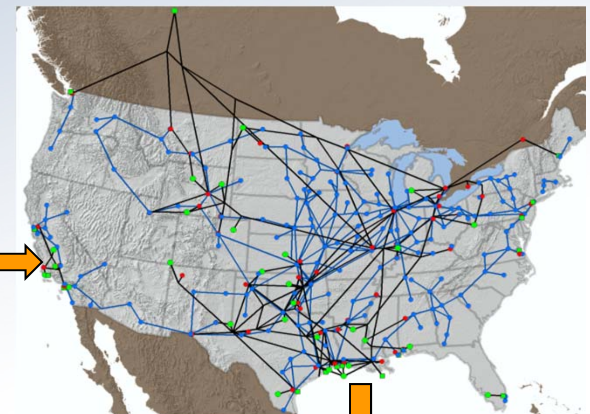


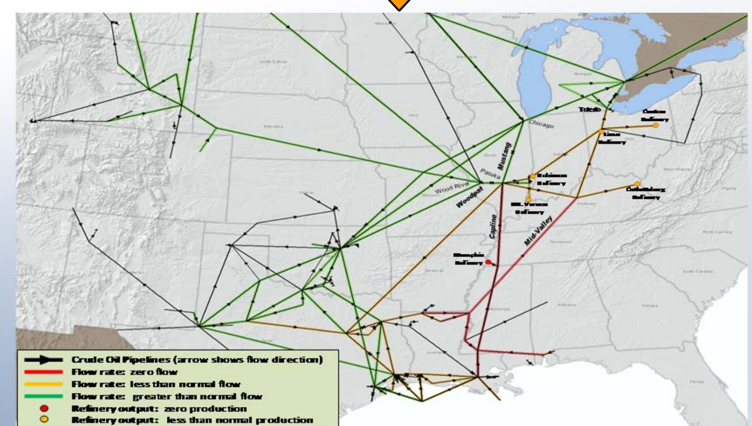
Petroleum Pipelines concentrated in central portion of US



Scenario Earthquake – Ground Motion

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





Changes in Fuel Production and Flows

For more information see the following website:

http://www.sandia.gov/CasosEngineering

Or contact Tom Corbet (tfcorbe@sandia.gov)

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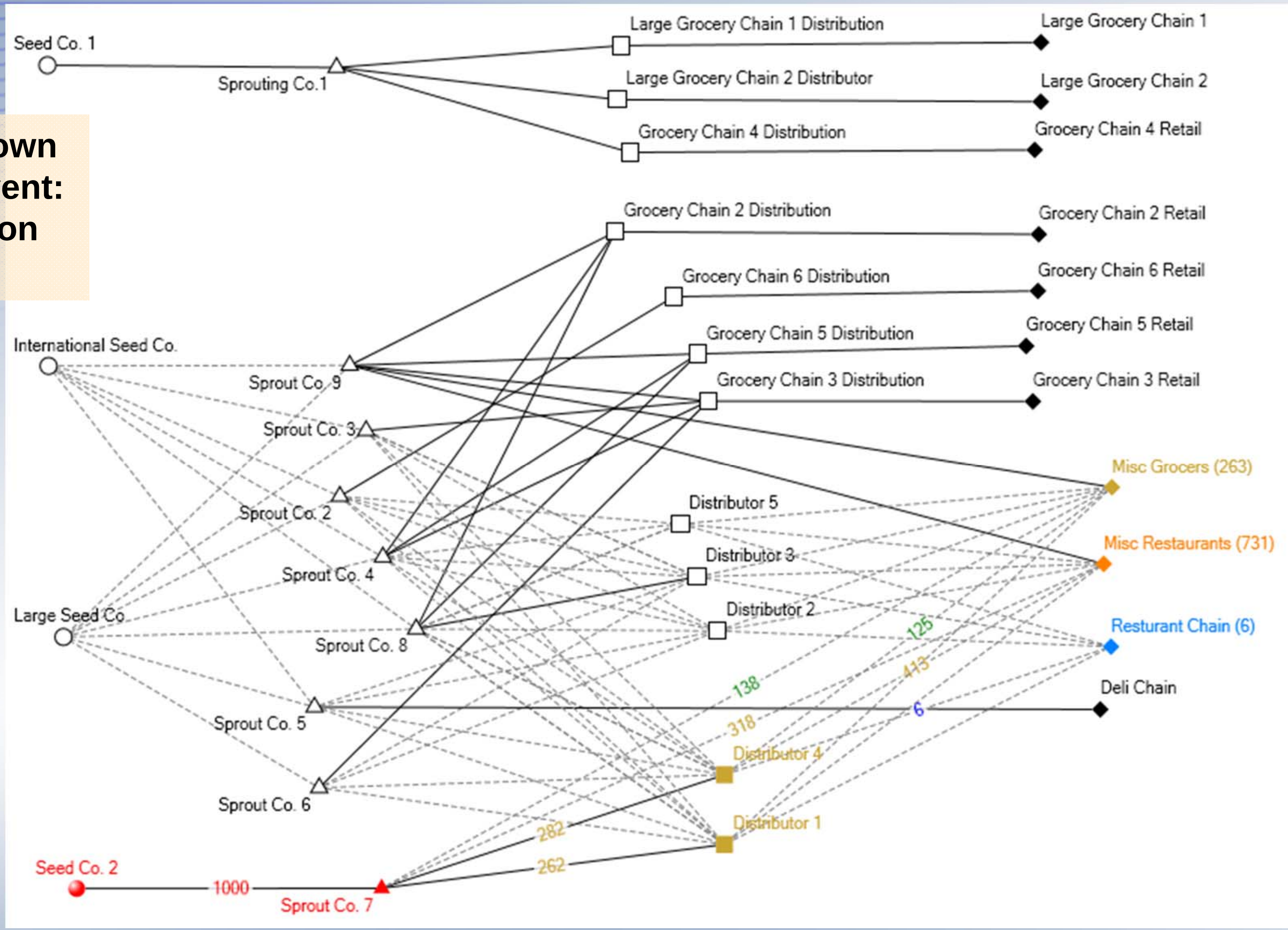
Food Defense: stochastic mapping to prioritize pathways for intervention

Forward Tracing of Known Seed Contamination Event: Potential Contamination Pathways



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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

	Sprout Co 1	Sprout Co 7	Sprout Co 2	Sprout Co 4	Sprout Co 10	Sprout Co 8
Large Grocery Chain 1	1.00	0.00	0.00	0.00	0.00	0.00
Deli Chain	0.00	0.18	0.27	0.18	0.09	0.09
Sprout Co. 7 Customers	0.00	1.00	0.00	0.00	0.20	0.00
Grocery Chain 2 Retail	0.00	0.07	0.13	0.40	0.53	0.20
Misc. Grocers	0.00	0.24	0.39	0.15	0.22	0.10
Misc. Restaurants	0.00	0.24	0.38	0.14	0.24	0.10
Grocery Chain 3 Retail	0.00	0.00	0.25	0.38	0.50	0.06
Large Grocery Chain 2	1.00	0.00	0.00	0.00	0.00	0.00
Restaurant Chain	0.00	0.24	0.38	0.14	0.24	0.10
Grocery Chain 4 Retail	1.00	0.00	0.00	0.00	0.00	0.00
Distributor 5 Customers	0.00	0.11	0.11	0.11	1.00	0.00
Grocery Chain 6 Retail	0.00	0.00	1.00	0.00	0.06	0.13
Grocery Chain 5 Retail	0.00	0.00	0.13	0.40	0.53	0.20
Unconditional Probability	0.16	0.20	0.32	0.12	0.20	0.08

For more details see:

The Value of Utilizing Stochastic Mapping of Food Distribution Networks for Understanding Risks and Tracing Contaminant Pathways, Stephen H. Conrad, Walter E. Beyeler, Theresa J. Brown, 2011, Proceedings of the 4th Annual Conference on Infrastructure Systems: Challenges and Research For Next Generation Infrastructures in the 21st Century, November 2011, Norfolk, VA

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Policy Design:
Pandemic Influenza Containment Strategy

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

<u>Constraints</u>

Antiviral Stockpile

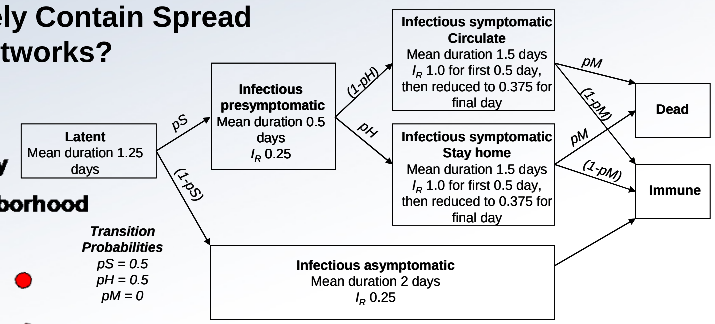
Compliance with Containment Policy

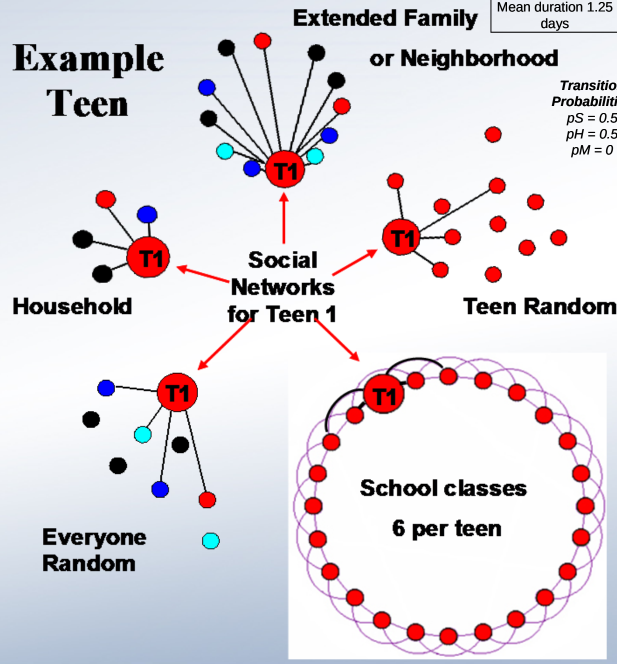
Hospital/Treatment Capacities

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.

Social contact networks for the spread of pandemic influenza in children and teenagers, LM Glass, RJ Glass, *BMC Public Health*, February, 2008.

Rescinding Community Mitigation Strategies in an Influenza Pandemic, VJ Davey and RJ Glass, *Emerging Infectious Diseases*, March, 2008.

***Effective, Robust Design of Community Mitigation for Pandemic Influenza**: A Systematic Examination of Proposed U.S. Guidance*, VJ Davey, RJ Glass, HJ Min, WE Beyeler and LM Glass, PLoSOne, July, 2008.

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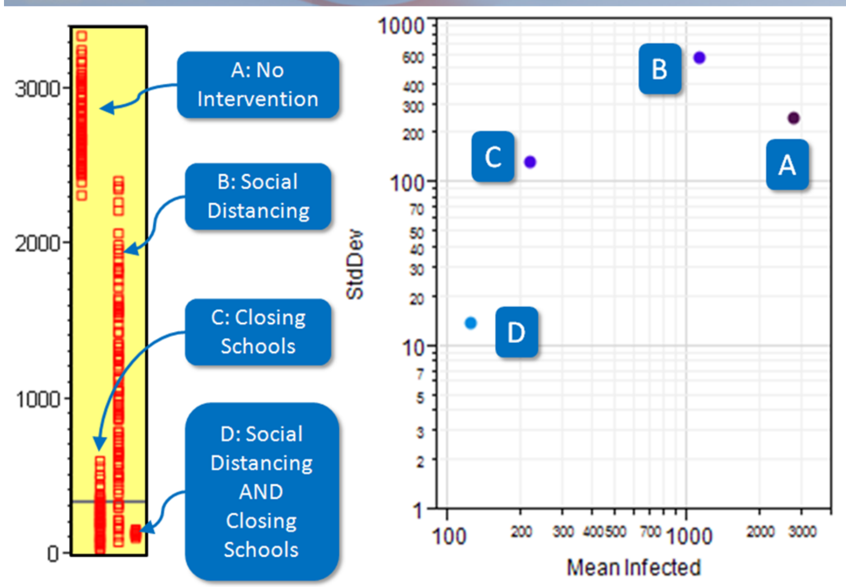
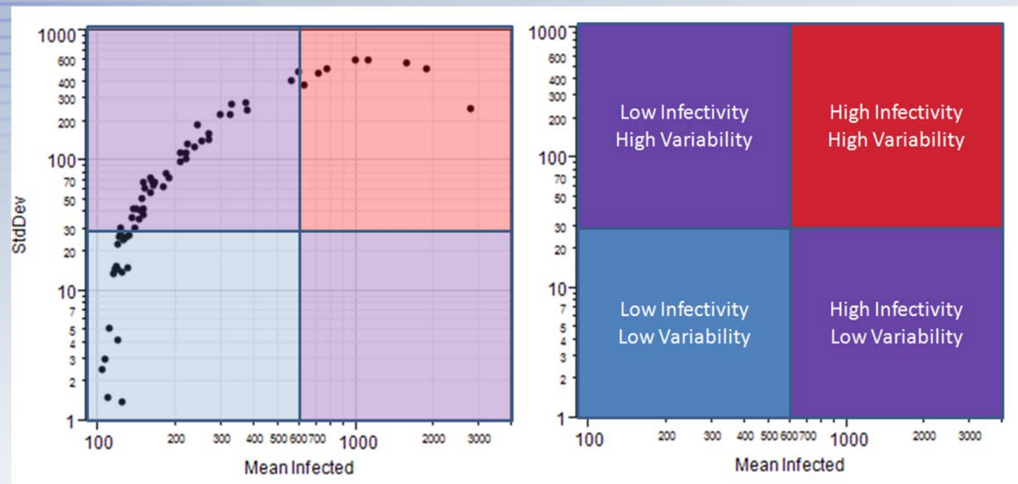
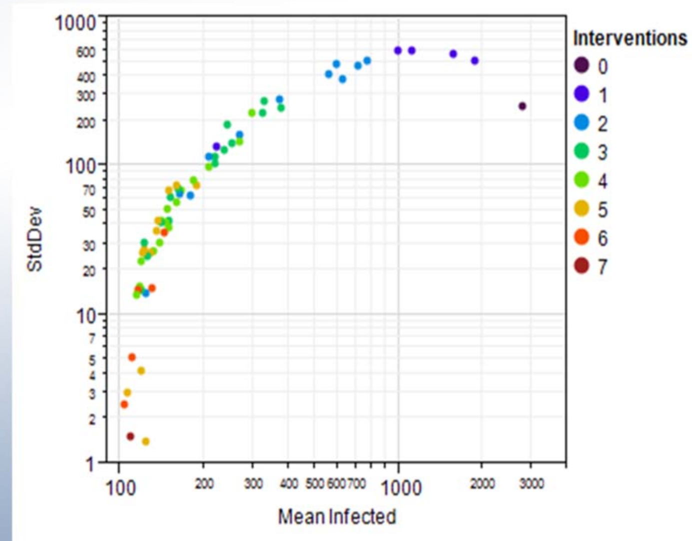
Policy Design: Robustness to Uncertainty





- 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)

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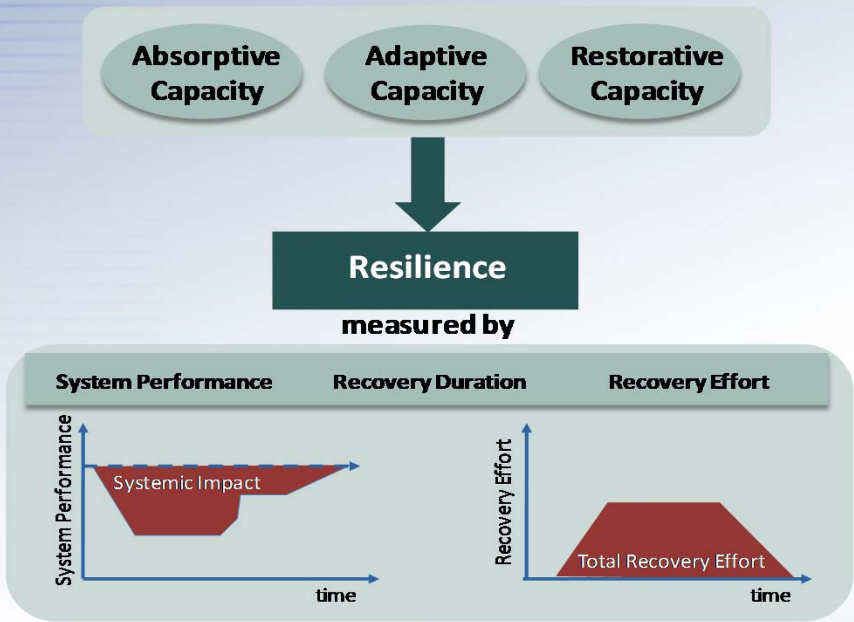
Infrastructure Resilience

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:

Vugrin, E. D., D. E. Warren, M. A. Ehlen, and R. C. Camphouse (2010a), "A Framework for Assessing the Resilience of Infrastructure and Economic Systems," in *Sustainable and Resilient Critical Infrastructure Systems: Simulation, Modeling, and Intelligent Engineering*, K. Gopalakrishnan and S. Peeta, eds., Springer-Verlag, Inc., 2010.

Vugrin, E. D., M. A. Turnquist, N. Brown, and D. E. Warren (2010b), "Measurement and Optimization of Critical Infrastructure Resilience," presentation to the 4th Annual Meeting of the Security and Risk Management Association, Arlington, VA, October 5-5, 2010. (Journal paper in preparation)

Vugrin, E.D., and R. C. Camphouse (2011), "Infrastructure resilience assessment through control design," *International Journal of Critical Infrastructures*, 7(3), pp. 243-260.

Vugrin, E. D., D. E. Warren, and M. A. Ehlen (2011), "A resilience assessment framework for infrastructure and economic systems: Quantitative and qualitative resilience analysis of petrochemical supply chains to a hurricane," *Process Safety Progress*, 30, pp. 280–290

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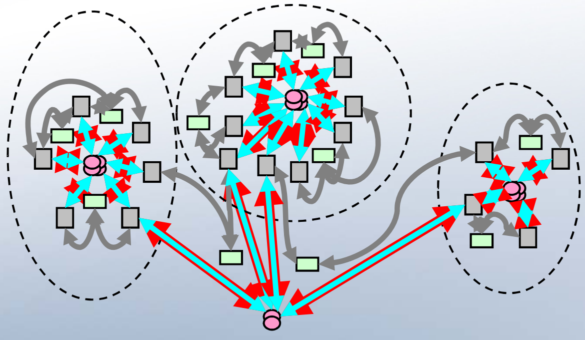
NISAC Program Capabilities

- **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.

CASoS Engineering – Experience

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)



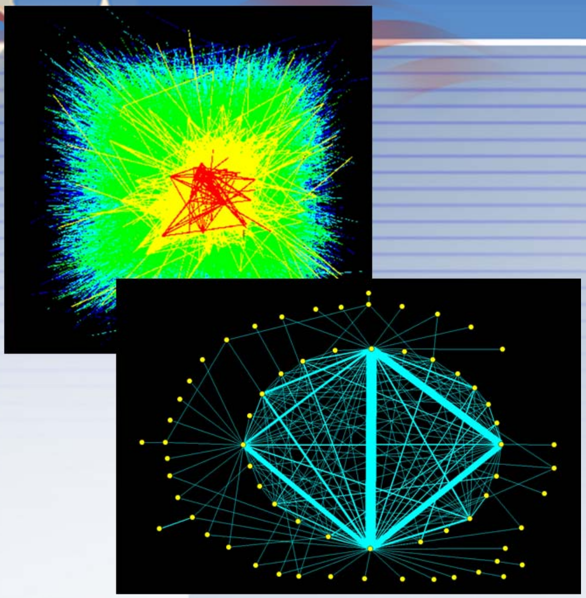
Payment and Global Monetary System Risks

The NISAC program funded us to identify risks in the banking and finance infrastructure

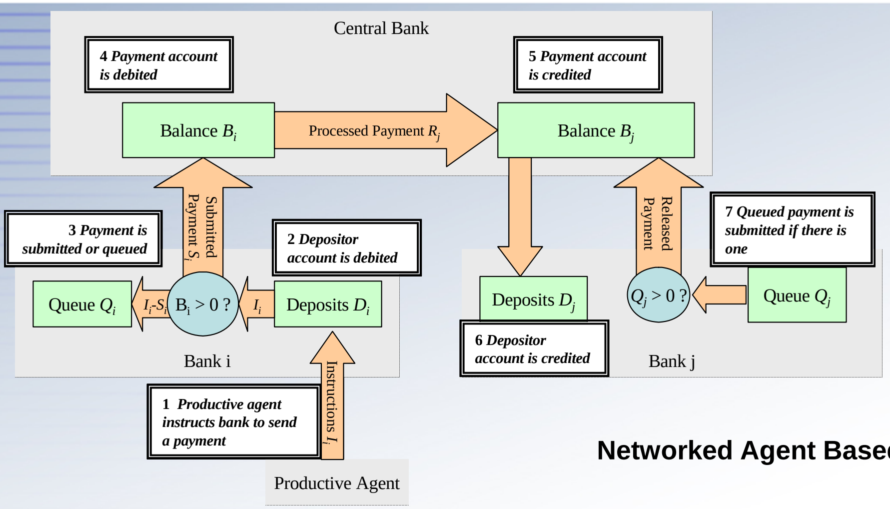
We worked with the Federal Reserve Bank of NY to develop an agent-based network modeling approach to evaluate Fedwire, the large transaction clearing system and with the Bank of Finland to develop a model of interacting global monetary systems

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.

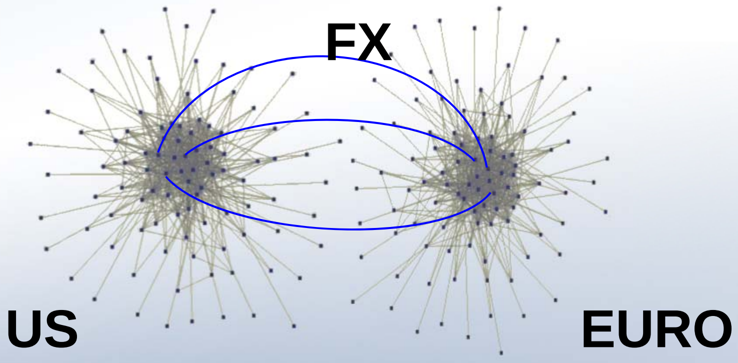
Understanding Congestion and Cascades in Payment Systems



Payment system network



Networked Agent Based Model



Global interdependencies

For Details see:

***The Topology of Interbank Payment Flows*, Soramäki, et al, *PhysicaA,* 1 June 2007; vol.379, no.1, p.317-33.**

***Congestion and Cascades in Payment Systems*, Beyeler, et al, *PhysicaA,* 15 Oct. 2007; v.384, no.2, p.693-718.**

***Congestion and Cascades in Coupled Payment Systems*, Renault, et al, Joint Bank of England/ECB Conference on Payments and monetary and financial stability, Nov, 12-13 2007.**

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Veterans Affairs – Identifying and Reducing Operational Risks

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

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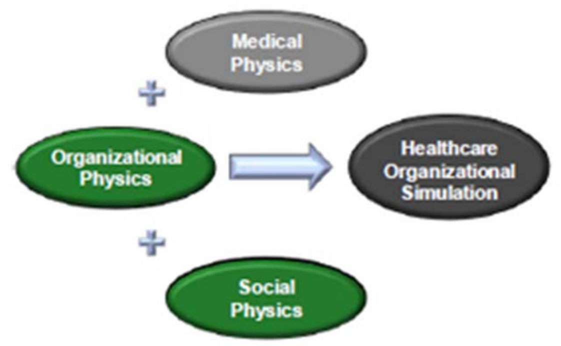
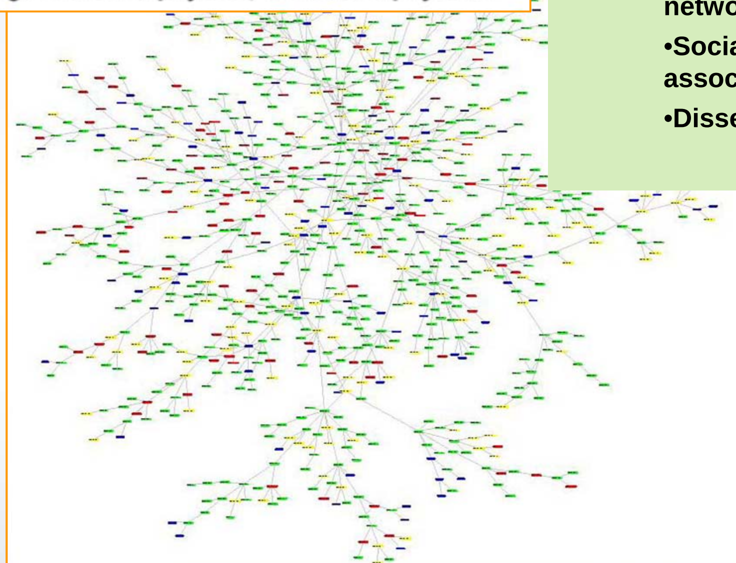
Evaluating Threats and Designing Mitigation Strategies for the Veterans Health Administration



Three fundamental building blocks needed to model a healthcare system: medical physics, organizational physics, and social physics.



- **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)

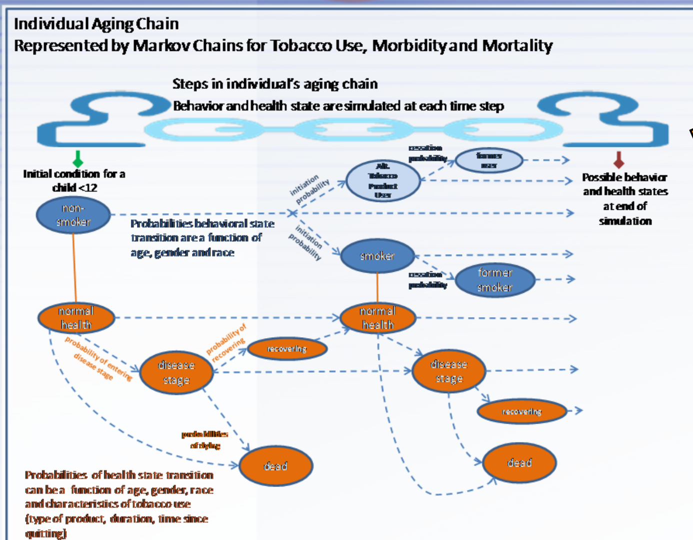
Loki-Infect 3: A Portable Networked Agent Model for Designing Community-Level Containment Strategies, Jacob A. Hobbs, Daniel C. Cannon, Leland B. Evans (Sandia National Laboratories), Victoria J. Davey (Department of Veterans Affairs), Robert J. Glass (Sandia National Laboratories) (Dec 2010)

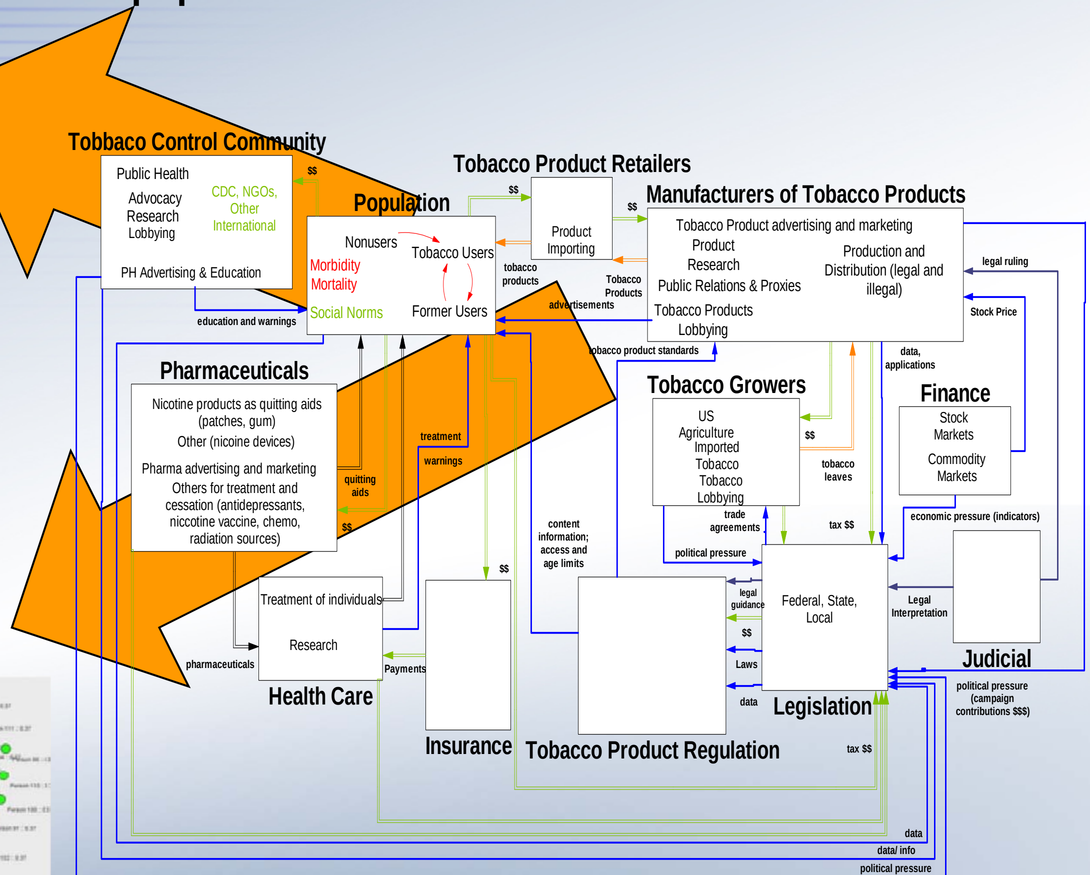
A Complex Adaptive Systems Modeling Framework for Public Health Action Exemplified by the Veterans Affairs Modeling Object Oriented Simulation Environment, Thomas W. Moore, John M. Linebarger, Patrick D. Finley, Roger Mitchell, Walter E. Beyeler (Sandia National Laboratories), Victoria J. Davey (Department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

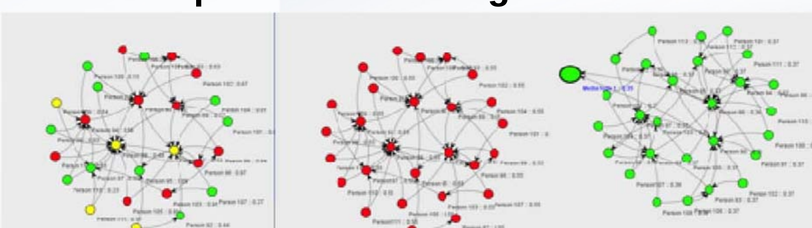
Application: Tobacco Control Policy Impacts on Population Health

Population Structure Model : impacts of tobacco use on population health





Opinion Dynamics Modeling : impacts on smoking behavior



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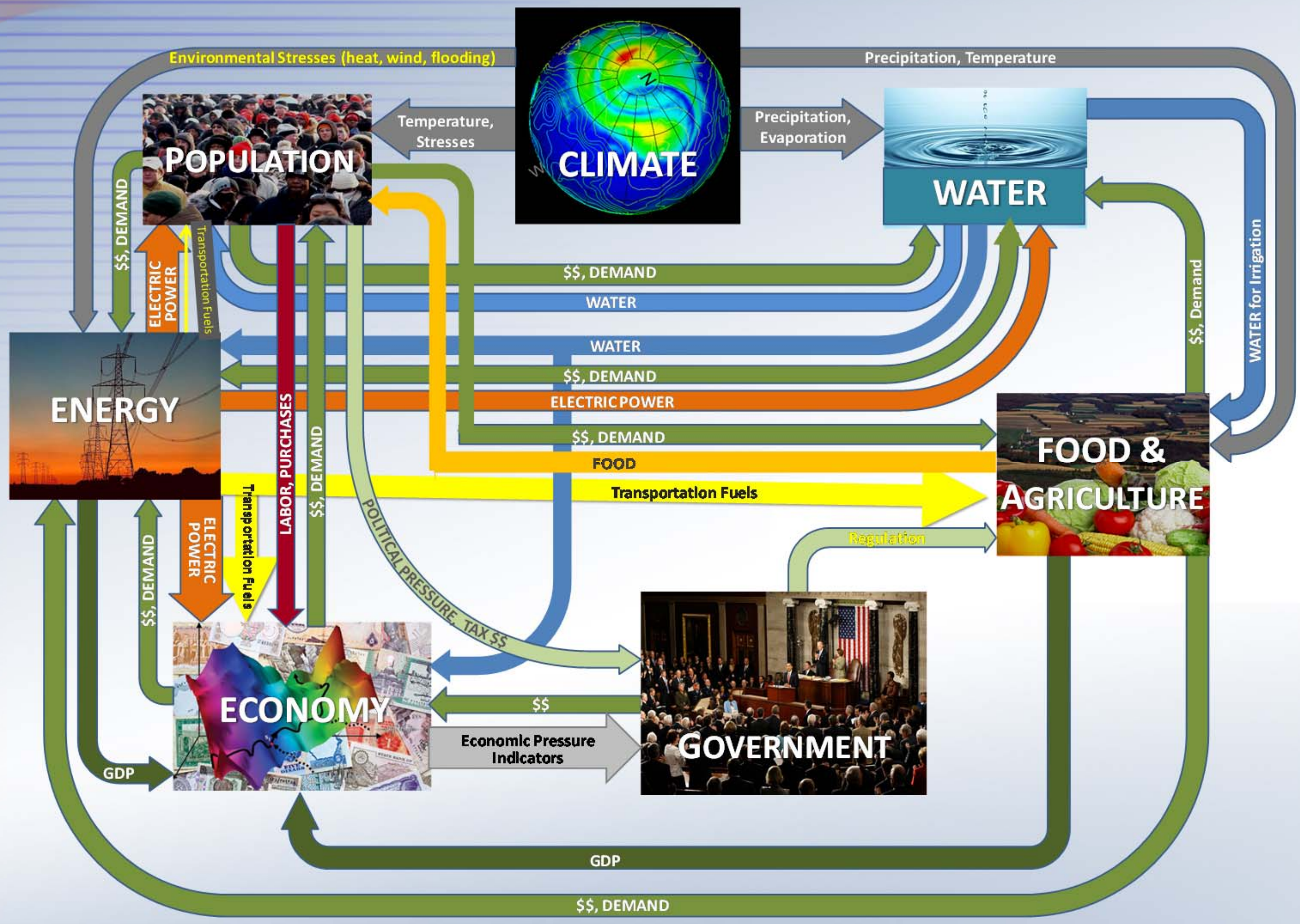
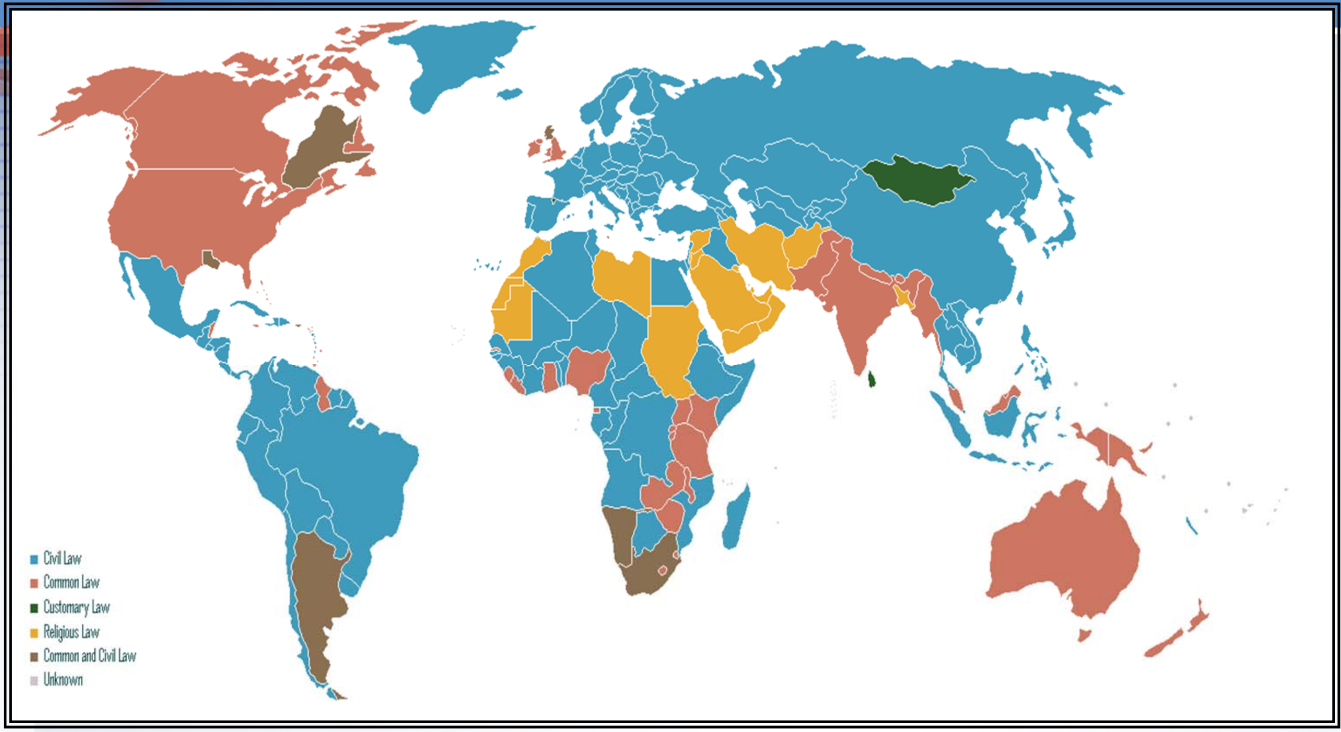
CASoS Engineering Example- Adaptation to Climate Change Impacts

- 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

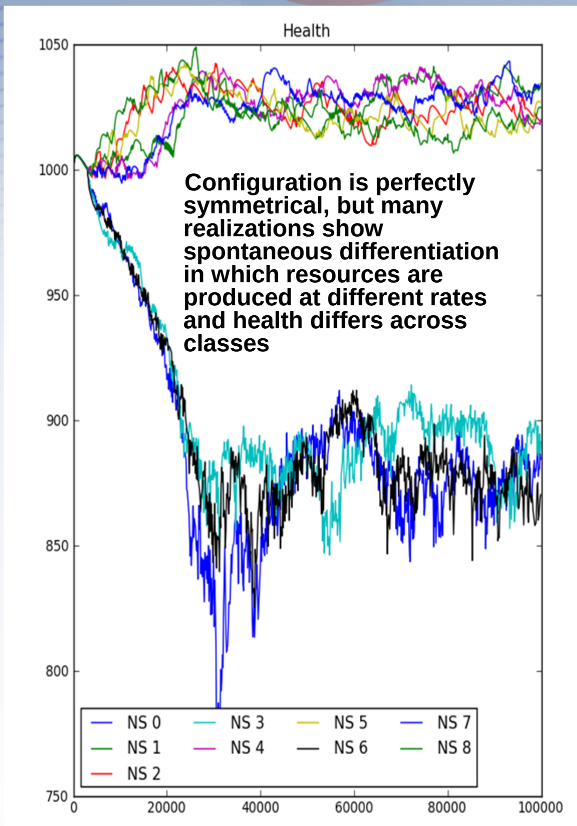


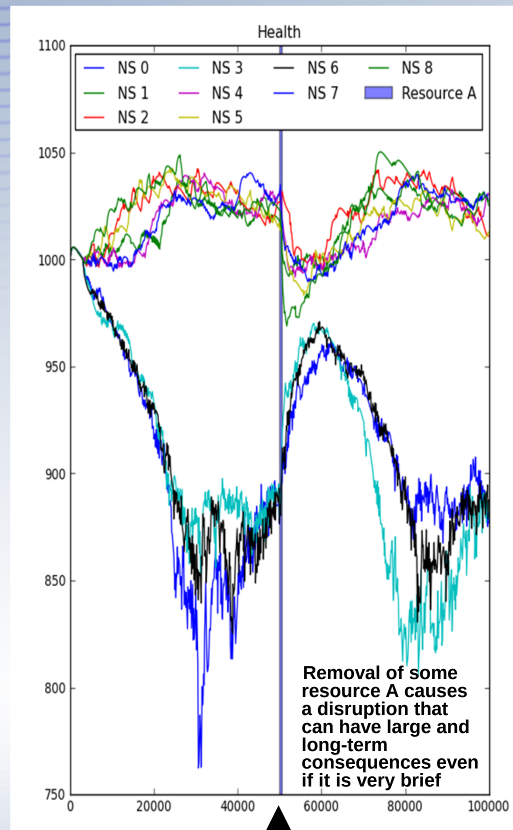
Global Security Focus

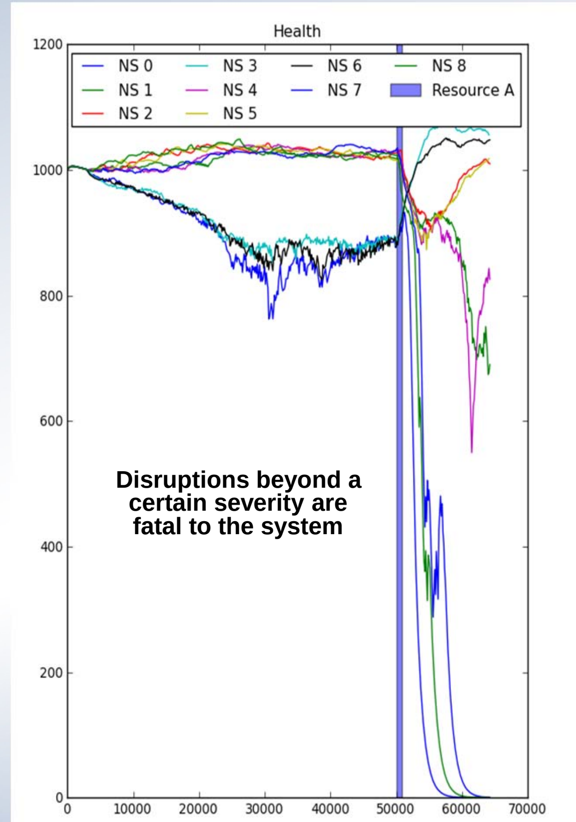


- **Global socio-economic interdependent CASoS**
- **System Stability in context Perturbations and Stressors (e.g., climate)**
- **Design policy that enhances system resilience**

Example Results: Entity and Global Health in context of finite energy shocks







Small Shock

Large Shock

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Complex Adaptive System of Systems (CASoS) Engineering

http://www.sandia.gov/CasosEngineering/

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