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CSYS 300 – COMPLEX SYSTEMS FUNDAMENTALS, METHODS & APPLICATIONS

Overview of Complex Systems

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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CSYS 300 – COMPLEX SYSTEMS FUNDAMENTALS, METHODS & APPLICATIONS

Overview of Complex Systems

Outline of Presentation

- Brief Biographical Note
- Where this Section Fits in the Structure of the Complex Systems Course
- Complex Adaptive Systems – definition for engineering
- Applications - Modeling and analysis to inform policy decisions
- Summary
- Question & Answer Session

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Brief Biographical Note on Theresa Brown

- Ph.D. Geology (University of Wisconsin-Madison), M.A. Geology (UT-Austin), BS Earth Science and Secondary Education (Adams State)
- UNM – adjunct professor, geology; City of Stevens Point, WI wellhead protection study - lead; Associated Drilling Co. – geologist; National Geographic Paleontological Dig at Hansen's Bluff – crew leader.
- SNL – CASoS Engineering Lead and Distinguished R&D
  - CASoS Engineering - applications lead
  - NISAC - program technical lead
  - NISAC - DIISA modeling lead
  - YMP, GCD and NRC projects – probabilistic risk and performance assessments

CSYS 300 – COMPLEX SYSTEMS FUNDAMENTALS, METHODS & APPLICATIONS

Structure of the Course

	Focus of this session
▪ Fundamentals of Complex Systems	✔
▪ Methods	
▪ Modeling Techniques	✔
▪ Approaches to Examining Complex Systems	✔
▪ Applications	
▪ Examples of the use of complex systems fundamentals to solve problems	✔
▪ Learning how to use complex systems modeling tools	☐

*Note: These approaches represent a simplified set of complex systems concepts chosen for the CSYS500 systems lectures. Please see the initial two lectures for additional detail and expanded references.

What are Complex Adaptive Systems (CAS) and why do we want to reduce their risks?

- A CAS as one in which the structure modifies to enable success in its environment
  - structure and behavior are products of all the perturbations the system has experienced and modifications it has implemented.
  - certain structural characteristics emerge, hierarchical and modular, with simple rules for interaction among the elements
- Many persistent, large-scale engineering challenges involve multiple interacting CAS or Complex Adaptive Systems of Systems (CASoS).

Reference: A Case for Sandia Investment in Complex Adaptive Systems Science and Technology, Curtis M. Johnson, George A. Backus, Theresa J. Brown, Richard Colbaugh, Katherine A. Jones, Jeffrey Y. Tsao, May 2012 (SAND2012-3320)

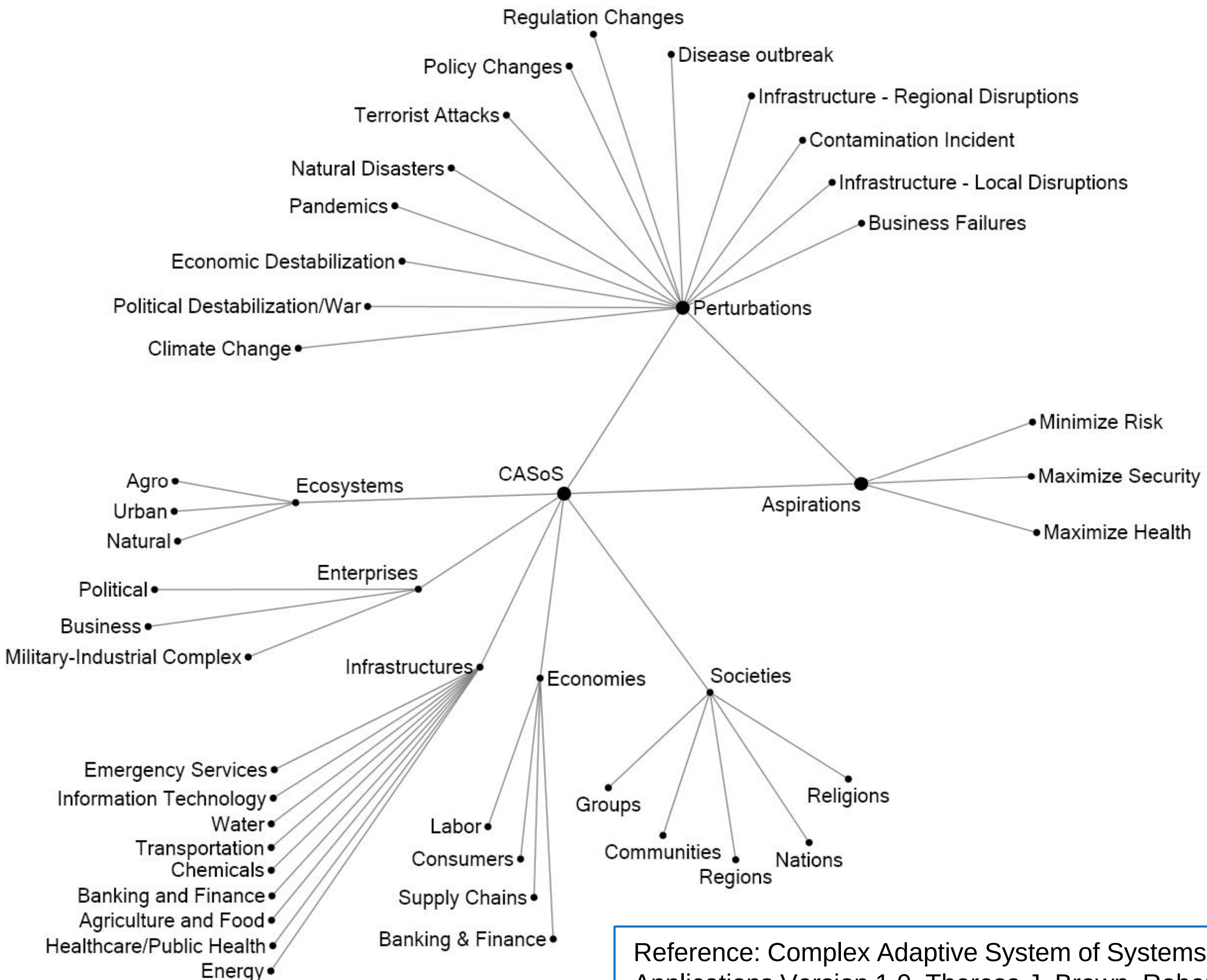
Why CASoS Engineering?

- Complex adaptive systems are central to many persistent problems locally and globally
  - Climate change, economic crises, energy and food supply disruptions have global effects
  - Evaluating the dynamic interactions improves our understanding of risks and how to reduce them
- Climate change and the challenge of addressing the global risks provides a common set of problems on which to build a global community of practice for engineering solutions to complex adaptive systems of systems problems.

References:
Complex Adaptive Systems of Systems (CASoS) Engineering and Foundations for Global Design, Glass RJ, Beyeler WE, Ames AL, Brown TJ, Maffitt SL, Brodsky NS, Finley PD, Moore TW, Mitchell MD, Linebarger JM, January 2012 (SAND2012-0675)

Phoenix: Complex Adaptive System of Systems (CASoS) Engineering Version 1.0, Robert J. Glass, Theresa J. Brown, Arlo L. Ames, John M. Linebarger, Walter E. Beyeler, S. Louise Maffitt, Nancy S. Brodsky, and Patrick D. Finley, et al., October 2011 (SAND2011-3446)

The problem space is broad



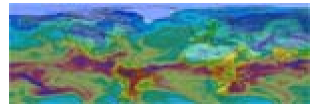
Reference: Complex Adaptive System of Systems (CASoS) Engineering Applications Version 1.0, Theresa J. Brown, Robert J. Glass, Walter E. Beyeler, Arlo L. Ames, John M. Linebarger, and S. Louise Maffitt, Sandia National Laboratories, October 2011 (SAND2011-8032)

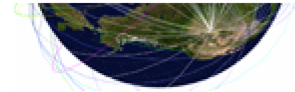
What capabilities do we need in order to solve these problems?

- Modeling and analysis processes that account for the dynamics of human-technical-natural systems
  - Causal relationships
  - Condition dependent behavior
  - Resource constraints
  - Delays and the effects of delays on system viability and performance
- 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

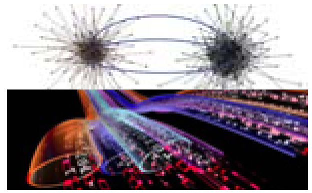
Examples of CASoS Engineering for Policy

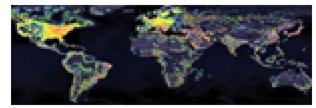

Global Security

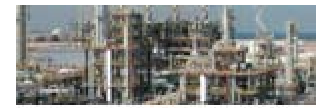

Adaptation to Climate Change impacts


Resource & Exchange Dynamics


Global Financial Systems


Global Payment Systems

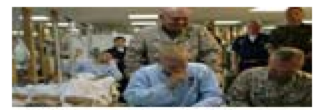

Global Energy System

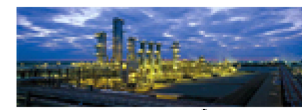

Petrochemical Supply Chains


Food Defense


Tobacco Control Policy

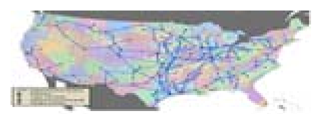

Pandemic Influenza

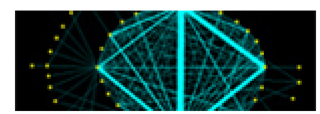

Veterans Health Threats

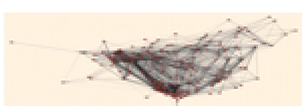

Petrochemical Regulatory Policy

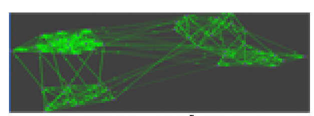

Livestock Transfer Risks

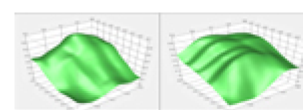

Natural Gas Networks


Petroleum Fuels


Congestion and Cascades

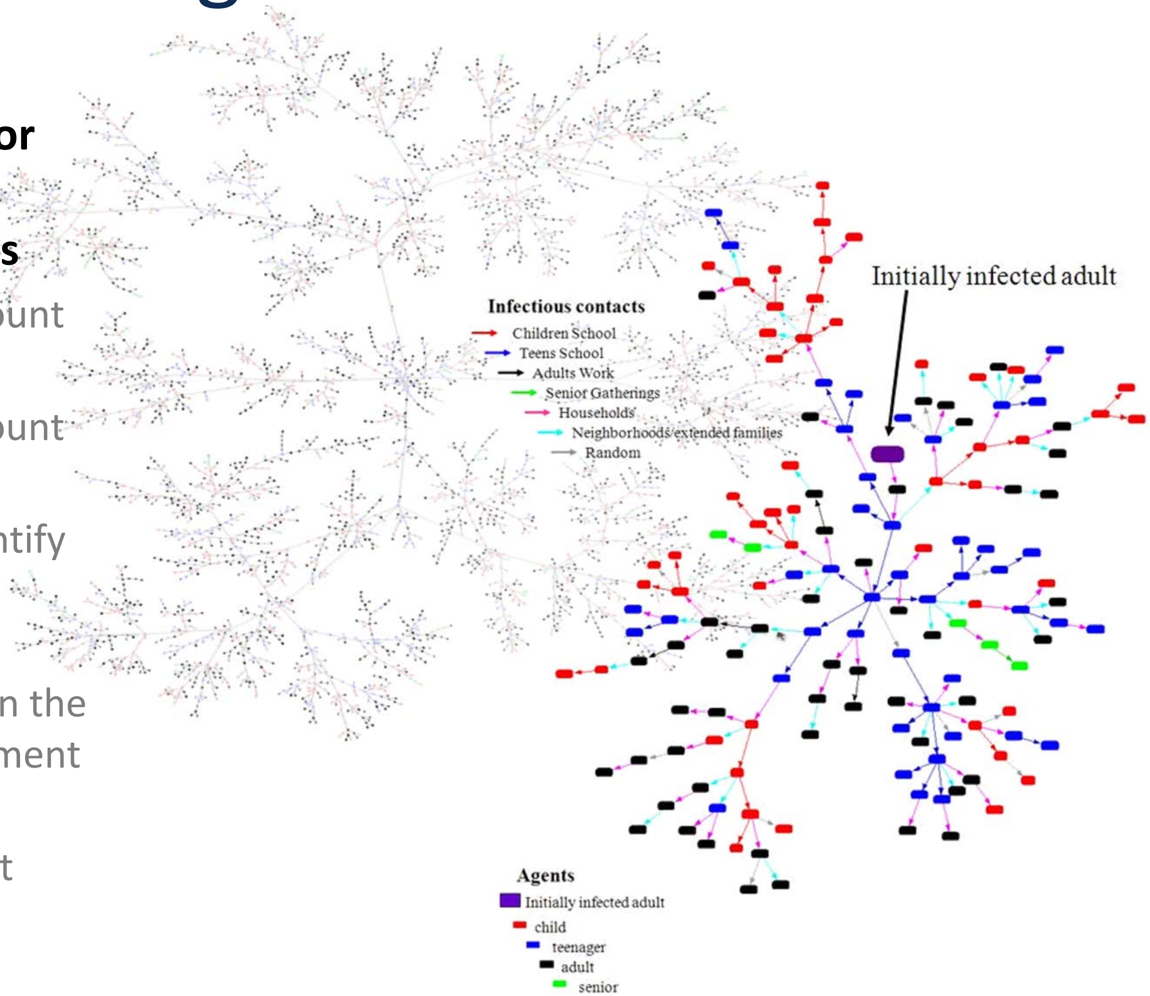

Social Network Interventions


Group Formation and Fragmentation


Means of Predicting Success of Interventions

Social-Networks and Disease Spread: Pandemic Planning

- **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

Social-Networks and Disease Spread: Pandemic Planning

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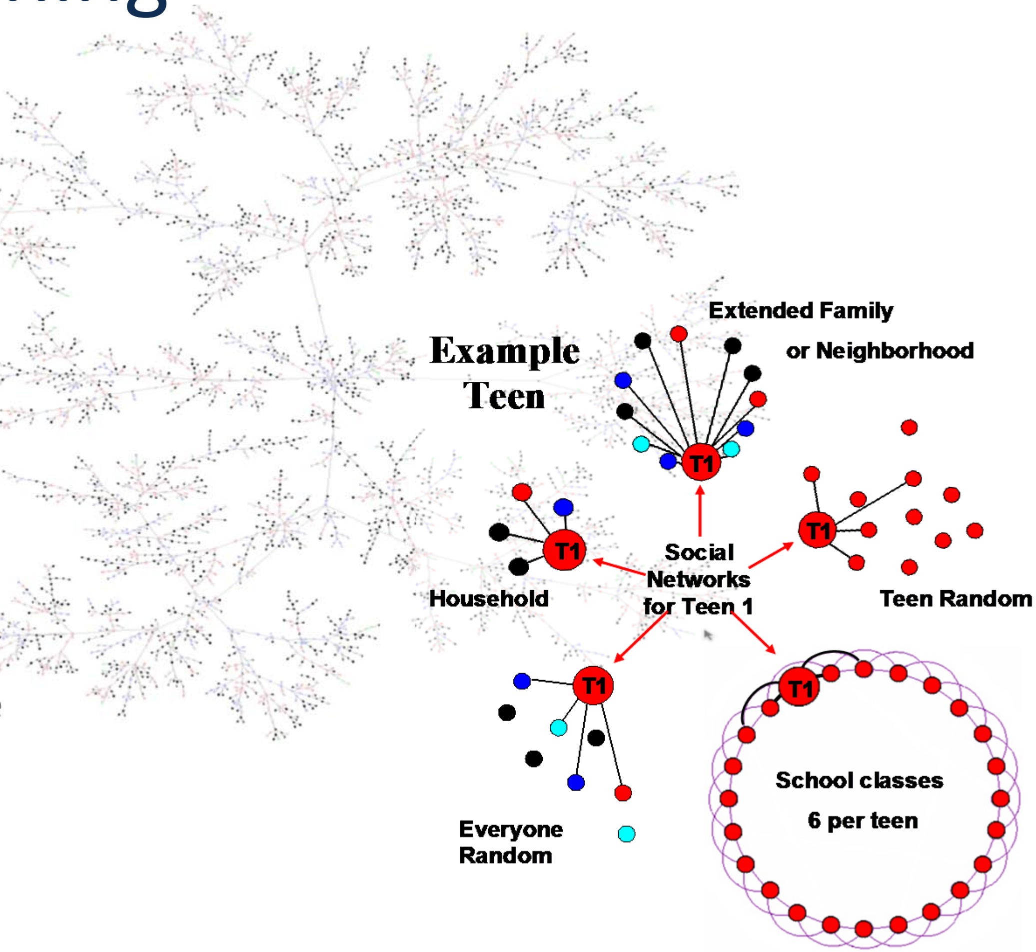

Multiple Social - Networks

Example Application of CASoS Engineering: Pandemic Planning

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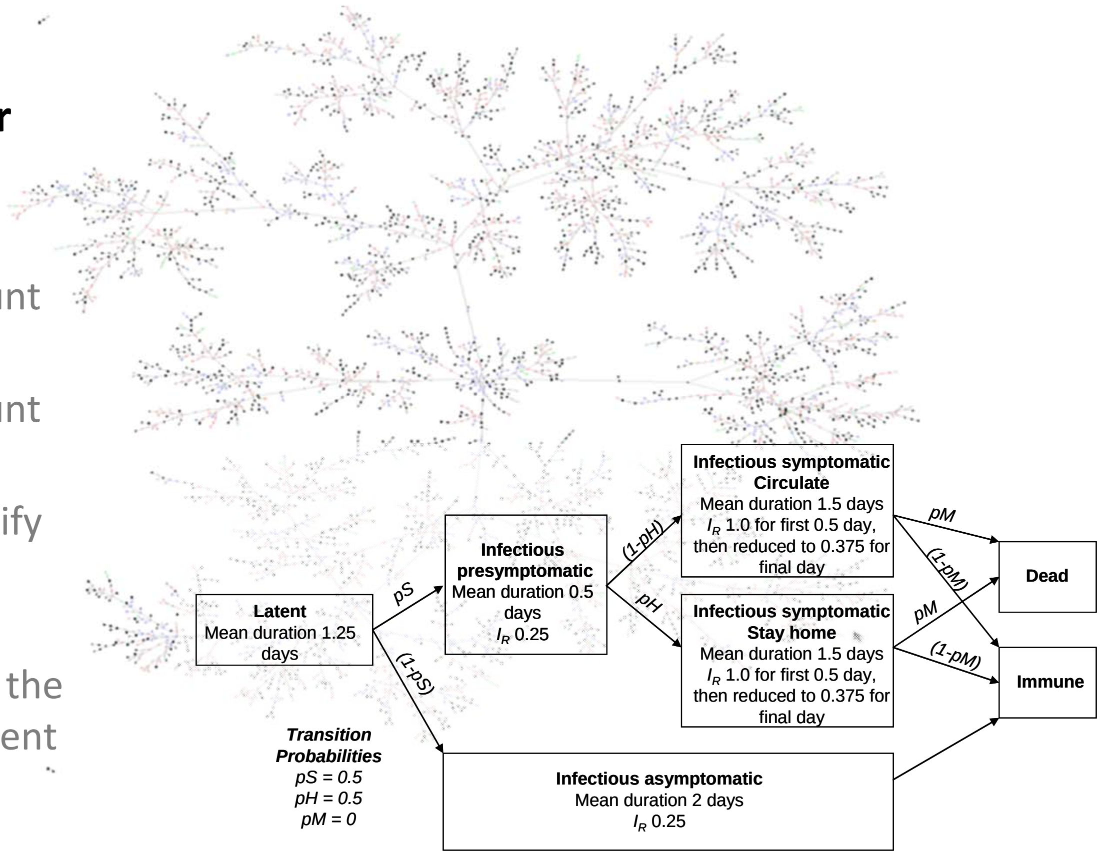

Epidemiological Model (Modified SEIR)

Example Application of CASoS Engineering: Pandemic Planning

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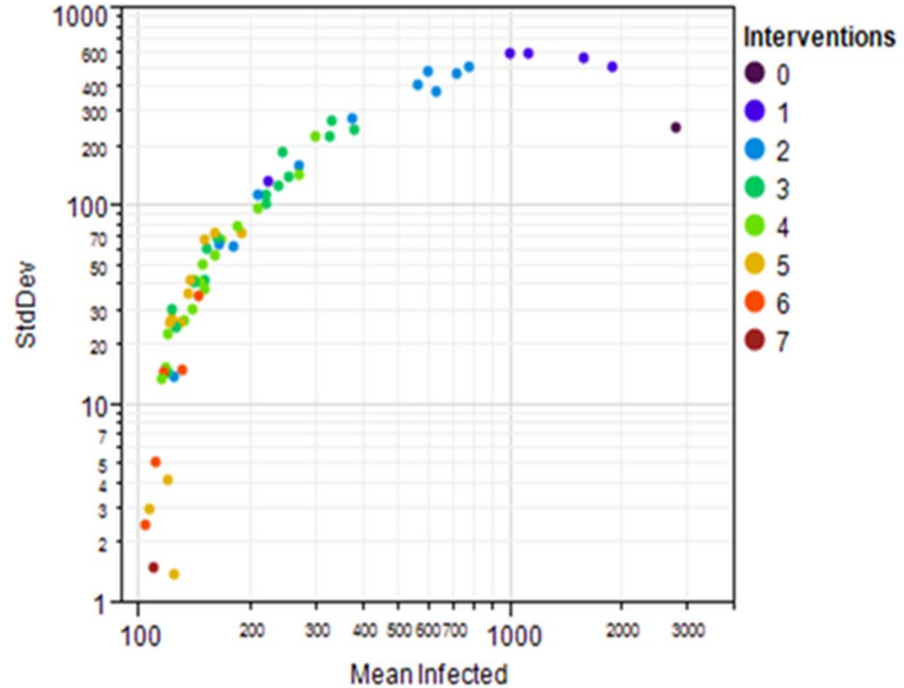

School closure, social distancing (children or adults), treatment, prophylaxis, quarantine, extended prophylaxis

- 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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Example Application of CASoS Engineering: Pandemic Planning

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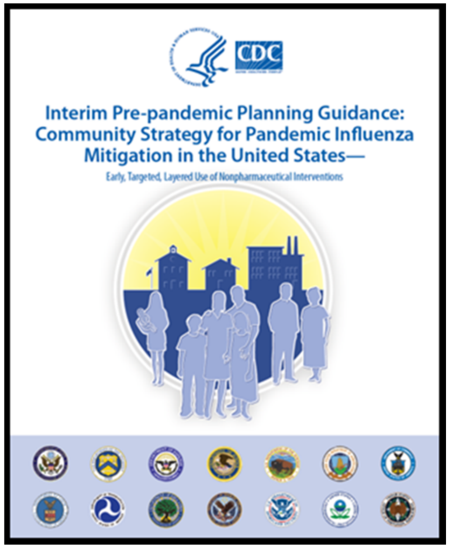
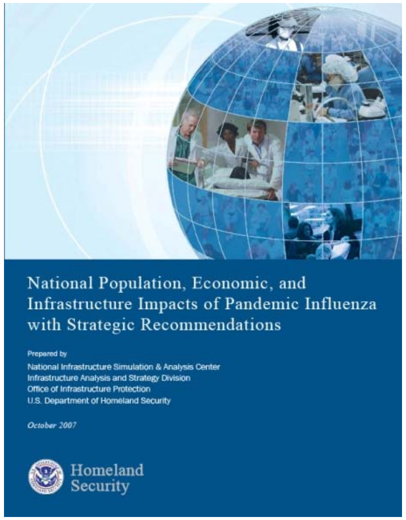




Local Mitigation Strategies for Pandemic Influenza, RJ Glass, LM Glass, and WE Beyeler, SAND-2005-7955J (Dec, 2005).

***Targeted Social Distancing Design for Pandemic Influenza*,** RJ Glass, LM Glass, WE Beyeler, and HJ Min, *Emerging Infectious Diseases* November, 2006.

Design of Community Containment for Pandemic Influenza with Loki-Infect, RJ Glass, HJ Min WE Beyeler, and LM Glass, SAND-2007-1184P (Jan, 2007).

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.

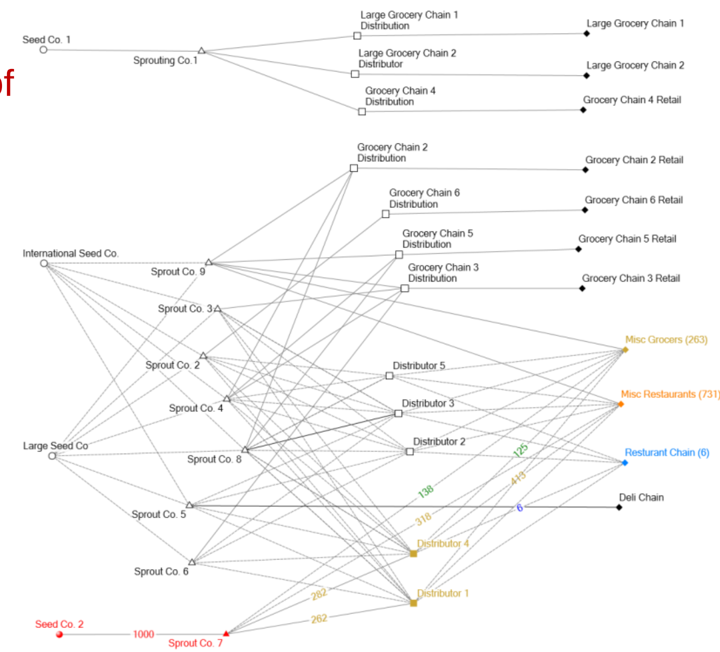
Pandemic Influenza and Complex Adaptive System of Systems (CASoS) Engineering, Glass, R.J., Proceedings of the 2009 International System Dynamics Conference, Albuquerque, New Mexico, July, 2009.

Health Outcomes and Costs of Community Mitigation Strategies for an Influenza Pandemic in the U.S, Perlroth, Daniella J., Robert J. Glass, Victoria J. Davey, Alan M. Garber, Douglas K. Owens, Clinical Infectious Diseases, January, 2010.

Example Policy Application: Food Defense

- Goals:
  - Improve understanding of vulnerabilities
  - Improve contaminant tracing (forward and backward) to reduce population health risks
- Approach:
  - Risk-based analysis
  - Exchange network models to represent supply chain dynamics and interactions
  - Stochastic mapping of conditional probabilities

Forward tracing of contamination produces the conditional probability contamination downstream in the supply chain for a specific contamination event



Backward tracing of contamination produces the conditional 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

Reference:

The Value of Using Stochastic Mapping of Food Distribution Networks for Understanding Risks and Tracing Contaminant Pathways, Stephen H. Conrad, Walter E. Beyeler, Theresa J. Brown, Int. J. Critical Infrastructures, Vol. 8, Nos. 2/3, September 2012, 216-224.

Example Policy Application: National Fuel Networks

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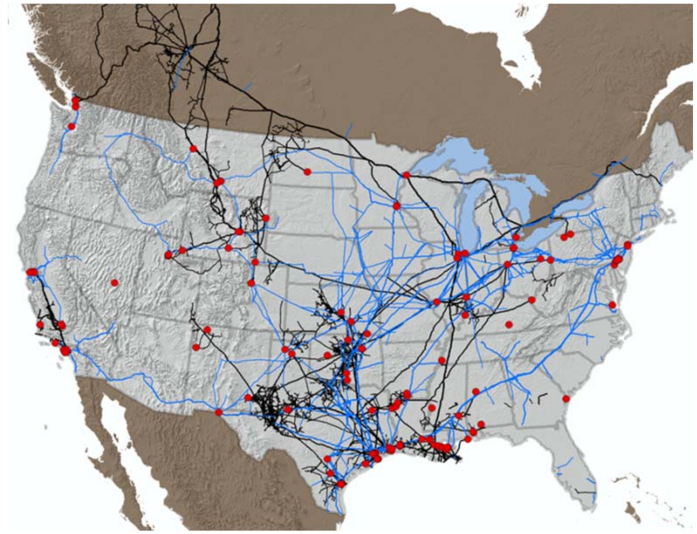
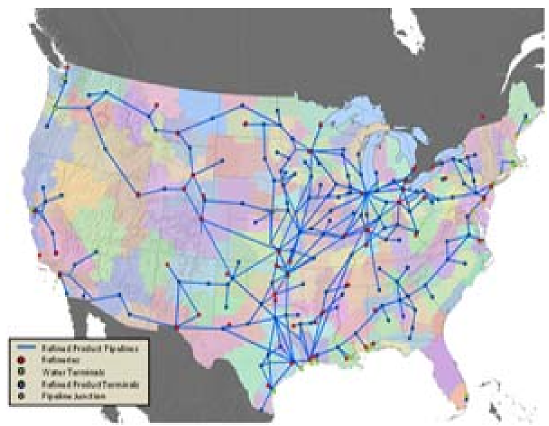
- Goals:
  - understanding risks of specific incidents (hurricanes, earthquakes, equipment failures
  - identifying effective risk mitigations
- Approach:
  - incident and scenario-based analyses
  - national network model
- Developed for the National Infrastructure Simulation and Analysis Center (NISAC) (http://www.sandia.gov/nisac/)





NISAC National Transportation Fuel Model

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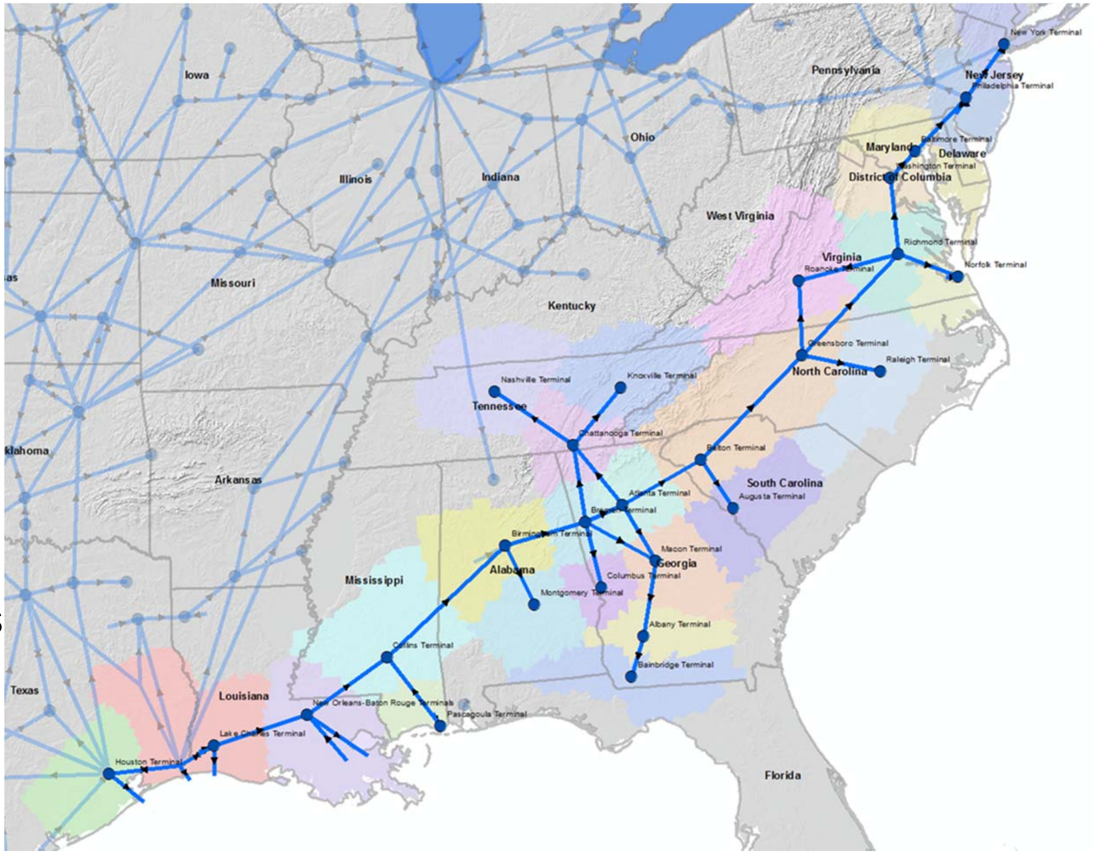
- The functionality of any asset (e.g. pipeline segment, refinery, terminal) can be degraded for any period of time to simulate specific disruptions.
- Each node in the network (e.g., refinery, tank farm, terminal) strives both to meet the demands of consumers and to maintain sufficient stocks of crude or refined products.
- Crude oil or refined products flow toward regions that are experiencing shortages by a diffusion-type process in which knowledge of the shortage propagates throughout the network over time.



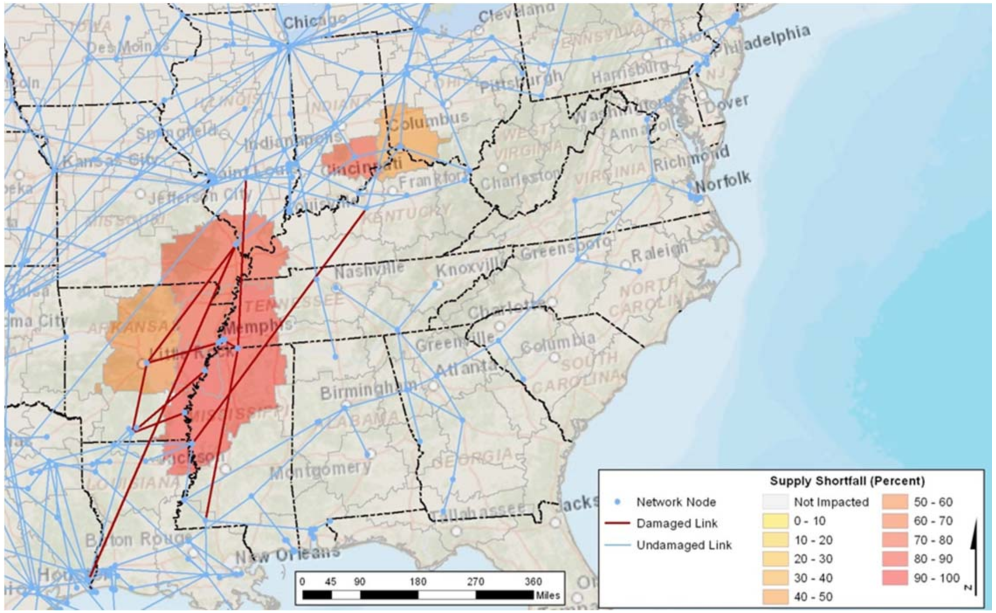
Demand is aggregated at the fuel-terminal service area

Reference:

A Demand-driven, Capacity-constrained, Adaptive Algorithm for Computing Steady-state and Transient Flows in a Petroleum Transportation Network, WE Beyeler, TF Corbet Jr., JA Hobbs (2012) SAND2012-9487.

Example Scenario: Central U.S. Earthquake

- The New Madrid Seismic Zone (NMSZ) stretches along the Mississippi River Valley from southern Illinois to Memphis
- A cluster of very powerful earthquakes occurred during the winter of 1811–1812.
- The U.S. Geological Survey estimates a 7 to10 percent chance of earthquakes with magnitudes equivalent to the 1811–1812 quakes occurring in any 50-year period*
- A similar cluster of earthquakes occurring today would cause extensive damage to oil and gas transmission pipelines



* Reference: USGS, Center for Earthquake Research and Information Fact Sheet 2006-3125).

Summary of the Challenges

- Providing information that is useful
  - Scenario analyses are a way to communicate and identify potential pitfalls
  - Uncertainty quantification is key to risk analysis and designing robust solutions
- Building confidence in CAS models and analyses
  - Analysis outcomes that demonstrate understanding of the potential dynamics
  - Multiple-modeling approaches
  - Uncertainty explicitly represented
  - Identifying feasible solutions that are robust to uncertainty
- Building a community of practice

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QUESTIONS & ANSWERS

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