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CSYS 300 – COMPLEX SYSTEMS FUNDAMENTALS, METHODS & APPLICATIONS

WELCOME, SYLLABUS, EXAMPLES OF COMPLEX SYSTEMS (AND THEIR FAILURES)

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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

Welcome, Syllabus, Examples of Complex Systems (and their Failures)

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Outline of Presentation

- Brief Biographical Note
- Welcome
- What This Class is about
- Syllabus
  - Class Project
- What is a Complex System?
- Examples of Complex Systems
- Examples of Complex Systems Failures
- Understanding Complex Systems
- Summary
- Question & Answer Session

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Brief Biographical Note on Kevin L. Stamber

- BSIE University of Pittsburgh
- MSIE, Ph. D. Purdue University
  - Staff, State Utility Forecasting Group
- Sandia National Laboratories, 1998-present
  - Critical Infrastructure Modeling, Simulation & Analysis
  - DOE Power Outage Study Team (1998-99)
  - National Infrastructure Simulation and Analysis Center (NISAC)
    - Analysis Lead
    - Chemical Supply Chain Modeling
    - Infrastructure Resource Allocation and Prioritization during Incidents (IRAPI)
- Member IIE, INFORMS

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 - lead
  - NISAC - program technical lead
  - NISAC - DIISA modeling lead
  - YMP, GCD and NRC projects – probabilistic risk and performance assessments

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Brief Biographical Note on Stephen D. Kleban

- BA Computer Science University of California, San Diego
- MS Computer Science University of New Mexico
  - Focus on Artificial Intelligence & Machine Learning
- Stanford Linear Accelerator Center
  - Intelligent Beam Line diagnostics
- Sandia National Laboratories, 1993-present
  - Technical Work – 12 years
  - Management – 8 years
- Healthcare and Public Health
- Complex Systems Research Challenge & Complex Systems Institute

CSYS 300 – COMPLEX SYSTEMS FUNDAMENTALS, METHODS & APPLICATIONS

Welcome

- Division 6000 has Four Capability Portfolio Homerooms which includes
  - Global Security of WMD
  - Complex & Intelligent Systems
  - Intersection between Earth and Engineered Environments
  - Energy Systems & The Nuclear Fuel Cycle
- Course is funded by Complex & Intelligent Systems (C&IS) Capability Portfolio Homeroom
  - C&IS Homeroom also funding the workshops discussing a Sandia Complex Systems Institute
- What we hope you take from this class
  - Learn where Complex Systems have a role in Sandia’s National Security Mission
  - Learn where a Complex Systems approach is useful
  - Networking

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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 CSYS300 systems lectures. Please see the initial two lectures for additional detail and expanded references.

CSYS 300 – COMPLEX SYSTEMS FUNDAMENTALS, METHODS & APPLICATIONS

Syllabus

Date	Topic	Instructor(s)	Location
March 18, 2014	Welcome, Syllabus, Overview of Complex Systems (and Complex Systems Failures)	Kevin Stamber/Steve Kleban/Theresa Brown	856/104
March 20, 2014	System Dynamics Fundamentals	Len Malczynski/Asmeret Bier	856/104
March 25, 2014	System Dynamics Applications	Len Malczynski/Asmeret Bier	856/104
March 27, 2014	Agent-Based Modeling Fundamentals Student Project Overview and Examples	Kevin Stamber/Mark Ehlen Kevin Stamber/Steve Kleban	856/104
April 1, 2014	Agent-Based Modeling Applications	Steve Verzi	856/104
April 3, 2014	Optimization: Overview of Linear Programming	Jared Gearhart	880/D48A
April 8, 2014	Optimization: Heuristic Methods and Applications	Nat Brown	856/104
April 10, 2014	(Social) Network Analysis	TBD	856/104
April 15, 2014	System of Systems Modeling Student Project Selection	Hai Le Kevin Stamber	880/D48A*
April 17, 2014	Digital System Analysis	Jackson Mayo	856/104
April 22, 2014	Resilience Theory and Application	Eric Vugrin	856/104

* Session runs 3 PM to 5 PM MT; all others run 3 PM to 4:30 PM MT.

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Syllabus

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Date	Topic	Instructor(s)	Location
April 24, 2014	Social Dynamics	Tom Moore	856/104
April 29, 2014	Serious Gaming	Fred Oppel	856/104
May 1, 2014	Behavioral Influence Assessment	Michael Bernard	856/104
May 6, 2014	BREAK – Prepare for presentations		
May 8, 2014	BREAK – Prepare for presentations		
May 13, 2014	BREAK – Prepare for presentations		
May 15, 2014	BREAK – Prepare for presentations		
May 20, 2014	Student Presentations	Students	880/D48A
May 22, 2014	Student Presentations	Students	856/104

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Class Project

- Teams of three, ideally
- Take one of the subjects discussed in the class
- Apply to a problem in your knowledge space or interest area
- Class lecturers will be available to provide assistance
- Will present as part of one of three student lecture sessions two weeks after final subject matter
  - Session will be by random draw
- Team identification by 1 April
- Project identification by 15 April

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What is a Complex System?

- Many (and often varying) components
- Dynamic Interaction
  - Among components
  - With the "external world"
- Composition and decomposition into hierarchies
- Self-organization into levels with "common" behavior
- From this we can see emergent behavior

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Examples of Complex Systems

- In reality, rather than asking “What is a Complex System?”, the more appropriate question is “What *isn’t* a Complex System?”
- Communities – People – organ systems – organs – cells – DNA
- Infrastructure systems – individual infrastructures – operating elements of infrastructure

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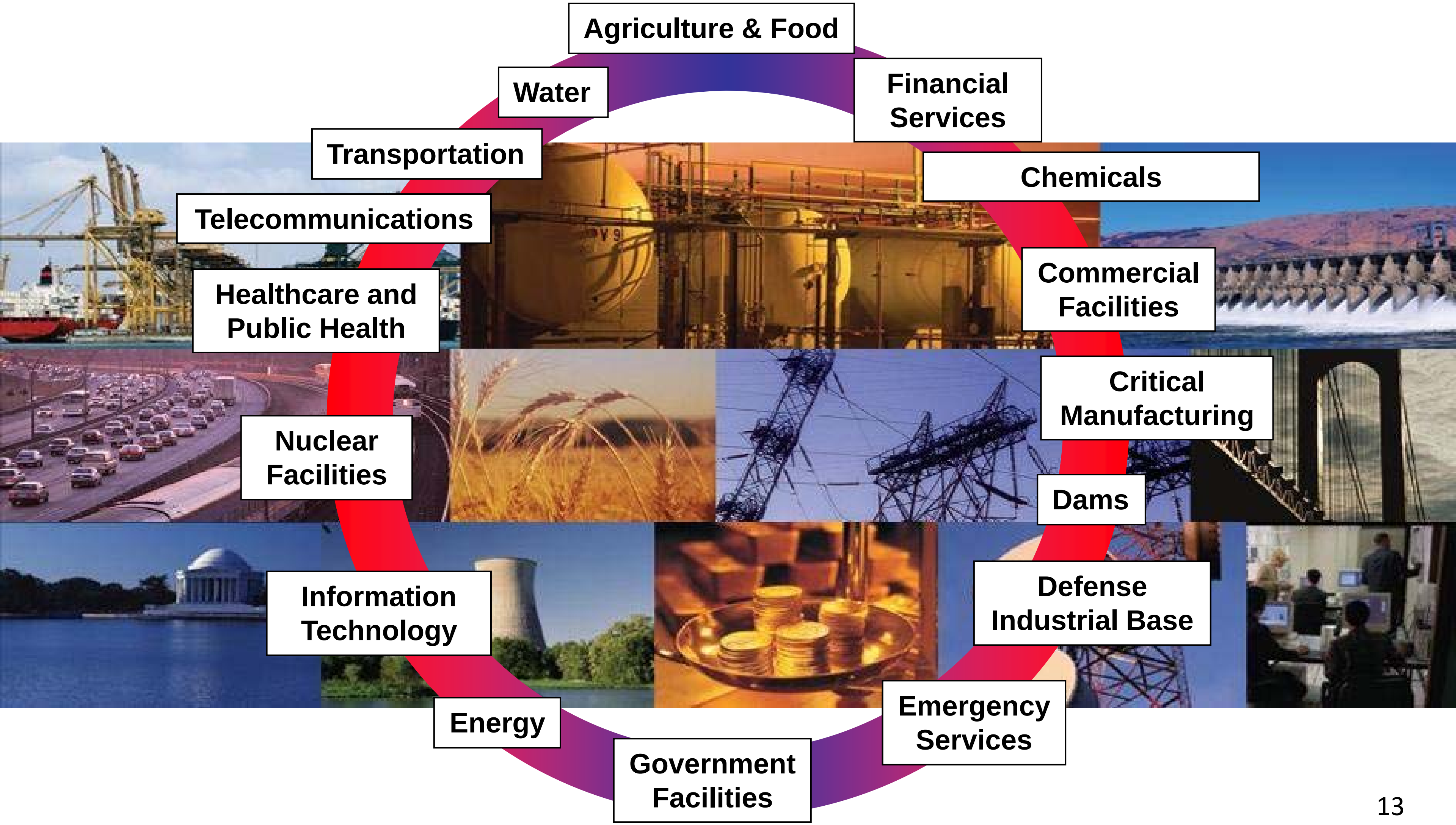
Examples of Complex Systems



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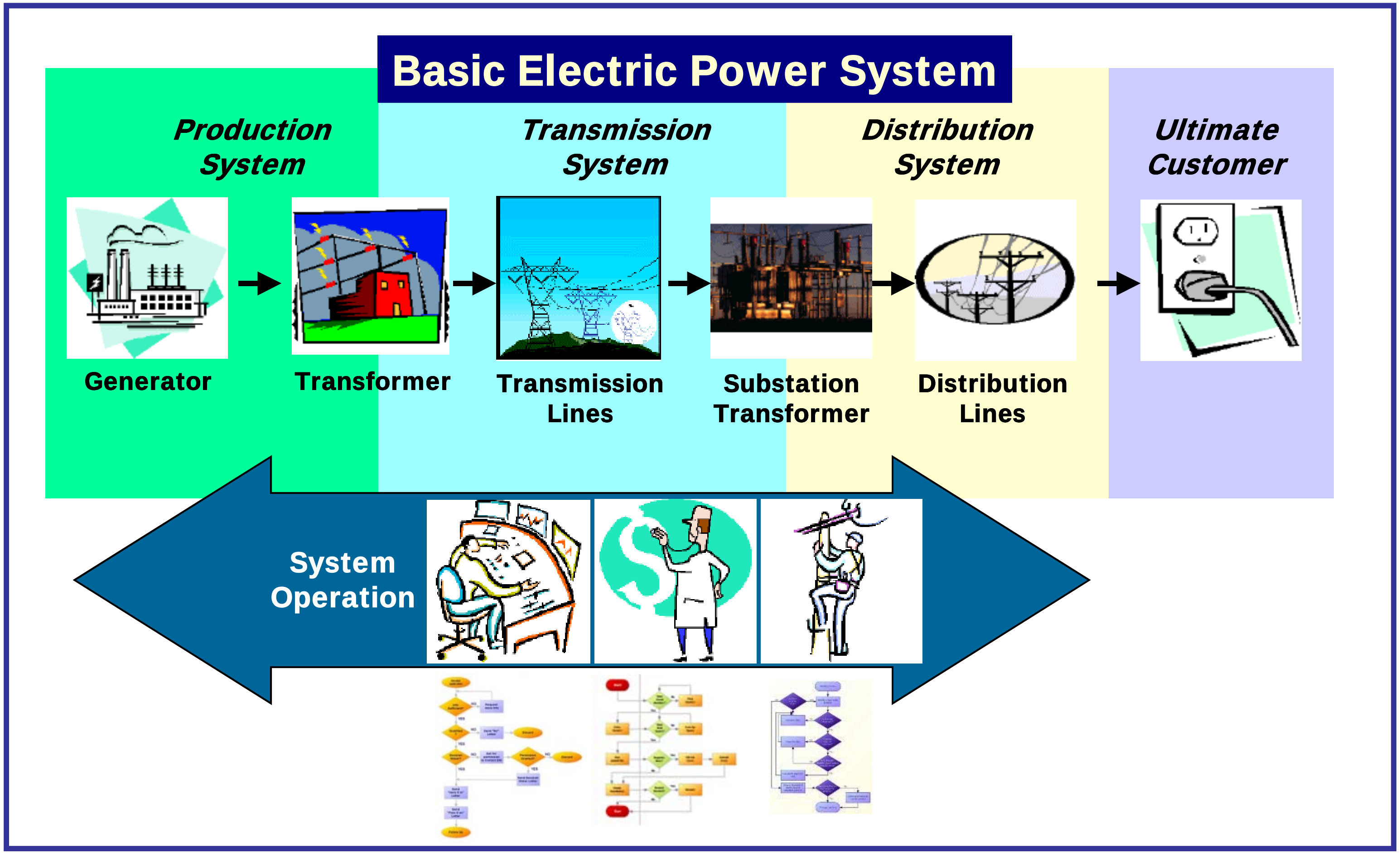
Examples of Complex Systems



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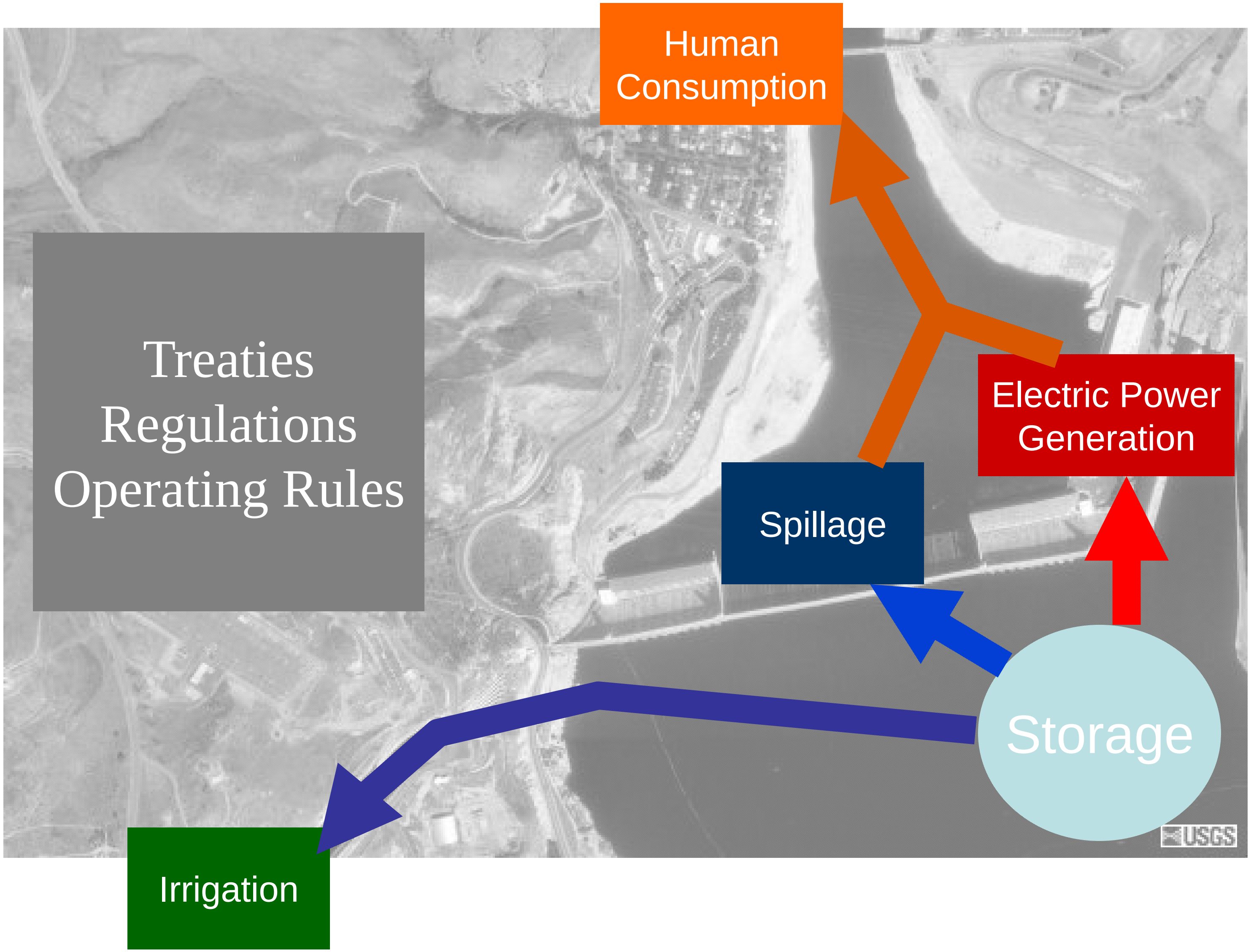
Examples of Complex Systems



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Examples of Complex Systems Failures

NW Airlines Loses Communication

EAGAN, Minn. (AP) -- Northwest Airlines lost most of its communications lines systemwide for about 2 1/2 hours Tuesday when an independent contractor hit a fiber-optic cable, leading to cancellations and delays around the country.

Passengers aboard planes were not in danger, but Northwest temporarily suspended boarding additional flights until the problem was fixed, said spokeswoman Mary Beth Schubert.

About **130 of the airline's 1,700 daily flights were canceled** systemwide, and an undetermined number were delayed. Schubert said communications lines went down just after 2 p.m. CST, affecting reservations and baggage information and the airline's electronic ticketing system.

Major delays were reported in Detroit, where about 30 flights were canceled, according to Northwest spokesman Doug Killian.

Another 19 were canceled in Minneapolis, with the remainder scattered around the system. **Some delays also were experienced in Singapore and Bangkok**, he said.

Northwest's Web site also was out of service because of the severed cable.

Kim Bothun, a spokesman for U S West, the telecom that owns the fiber-optic cable, said the **line was cut by a competitor McLeod USA, a local and long-distance telecommunications company based in Cedar Rapids, Iowa**. She said it is not uncommon for telecommunications companies' cables to be very close to each other.

Calls to McLeod USA were met with a busy signal Tuesday night.

Northwest officials said the airline expected to be back to normal operations by Wednesday morning.

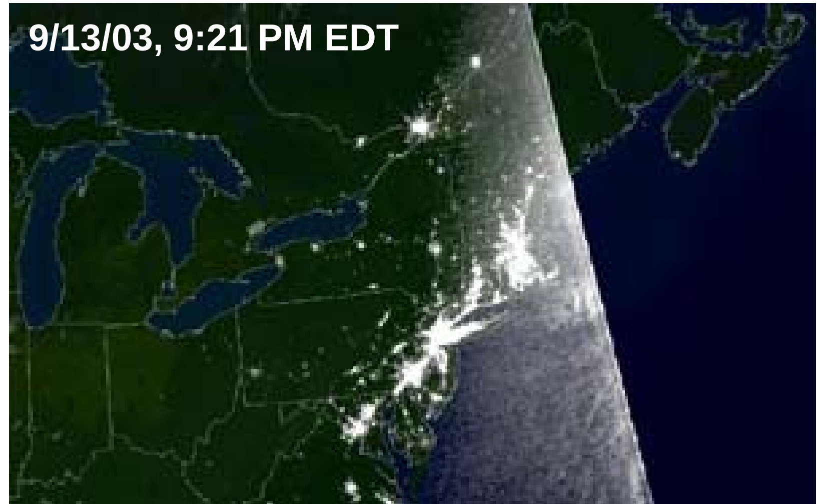
Passengers scheduled to fly on Northwest Tuesday evening were given the option of rescheduling their flights.

Associated Press Archive - March 22, 2000, at http://newslibrary.com

Examples of Complex Systems Failures

- August 14, 2003 Blackout
- 61,800 MW load lost
  - Ohio, Michigan, Pennsylvania, New York, Vermont, Massachusetts, Connecticut, New Jersey, and Ontario
  - Estimated 50 million people affected
- $4 to $10 billion impact in the US

Reference: "The Economic Impacts of the August 2003 Blackout," Electric Consumer Research Council (ELCON), February 2, 2004.



Images: NOAA

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).

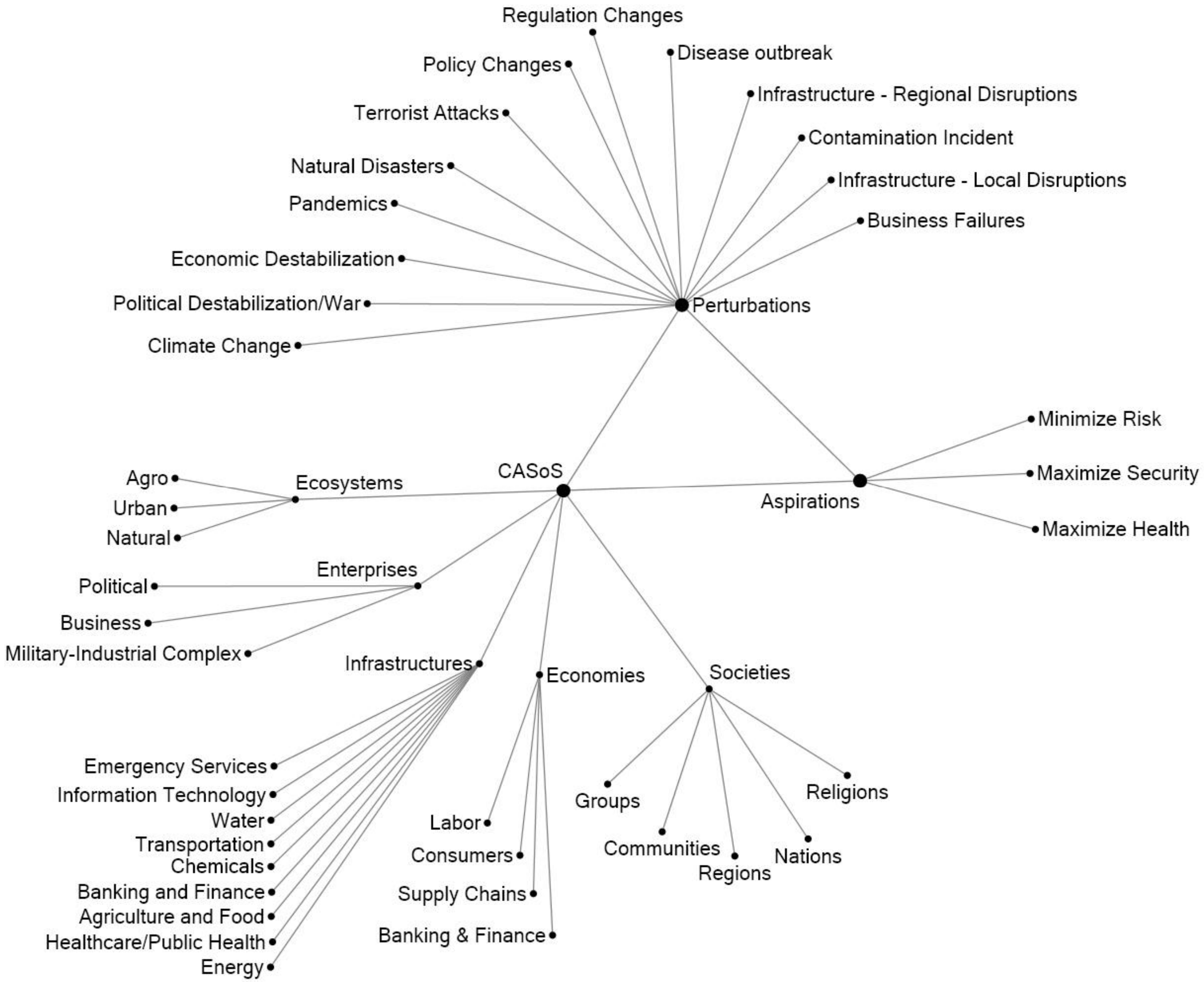
* Reference: A Case for Sandia Investment in Complex Adaptive Systems Science and Technology, Curtis M. Johnson, George A. Backus, Theresa J. Brown, Richard Colbaugh, Katherine A. Jones, Jeffrey Y. Tsao, May 2012 (SAND 2012-3320)

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.

The problem space is broad

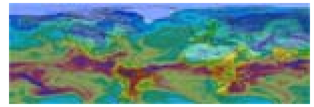


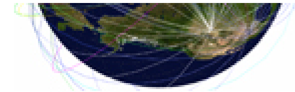
What capabilities do we need in order to solve these problems?

- 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

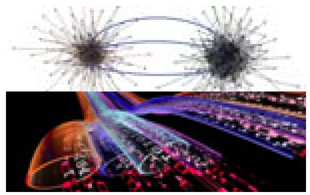
Examples of CASoS Engineering for Policy

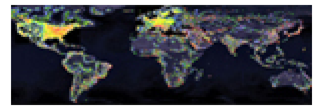

Global Security

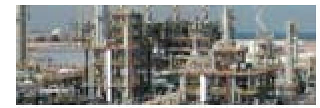

Adaptation to Climate Change impacts


Resource & Exchange Dynamics


Global Financial Systems


Global Payment Systems

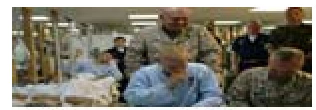

Global Energy System

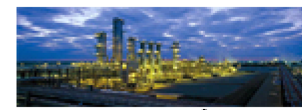

Petrochemical Supply Chains


Food Defense

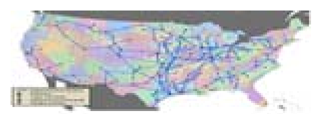

Tobacco Control Policy

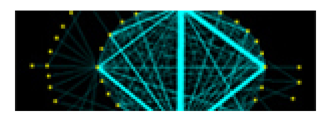

Pandemic Influenza


Veterans Health Threats

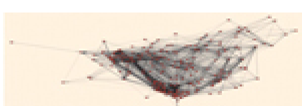

Petrochemical Regulatory Policy

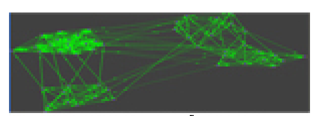

Natural Gas Networks

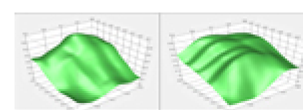

Petroleum Fuels


Congestion and Cascades


Livestock Transfer Risks

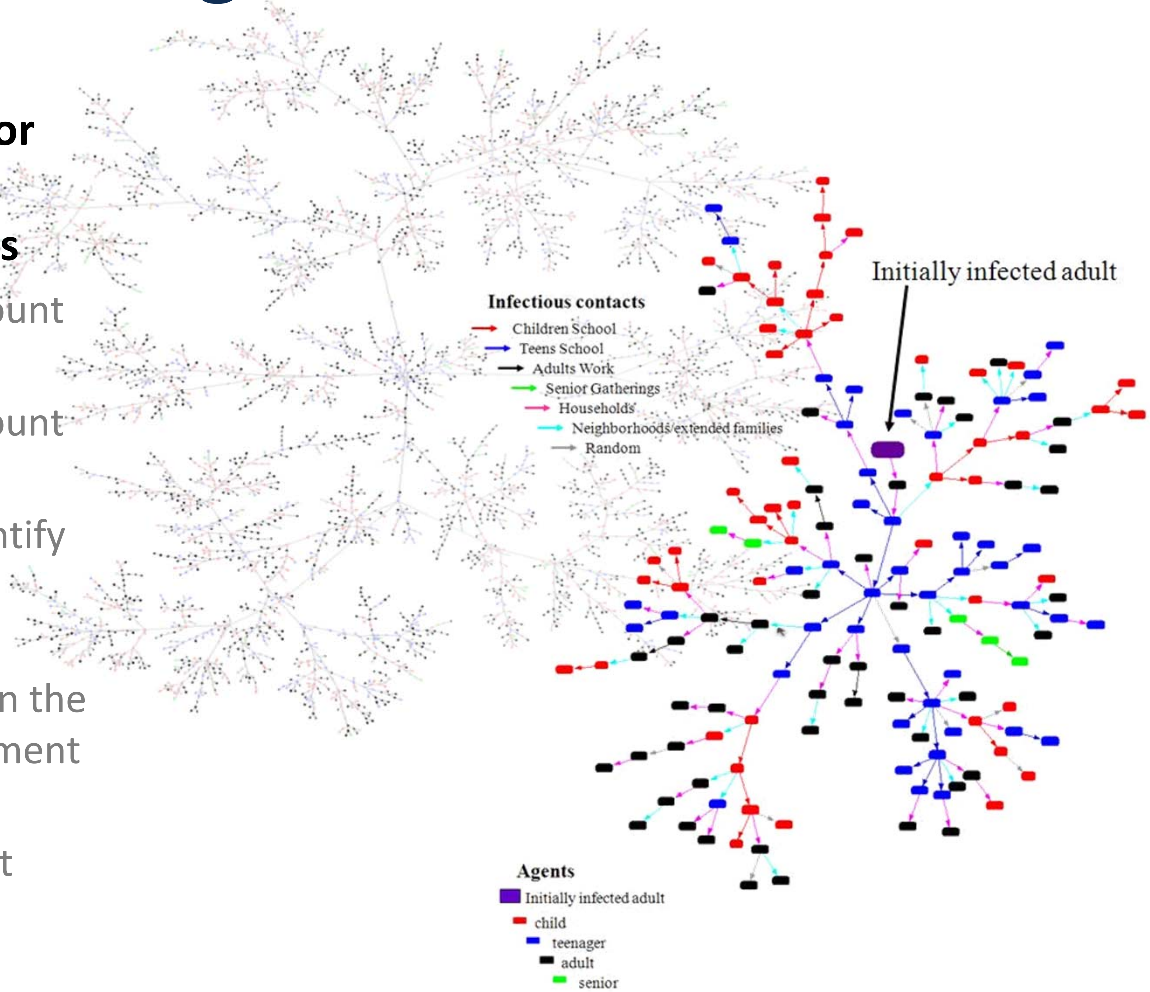

Social Network Interventions


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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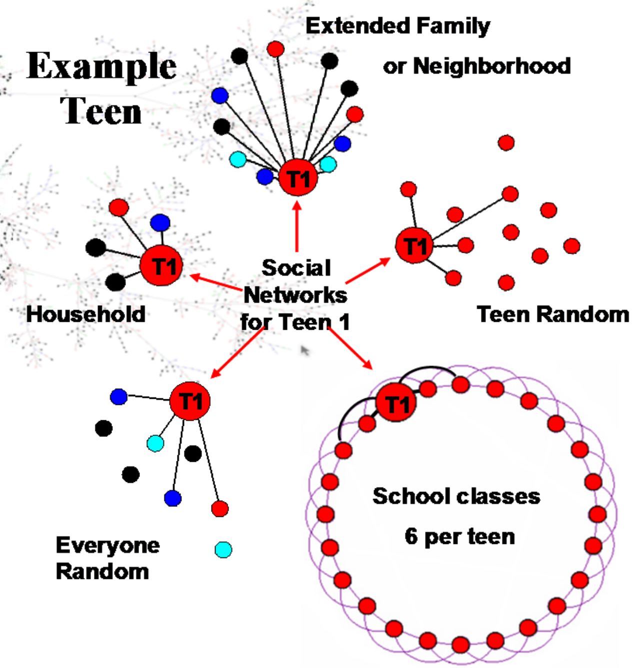

Multiple Social - Networks

Example Application of CASoS Engineering: Pandemic Planning

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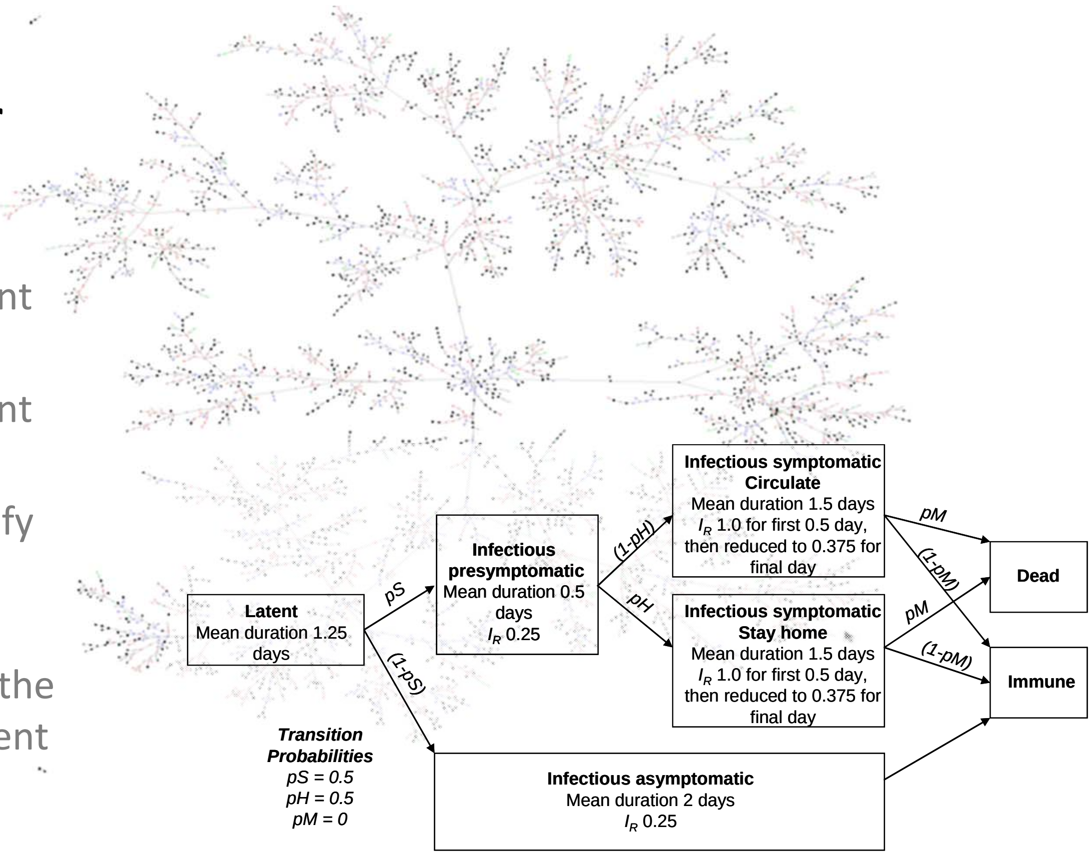

Epidemiological Model (Modified SEIR)

Example Application of CASoS Engineering: Pandemic Planning

- Modeling and analysis processes that account for the dynamics of human-technical-natural systems
- **Explicitly represent and account for uncertainties**
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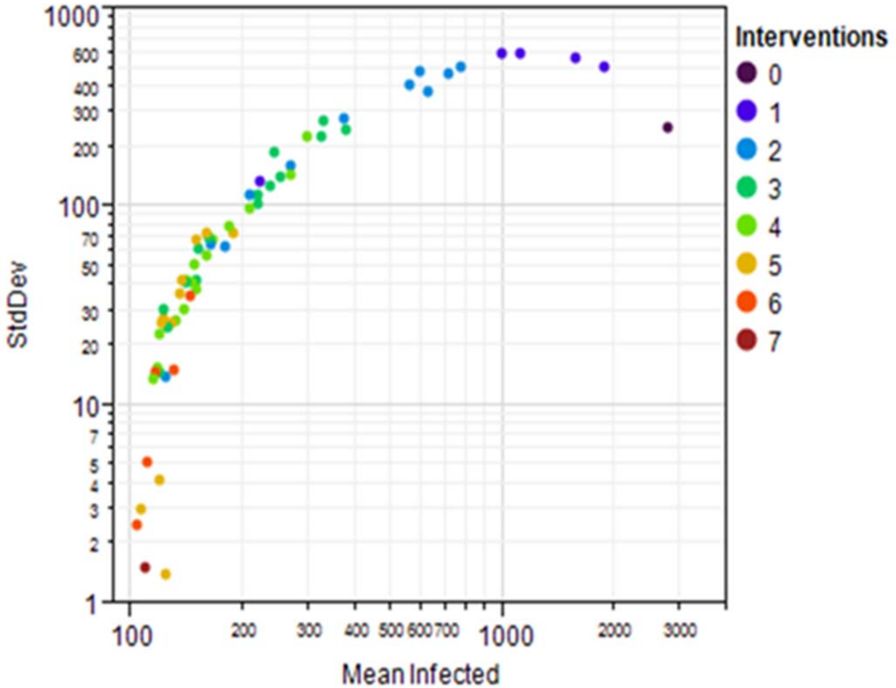

School closure, social distancing (children or adults), treatment, prophylaxis, quarantine, extended prophylaxis

- 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)

Example Application of CASoS Engineering: Pandemic Planning

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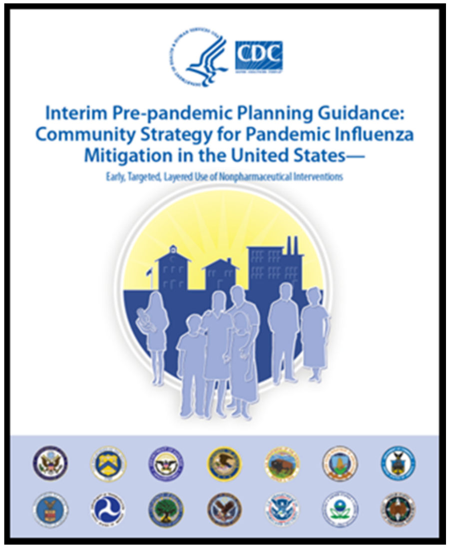
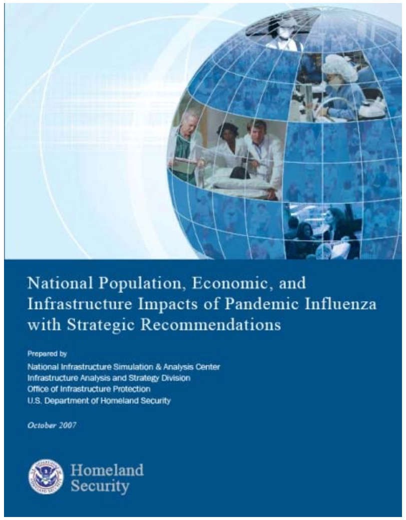
- Modeling and analysis processes that account for the dynamics of human-technical-natural systems
- Explicitly represent and account for uncertainties
- Explicitly represent and account for risk reduction strategies
- Comparative analysis to identify solutions that are robust to uncertainty
- **Decision maker confidence in the analysis and ability to implement the engineered solution**
- **Evaluation and improvement**

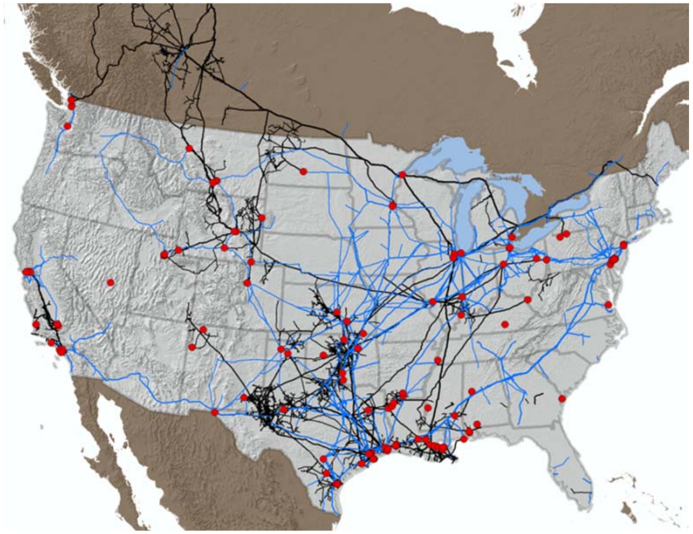


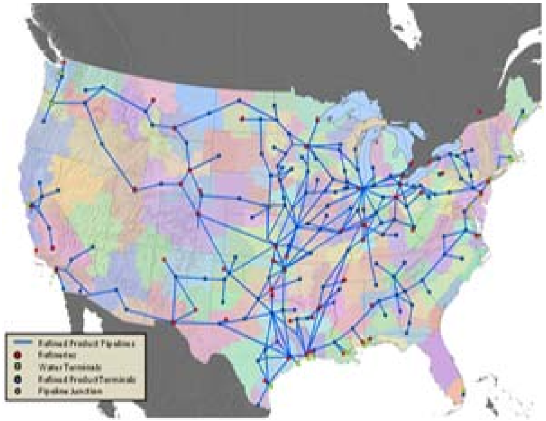


Local Mitigation Strategies for Pandemic Influenza, RJ Glass, LM Glass, and WE Beyeler, SAND-2005-7955J (Dec, 2005).
Targeted Social Distancing Design for Pandemic Influenza**,** RJ Glass, LM Glass, WE Beyeler, and HJ Min, *Emerging Infectious Diseases* November, 2006.
Design of Community Containment 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: National Fuel Networks

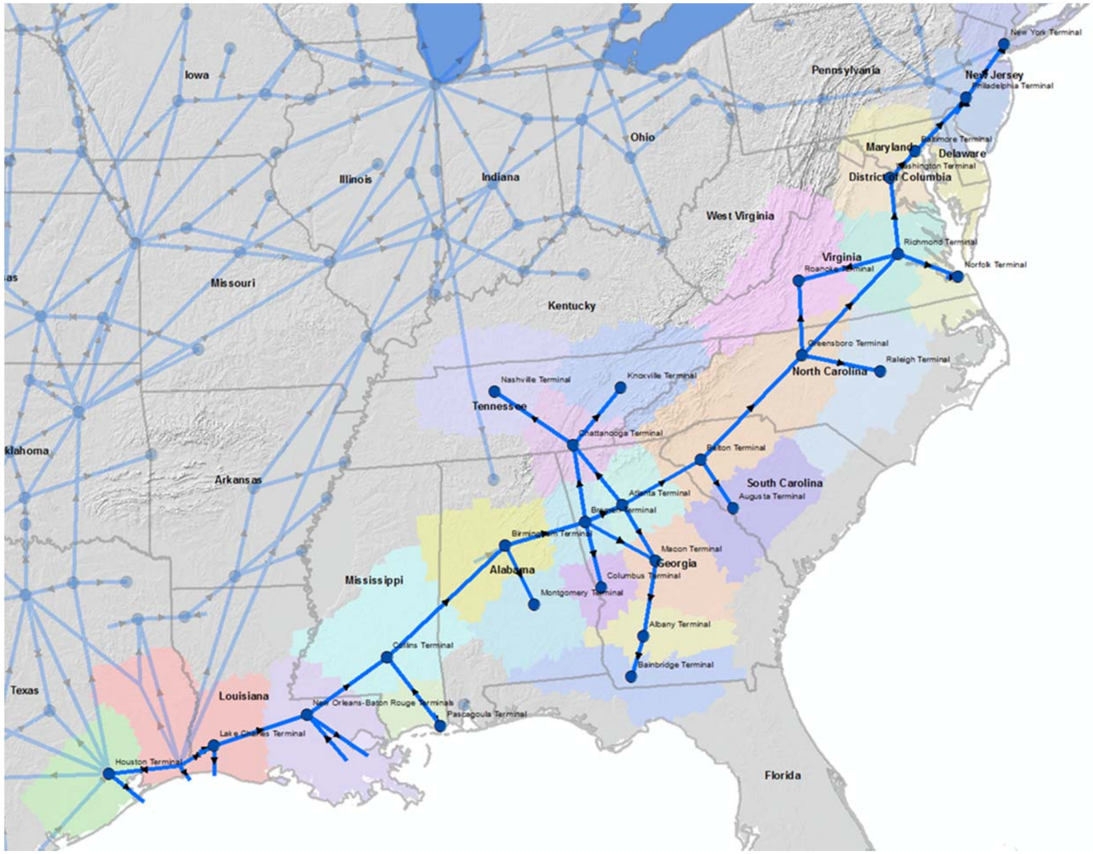
- Goals:
  - understanding risks of specific incidents (hurricanes, earthquakes, equipment failures
  - identifying effective risk mitigations
- Approach:
  - incident and scenario-based analyses
  - national network model
- Developed for the National Infrastructure Simulation and Analysis Center (NISAC)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





NISAC National Transportation Fuel Model

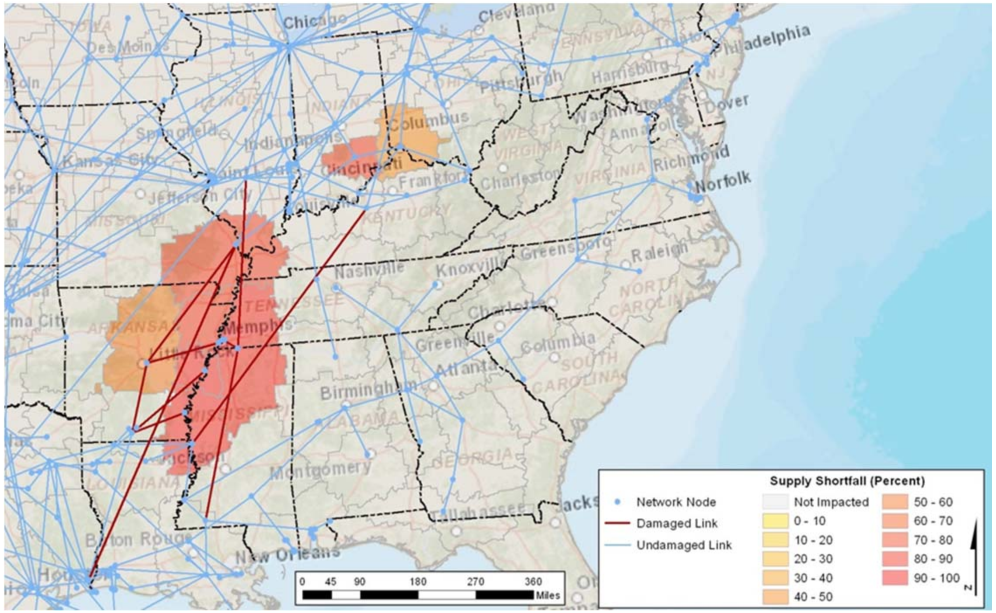
- The functionality of any asset (e.g. pipeline segment, refinery, terminal) can be degraded for any period of time to simulate specific disruptions.
- Each node in the network (e.g., refinery, tank farm, terminal) strives both to meet the demands of consumers and to maintain sufficient stocks of crude 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

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



Projected service area shortfalls

*(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

CSYS 300 – COMPLEX SYSTEMS FUNDAMENTALS, METHODS & APPLICATIONS

Welcome, Syllabus, Examples of Complex Systems (and their Failures)

QUESTIONS & ANSWERS

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