
Robert J Glass
Sandia National Laboratories

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Slides selected from material on:
http://www.sandia.gov/CasosEngineering/
Established by the national laboratories in 2000, NISAC was incorporated into the USA Patriot Act of 2001 and became part of DHS upon its inception in May 2003.

Congress mandated that NISAC serve as a “source of national expertise to address critical infrastructure protection” research and analysis.

http://www.sandia.gov/nisac
Critical Infrastructures:

- Are **Complex**: composed of many parts whose interaction via local rules yields *emergent structure (networks) and behavior (cascades)* at larger scales
- **Grow and adapt** in response to local-to-global *policy*
- **Contain people**
- Are interdependent "**systems of systems**"

Critical infrastructures are -

**Complex Adaptive Systems of Systems: CASoS**

On Halloween (2005) NISAC got a call from DHS. Public health officials worldwide were afraid that the H5NI “avian flu” virus would jump species and become a pandemic like the one in 1918 that killed 50M people worldwide.

DHS asked NISAC to put together a briefing package to prepare DHS Sec Chertoff for a White House table top exercise the second week of December.

_Pandemic NOW._
_No Vaccine, No antiviral._

*Chickens being burned in Hanoi*
Our CASoS Applications in NISAC at the time

- We were applying a generic CASoS approach to power grids, to the movement of funds from bank to bank within the FED’s Fedwire system (2+T a day) and between the ECB’s Target system and Fedwire, to the contagious transfer of ideas and action in settings of civil disobedience...

- In these systems we see cascades of activity, emergence of power-laws for distribution of event sizes vs event frequency, fractals, all the hallmarks of Complex Systems

- In context of these systems, we were interested in questions that had to do with keeping a system from cascading and if it did, defining the right corrective action to dissipate the cascade.
Definition of the CASoS

- **System**: Global transmission network composed of person to person interactions beginning from the point of origin (within coughing distance, touching each other or surfaces…)

- **System of Systems**: People belong to and interact within many groups: Households, Schools, Workplaces, Transport (local to regional to global), etc., and health care systems, corporations and governments place controls on interactions at larger scales…

- **Complex**: many, many similar components (Billions of people on planet) and groups

- **Adaptive**: each culture has evolved different social interaction processes, each will react differently and adapt to the progress of the disease, this in turn causes the change in the pathway and even the genetic make-up of the virus

**HUGE UNCERTAINTY**

*How could we avert the carnage?*
Analogy with other Complex Systems

Simple analog:

- **Forest fires**: You can *build fire breaks* based on where people throw cigarettes... or you can *thin the forest* so no that matter where a cigarette is thrown, a percolating fire (like an epidemic) will not burn.

Problem Definition:

- Could we target the social network within individual communities and thin it?
- Could we thin it intelligently so as to minimize impact and keep the economy rolling?

Focus on Local Community Mitigation
A Conceptual Lens for CASoS Modeling

Take any system and Abstract as:

- Nodes (with a variety of “types”)
- Links or “connections” to other nodes (with a variety of “modes”)
- Local rules for Nodal and Link behavior
- Local Adaptation of Behavioral Rules
- “Global” forcing, Local dissipation

Connect nodes appropriately to form a system (network)

Connect systems appropriately to form a System of Systems

Lumped to discrete
System dynamics to agent based
Infinite to Finite State machines

Hybrid
Stylized Social Network
(nodes, links, frequency of interaction)

Disease manifestation based on data from the literature
(node and link behavior)

Example Teen
Extended Family
or Neighborhood

Social Networks for Teen 1

Household

Teen Random

Everyone Random

School classes
6 per teen

Latent
Mean duration 1.25 days

Infectious presymptomatic
Mean duration 0.5 days
IR 0.25

Infectious symptomatic
Circulate
Mean duration 1.5 days
IR 1.0 for first 0.5 day,
then reduced to 0.375 for final day

Infectious symptomatic
Stay home
Mean duration 1.5 days
IR 1.0 for first 0.5 day,
then reduced to 0.375 for final day

Infectious asymptomatic
Mean duration 2 days
IR 0.25

Transition Probabilities
pS = 0.5
pH = 0.5
pM = 0

Immune

Dead

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6 of 10 seeds developed secondary infections

1 seed created the epidemic

We ran the model and it hit the numbers by age class from past pandemics when single overall “infectivity” of the disease tuned to yield the attack rate. We had representative node and link behavior and contact network; we had the right “physics”.
Network of Infectious Contacts

Adults (black)
Children (red)
Teens (blue)
Seniors (green)

Children and teens form the Backbone of the Epidemic
Closing Schools and Keeping the Kids Home

**ID Factor 1.0**

- **Unmitigated**: The number of infected individuals increases rapidly, reaching a peak in the first 20 days and then gradually declining.
- **Closing Schools**: The peak is significantly reduced compared to the unmitigated scenario.
- **50% Compliance**: The peak is further reduced compared to both unmitigated and closing schools.
- **100% Compliance**: The peak is further reduced compared to both 50% compliance and closing schools.

**ID Factor 1.5**

- **Unmitigated**: Similar to ID Factor 1.0, the peak is reached in the first 20 days and then declines.
- **Closing Schools**: The peak is reduced compared to the unmitigated scenario.
- **50% Compliance** and **100% Compliance**: The peaks are further reduced compared to closing schools.
• Sec Chertoff briefed, open release SAND report written.
• White House table top: everyone several steps behind our thinking, fixated on closing borders, etc. Closing borders = building fire breaks. *They don’t solve the problem.*
• Big names in epidemiology modeling the movement of the disease across the US with massive models at LANL and in Great Britain (published rapidly in Science and Nature) suggested there was little that could be done. The pandemic would wash over the US without antivirals.

*But their tools were not built to consider the intricacies of the underlying social network on which the pandemic would spread in a local community.*
Getting our results used…

- We needed to **INFLUENCE PUBLIC POLICY** and quickly.
- I submitted to **Science**… Rejected
- I tried to enlist the help of **the big names** in the field… they didn’t reply.
- I then decided to use the **informal social-influence network** instead of the command and control hierarchy to get our work to the critical nodes with control.
- I sent our SAND report to a **acquaintance** at the VA who sent it to a **colleague** who was the VA’s rep on the White House Homeland Security Council (HSC) Pandemic Implementation Plan Writing Team, who sent it to the **team lead** who sent it to the **Senior Director for Biodefense Policy, HSC**.

Four Degrees of Separation!
I got on a plane and after a 4 hour presentation-interrogation-brain storming session, the HSC team and I had changed the course of public policy and started an avalanche of activity.
Identified critical questions/issues and worked with us to answer/resolve them

• How sensitive were results to the social net? Disease manifestation?
• How sensitive to compliance? Implementation threshold? Disease infectivity?
• How did the model results compare to past epidemics and results from the models of others?
• Is there any evidence from past pandemics that these strategies worked?
• What about adding or “layering” additional strategies including home quarantine, antiviral treatment and prophylaxis, and pre-pandemic vaccine?

ALL IN THREE WEEKS
We extended the model and put it on Sandia’s 10,000 node computational cluster... 10’s of millions of runs later we had the answers to:

- What is the best mitigation strategy combination? (choice)
- How robust is the combination to model assumptions? (robustness of choice to model uncertainty)
- What is required for the choice to be most effective? (critical enablers of system resilience)

Meanwhile a set of parallel efforts were set in motion…

• Our original report **expanded and published** in Emerging Infectious Diseases (Glass et al., 2006).

• **Targeted Layered Containment or “TLC”** was socialized across a set of critical governmental departments and institutions by the HSC-PIP team.

• Our **results were evaluated and corroborated** by modelers within the Models of Infectious Disease Agents Study (MIDAS) group funded by NIH (Halloran et al., 2008).

• **Triggers and whistles** were systematically evaluated with the Deputy Chief Officer of OPHEH (Davey et al., 2008a).

• **Epidemiological Forensics** were applied to previous pandemics to determine if community mitigation measures were effective (Hatchett et al., 2007; Markel et al., 2007)

• A comprehensive survey-based method applied to characterize the **social contact network of school aged children and teenagers** (Glass and Glass, 2008).

• A comprehensive study of the influence of pandemics on **critical infrastructure and the economy** was conducted (NISAC, 2007).
• In October, 2006 the Institute of Medicine conducted a review (IOM 2006a,b).

• On February 1, 2007 issued “Interim Pre-Pandemic Planning Guidance: Community Strategy for Pandemic Influenza Mitigation in the United States--Early, Targeted, Layered Use of Non-pharmaceutical Interventions”

And then came H1N1 (2009)…

For Details see:
• 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.
• Rescinding Community Mitigation Strategies in an Influenza Pandemic, VJ Davey and RJ Glass, Emerging Infectious Diseases, March, 2008.
Summarizing the main points

• We were dealing with a large complex adaptive system, a CASoS: a global pandemic raging across the human population within a highly connected world (social, economic, political)

• By similarity with other such systems, their problems, their solutions, we
  - defined **THE CRITICAL PROBLEM** for the pandemic
  - applied a **GENERIC APPROACH** for simulation and analysis
  - came up with a **ROBUST SOLUTION** that would work with minimal social and economic burden independent of decisions made outside the local community (e.g., politics, borders, travel restrictions).

• Through recognition that the **GOVERNMENT’s** global pandemic preparation was a CASoS, we
  - used CASoS concepts (social net, influence net, people) to **INFLUENCE PUBLIC POLICY** in short time. These concepts continue to be used by the HSC folks to implement the policy that we identified. And work continues…
• Harnessing the tools and understanding of Complex Systems, Complex Adaptive Systems, and Systems of Systems to Engineer solutions for some of the worlds biggest, toughest problems:

The CASoS Engineering Initiative

And our Web site at: http://www.sandia.gov/CasosEngineering/

• Current efforts span a variety of Problem Owners:
  - DOE, DHS, DoD, DVA,
  HHS, FDA and others

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Complex Adaptive System of Systems (CASoS) Engineering

2008: CASoS Engineering Pilot: Phoenix

New Applications

New Tools

New Theory, Methods and Approaches

FRAMEWORK

THEORY

APPLICATIONS

Tool Boxes
- Data
- Analysis
- Visualization
- Modeling
- Uncertainty quantification
- V&V

High performance computing resources
Detailed data driven to abstract
Situational awareness to policy definition

ENVIRONMENT

- System Definition
- Aspirations
- Conceptual Modeling
  - Analogy, Similarity
  - CA, ODE, PDE, SD ...
  - Networks, Adaptive Entities
- Solution Design
- Solution Evaluation
  - Robustness of choice
  - Enablers of Resilience
- Actualization

WIKI & LIVING DOCUMENTS:
- Phoenix
- Framework
- Environment
- Applications
Global Aspirations

Images: The Economist magazine, 2010-2011
Building a Taxonomy of Aspirations

From an engineering perspective, *Aspirations* fall into a set of clearly identified categories:

- **Predict** the evolution of the system and, in particular, the results of events (e.g., perturbations of a variety of qualities and quantities) with direct and consequential changes in system health.
- **Prevent or Cause** an event to occur.
- **Prepare** elements of the system for impending events (e.g., minimize/maximize influence).
- **Monitor** important aspects of a system to record the response of the system to events.
- **Recover or Change** in response to events.
- **Control** system behavior to avoid or steer the system towards specified regimes through the design of appropriate incentives and feedback.

→ Design a *CASoS Solution*. 
Building a CASoS Engineering Framework to Define and Solve Problems

Defining
- Define CASoS
- Define Aspirations
- Define Conceptual Model
- Test Aspirations

Problem Definition

Designing & Testing Solutions
- Design Detailed Solutions
- Define Detailed Models
- Characterize Models
- Test Solutions
- Compare Solutions Under Uncertainty

Design Solutions

Actualizing
- Field Solution
- Monitor Attainment

Monitor Attainment

Conceptual Model Definition

Problem Definition

Define Aspirations

Define CASoS

Test Aspirations

Define Detailed Models

Define Detailed Solutions

Characterize Models

Test Solutions
Building a Taxonomy of Problems and their Solutions

Complex Adaptive System of Systems (CASoS) Engineering

Economic Destabilization
- Political Destabilization/War
- Pandemics
  - Natural Disasters
  - Terrorist Attacks
  - Business Failures
  - Infrastructure - Local Disruptions
  - Contamination Incident

Perturbations
- Disease outbreak
- Infrastructure - Regional Disruptions

CASoS
- Ecosystems
- Enterprises
- Infrastructures
- Global Supply Chains
- Geopolitical Systems
- Global Economy
- Energy
- Chemicals
- Banking and Finance
- Agriculture and Food
- Transportation
- Emergency Services
- Healthcare/Public Health
- Information Technology
- Nuclear
- National Security
- Commercial Manufacturing
Audacious: Trans-Spectrum Global Security

Trans-Spectrum Global Security is intrinsically Trans-Scale and Trans-Network

- **Trans** is a Latin noun or prefix, meaning "across", "beyond" or "on the opposite side".
- **Trans Spectrum** is intrinsically Trans-Network: there are influence/consumption/production supply networks for each productive entity/sector/scale and they are combined into a single network that transcends the multi-network view.
- **Global Security** is Trans-Scale: security is recognized to cross multiple scales: communities, regions, states, nations, groups of nations, global (for government), or similar progressions for other spectra components such that it security maintained at all scales (scale independent).

• Global eco-socio-economic interdependent CASoS
• Evaluate System “Health” or “Goodness” in context Perturbations and Stressors (e.g., climate, energy, food, nuclear and conventional exchanges)
• Evaluate and Design policy that enhances system resilience and decreases risk
Sector and National “Health” in context of finite energy shocks

Configuration is perfectly symmetrical, but many realizations show spontaneous differentiation in which resources are produced at different rates and health differs across classes.

A disruption (here random removal of some resource A) can have large and long-term consequences even if it is very brief.

Disruptions beyond a certain severity are fatal to the system.