

**Pandemic Influenza and
Complex Adaptive System of Systems
(CASoS) Engineering**

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I present the story of my and colleagues' involvement in formulating the US's policy for mitigating pandemic influenza culminating in the Centers for Disease Control and Prevention's issuance of Interim Pre-Pandemic Planning Guidance in February 2007. Modeling lies at the heart of this formulation, but interaction, drive, serendipity, hard work, and advocacy for the use of models to select robust policy in the face of great uncertainty were required for its actualization. Reflecting on this entire process, and others in which high impact influence has been achieved, has led myself and colleagues to the recognition that nearly all the systems we wish to influence can be categorized as Complex Adaptive Systems of Systems or *CASoS* and that our field of endeavor is *CASoS Engineering*.

The Pandemic Story

Almost 4 years ago on Halloween 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



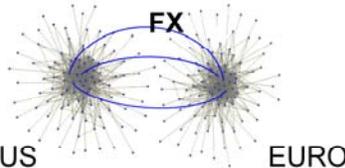
The Pandemic story:

-Two years ago on Halloween 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 wanted NISAC to put together a briefing package to prepare DHS Sec Chertoff for a White House table top exercise the second week of December.



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.



US EURO



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-Now, back to Halloween.



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





Conceptual Lens for Modeling/Thinking

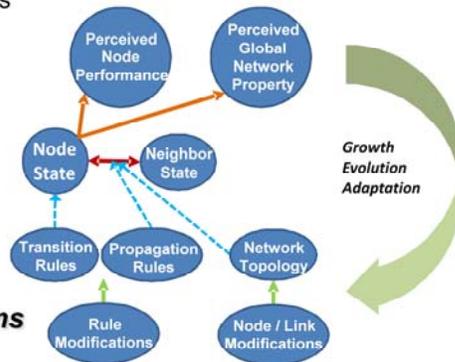
Take any system and Abstract as:

- 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

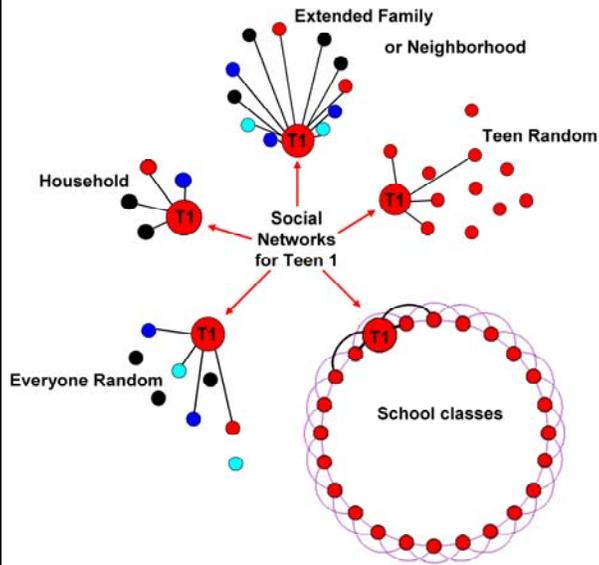
Connect nodes appropriately to form a system (network)

Connect systems appropriately to form a System of Systems

“Caricatures of reality” that embody well defined assumptions



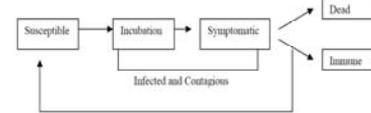
Lara Glass's Studies (2005 INTEL Science Fair)



Social Network from expert elicitation

- Links per group
- Group network structure
- Frequency of contact based on time in group

The progression of the disease in a person goes as follows:

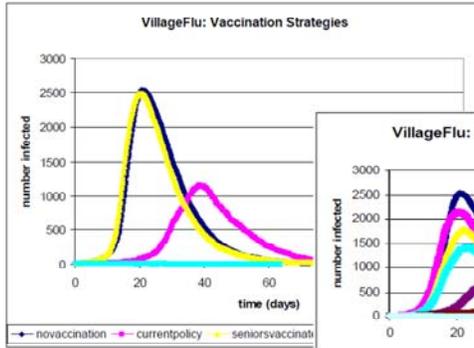


Simple Disease Manifestation

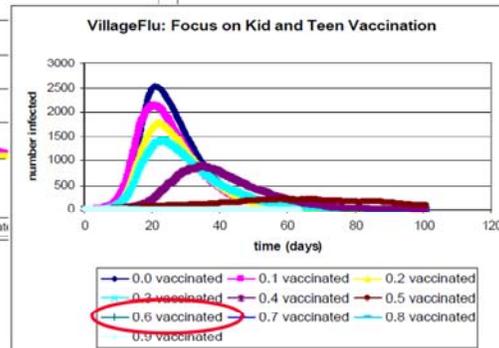


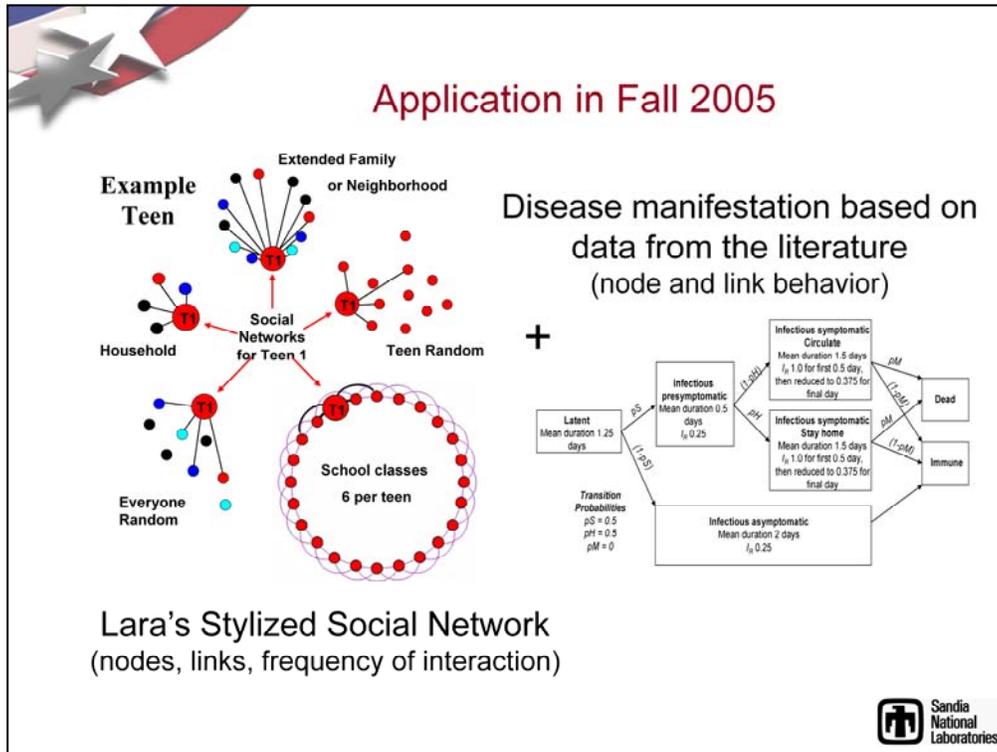


Lara's results for "whom to vaccinate when vaccine is scarce"

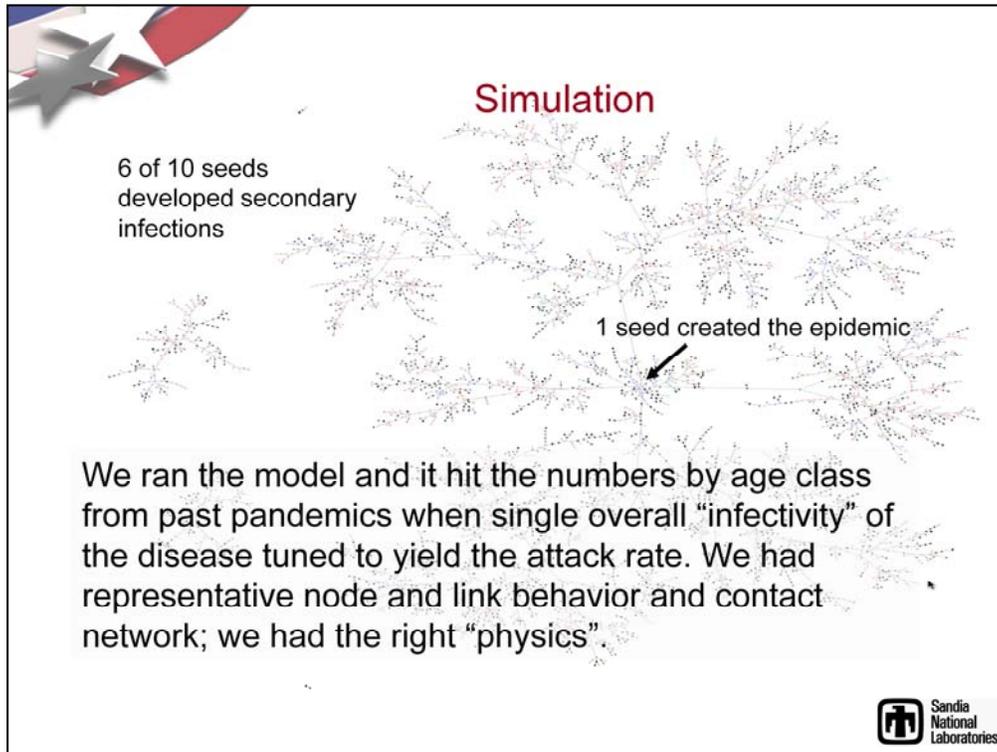


Vaccinate Kids and Teens!

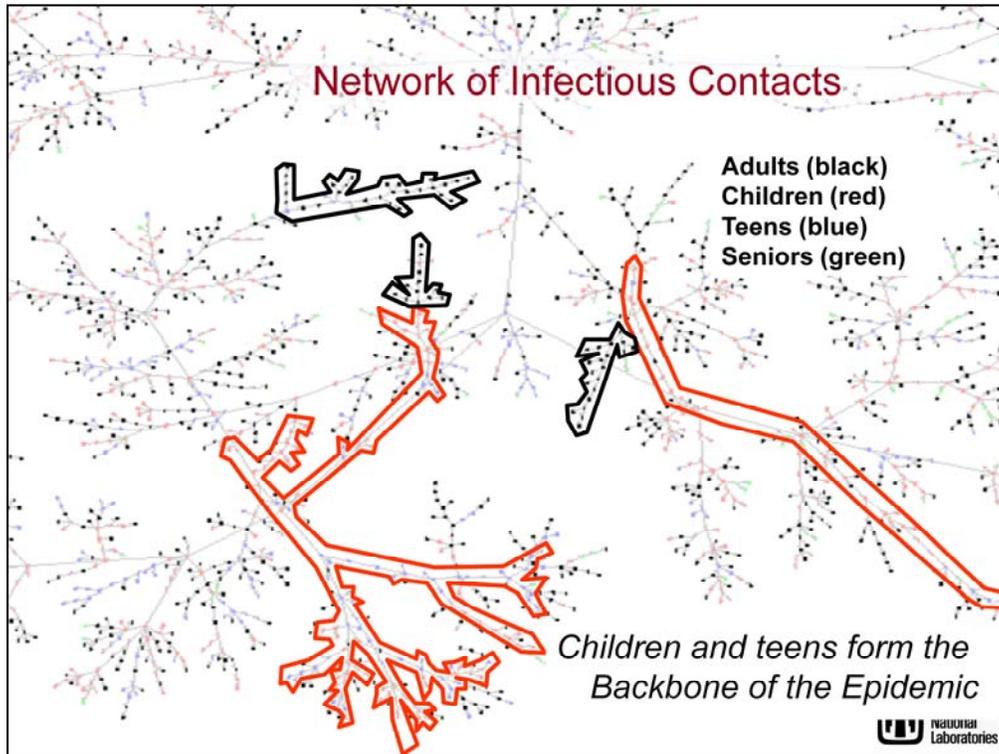




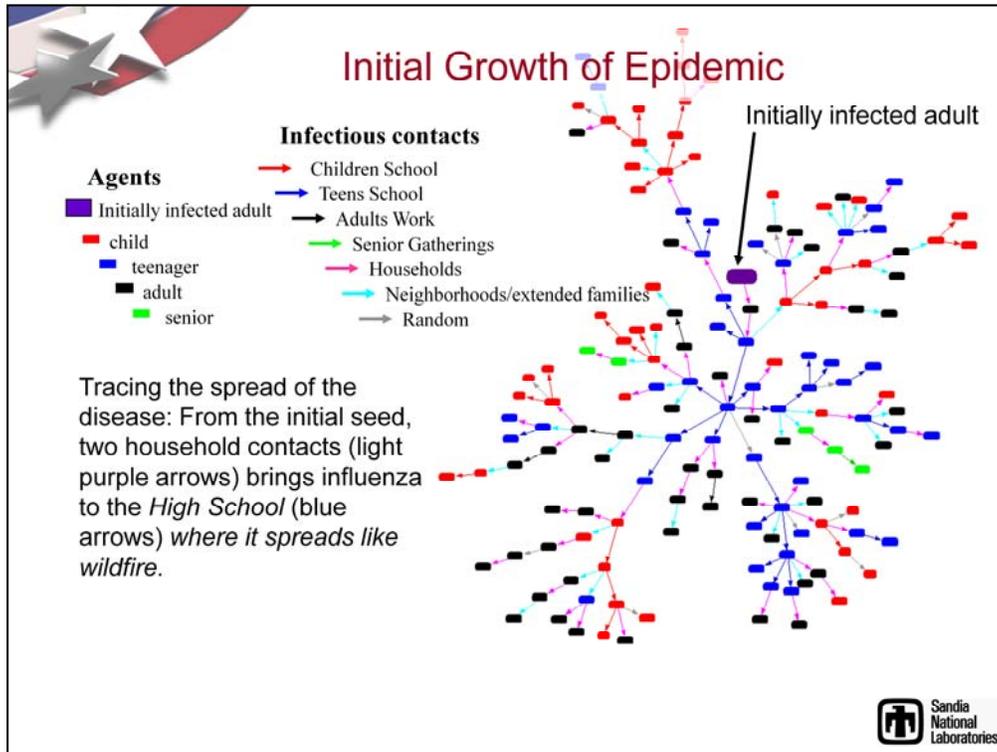
-We took our general approach and applied it to the pandemic problem. People were nodes, their interactions were links in the network. Disease would spread along these links from person to person. We put in the appropriate behavior of the disease and the physics of it's transmission. We then asked a series of experts: "what are your groups, how big are they, how often do you go to them and for how long, how many people do you interact with there". From this general information we constructed a network for a representative community.



-We ran the model and it hit the numbers from past pandemics without calibration (other's required this calibration). We had the right node and link behavior, the right network, we had the right "physics".



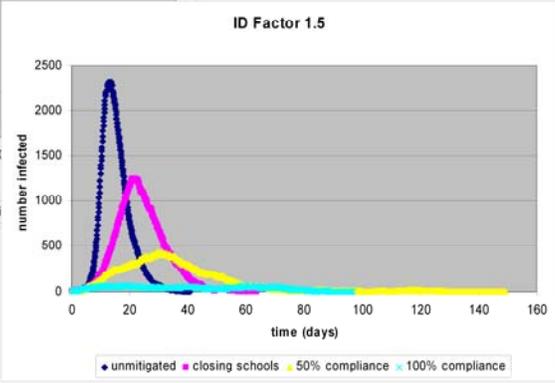
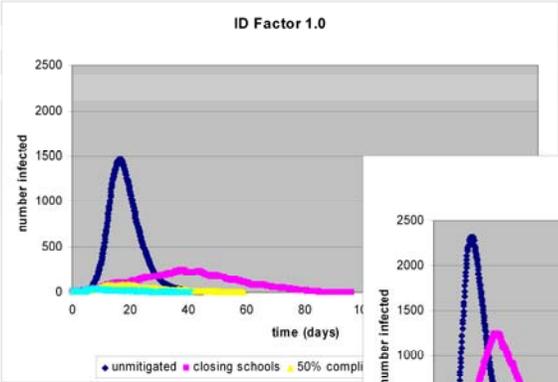
-By studying the burn path through the small community, we identified children and teens as the culprits. They form the backbone of the epidemic while adults are at the dead ends of the network.



-And the critical location for the spread was in the schools. We then targeted these groups: we closed the schools. If the kids and teens were allowed to adapt and go to the mall it actually made things worse. But if we kept them primarily at home, we could knock the local epidemic out.

-PROBLEM SOLUTION: Close the schools and keep the kids and teens at home.

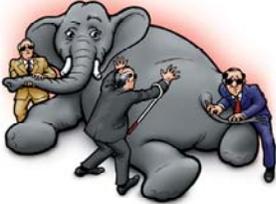
Closing Schools and Keeping the Kids Home





The Clouds Thicken...

- 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.



-We worked our results in to the briefing for Sec Chertoff and wrote an open release SAND report covering our results. As expected, the kinds of things that came up during the White House table top were several steps behind current thinking, such as closing boarders, etc. Closing boarders is just like building fire breaks. They don't solve the problem.

-The big names in epidemiology were busy modeling the movement of the disease across the US with massive models at LANL and in Great Britain. Their articles (published rapidly in Science and Nature) suggested there was little that could be done. The pandemic would wash over the US without antivirals. But ours, 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!



-We needed to **INFLUENCE PUBLIC POLICY** and quickly. How could we do this? The system was chock full of people with reputations at stake, the noise to signal ratio was much too large to be heard above the din. I decided to use the informal social-influence network instead of the command and control hierarchy. I had to get our work to the critical nodes with control.

-I sent our SAND report to a friend at the VA who sent it to a colleague at the VA who was their rep on the Homeland Security Council (HSC) Pandemic Implementation Plan Writing Team. He immediately called me. This was the first thing he had seen that was a solution, not just hand wringing. He sent it to the team lead, the team lead called me. This was the first thing that he had seen that gave a direction and hope. Then Rajeev Venkayya contacted me (Senior Director for Biodefense Policy, HSC, and Special Assistant to the President for Biodefense). I got on a plane and after a 4 hour presentation/interrogation/brain storming session, I had changed the course of public policy.

-I had started another kind of cascade. Over the next years, epidemiologists, forensic historians, public health researchers and officials challenged our problem solution. The HSC folks also worked to get the PI analysis at NISAC funded (which caused some consternation at DHS). Almost all of this subsequent work was done in the traditional way, by those who were already in the game using their own well understood hammers, none of which were quite right for the problem. The DHS NISAC-CIPDSS effort looked just like the **first figure of our CASoS report** and epitomized the normal approach that we (and everyone) tend to take toward solving CASoS problems.

-The story goes on and illustrates other critical features such as collaboration, reaction, adaptation, consensus building... and continuous use of CASoS principles to affect system behavior, but this is enough for our illustration today.



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.





With the White House Pandemic Implementation Plan writing team and VA OPHEH

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?

IN THREE WEEKS!





Systematic Evaluation of Choice

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)

Davey, V.J., R.J. Glass, H.J. Min, W.E. Beyeler and L.M. Glass, Effective, Robust Design of Community Mitigation for Pandemic Influenza: A Systematic Examination of Proposed U.S. Guidance, *PLoSOne*, July 2008, 3(7): e2606. doi:10.1371/journal.pone.0002606.





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).

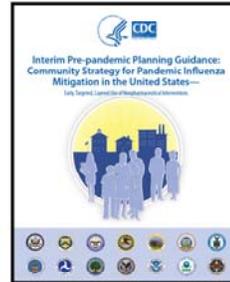




Culminating in...

- 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 Nonpharmaceutical Interventions*”

And the story continues.





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...



Let me summarize the main points:

-we were dealing with a large complex adaptive system: 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 (currently an art), applied a **GENERIC APPROACH** for simulation and analysis, and came up with a **ROBUST SOLUTION** that would work with minimal social and economic burden independent of what decisions were made outside the local community (e.g., politics, boarders, travel restrictions).

-through recognition that the **GOVERNMENT** and it's dealing with global pandemic preparation was a CASoS, we then used CASoS concepts (social net, influence net, people) to **INFLUENCE PUBLIC POLICY** in short time. These concepts continued to be used by the HSC folks over the past 1.5 years to implement the policy that we identified.

Notes:

-we didn't model the whole problem, only the critical parts (not a model of all things)

-we used generic approaches from CASoS (not epidemiology, not public health)

-we used CASoS principles to get it used (not the deadening upward battle through a skeptical set of bureaucrats)

Other illustrations:

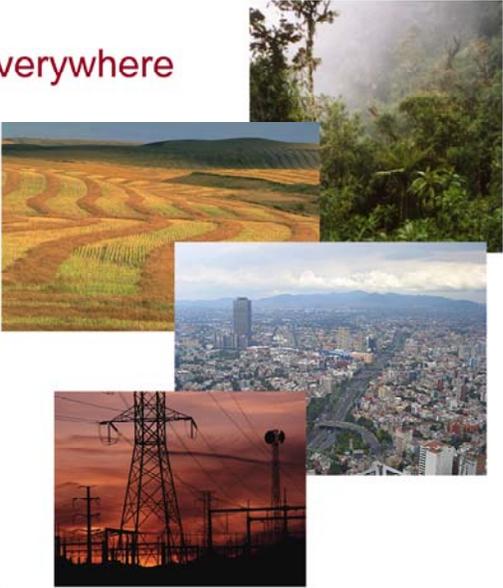
-We have another examples similar to the above but in national-international banking and their large value payment systems that move many trillions of dollars around the world on a daily basis.

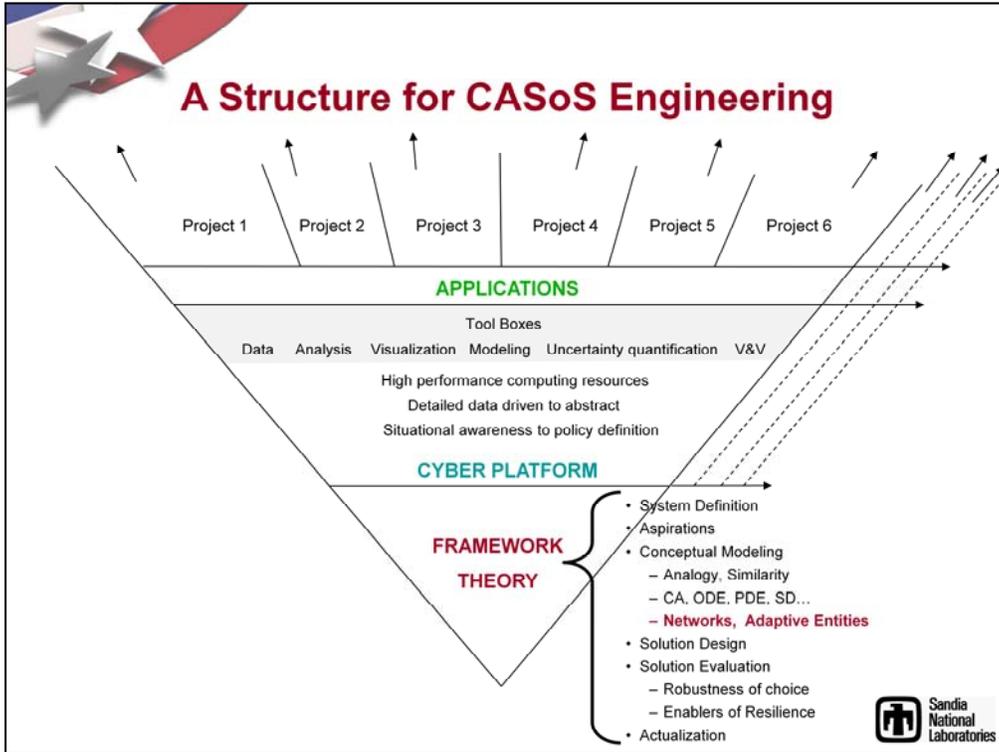
-Rich Colbaugh also has similar stories from his time at NSA and gives a nice presentation of both complex systems and their analysis from the perspective of the terrorism problem.



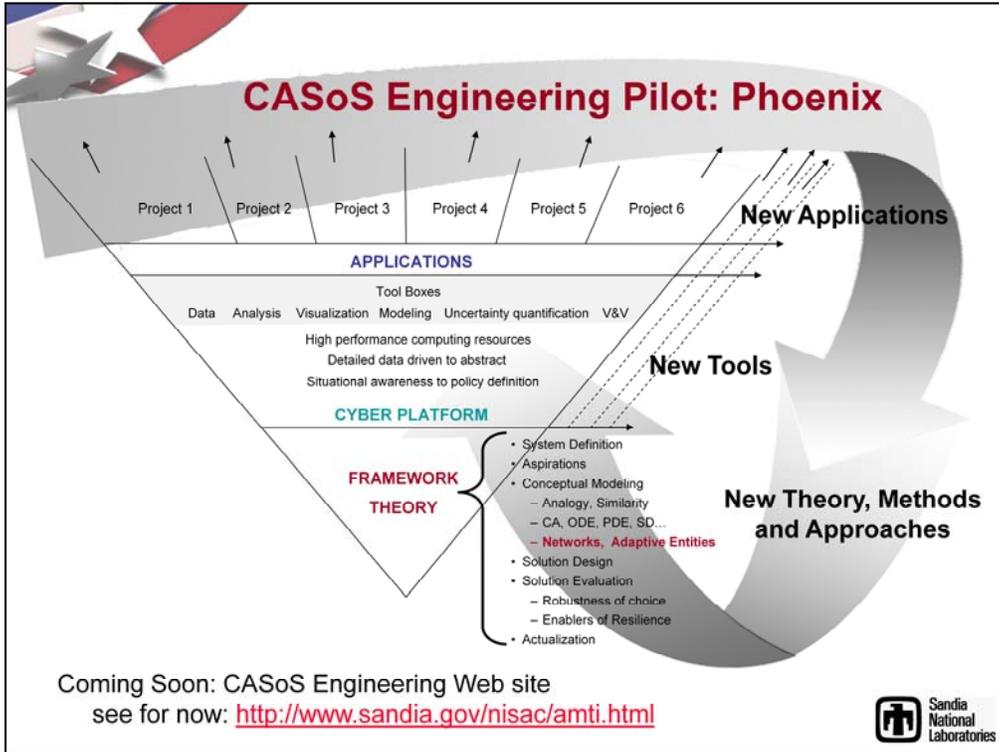
CASoS are everywhere

- Tropical Rain forests
- Agro-Eco systems
- Cities and Megacities (and their network on the planet)
- Interdependent infrastructure (local to regional to national to global)
- Government and political systems, health care systems, financial systems, economic systems and their supply networks (local to regional to national to global)... Global Energy System and Green House Gasses





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Thank you!

Arlo Ames, Walt Beyeler, Lara Glass, Tu-Thach Quach, Rich Detry, Pat Finley, Shirley Starks, Steve Conrad, Tom Corbet, Jim Ellison, Theresa Brown, Jason Min, George Backus, Rich Colbaugh, Steve Goldsmith, Bernie Zak, Vicky Davey (VHA), Richard Hatchett and Carter Mecher (HSC), Craig Hymes (FDA), Kimmo Soramaki (ECB), Morten Bech (NYFRB), Rabien Renault (BoF)

