SAND2014-2512P

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COMPLEX ADAPTIVE SYSTEM OF SYSTEMS (CASoS) ENGINEERING FOR ANALYSIS AND LEADERSHIP

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SAND 2014-xxxxC

U.S. DEPARTMENT OF ENERGY | NNSA

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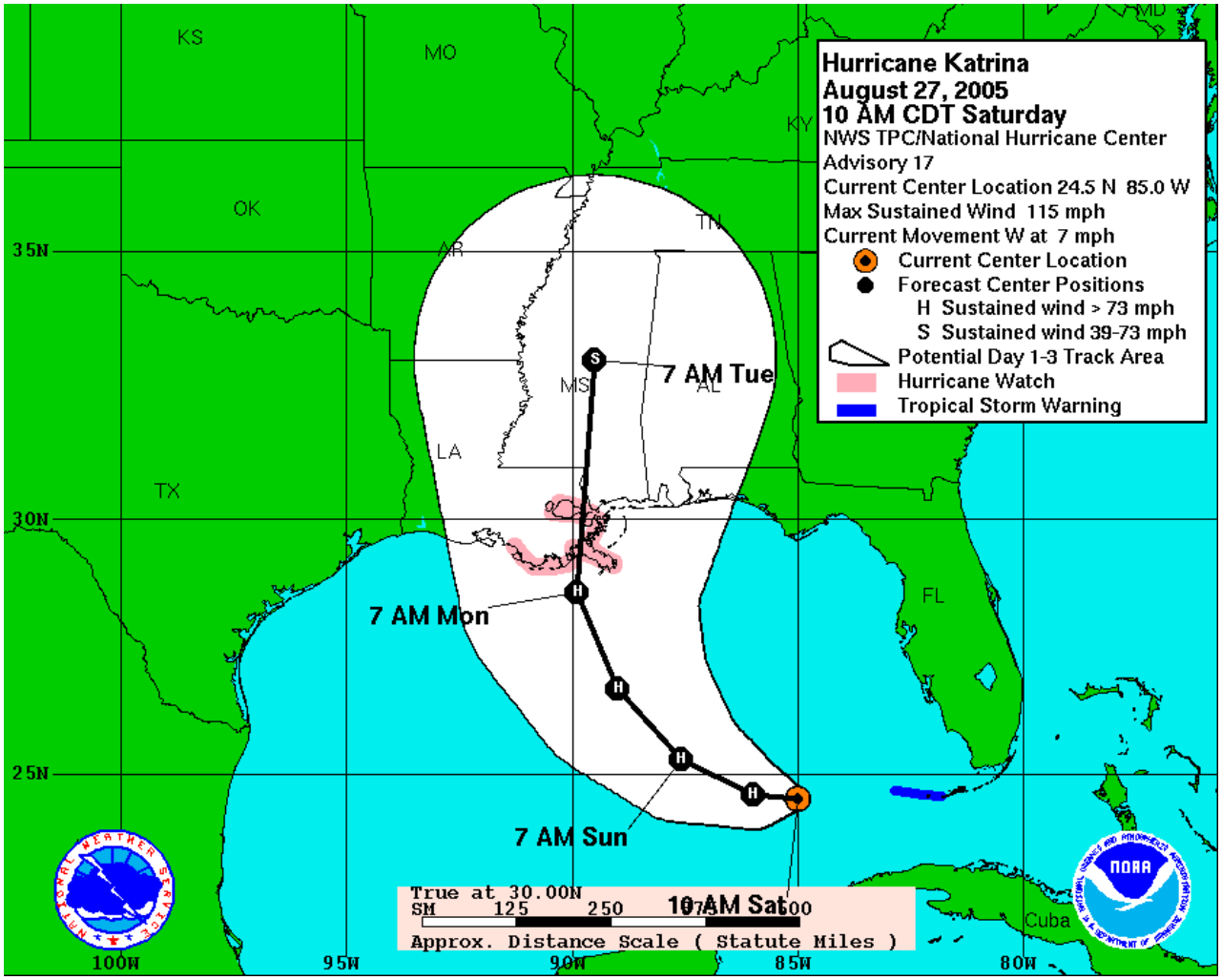
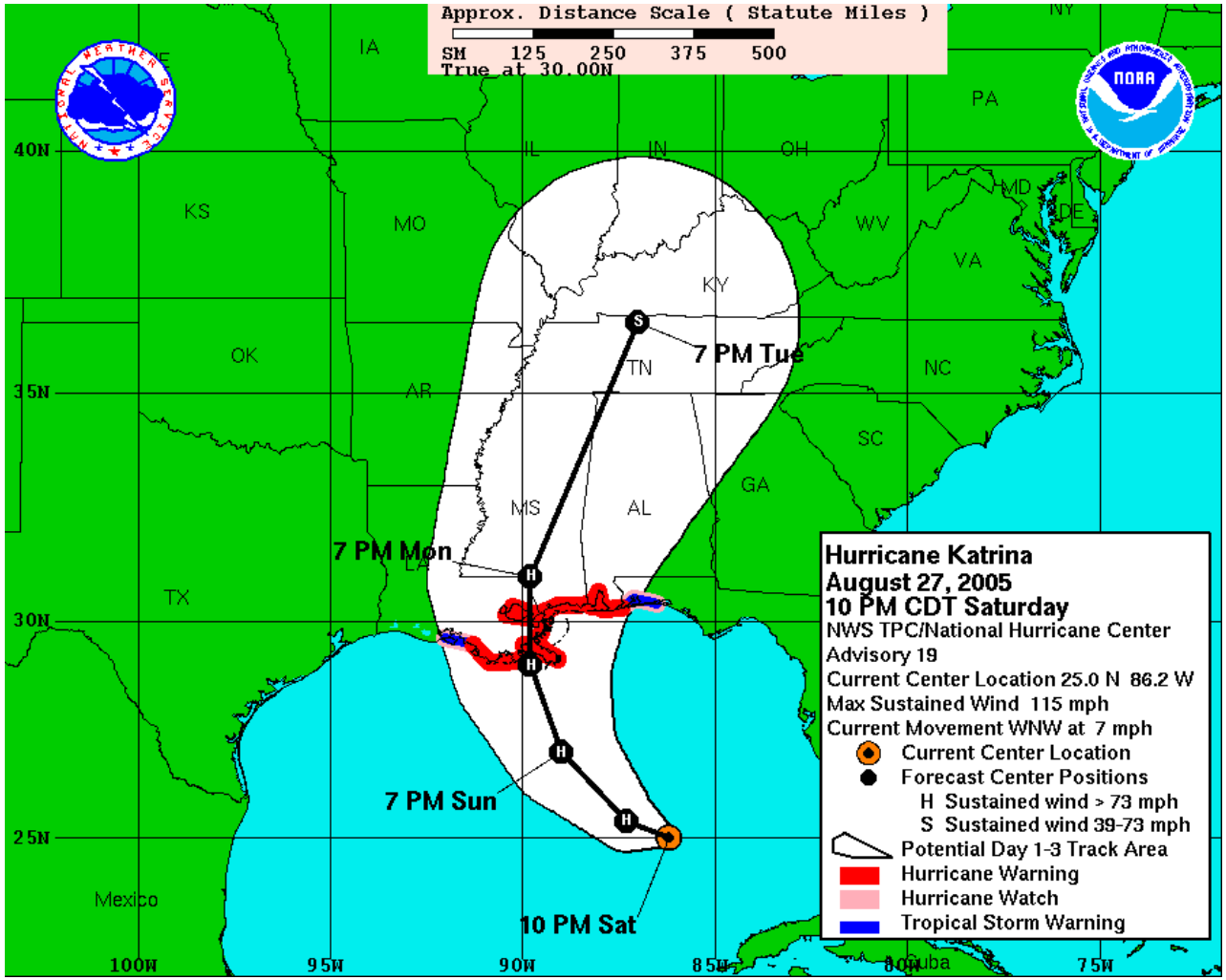
August 27, 2005



Source: National Hurricane Center, Katrina Graphics Archive, at http://www.nhc.noaa.gov/archive/2005/KATRINA_graphics.shtml

August 27, 2005



Source: National Hurricane Center, Katrina Graphics Archive, at http://www.nhc.noaa.gov/archive/2005/KATRINA_graphics.shtml

August 27, 2005

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The Irish Trojan's Blog

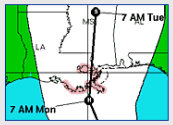
« Previous post | Next post »

Katrina a Cat. 3; expected to be 145+ mph at landfall

Posted by **Brendan Loy** on Saturday, August 27, 2005 at 12:58 pm

Katrina officially became a major hurricane overnight, with 115 mph winds, and her expected intensity at landfall was upped to 145 mph. Moreover, according to the 10:00 AM discussion, "IT IS NOT OUT OF THE QUESTION THAT KATRINA COULD REACH CATEGORY 5 STATUS AT SOME POINT BEFORE LANDFALL."

Also at 10:00 AM, the NHC issued a Hurricane Watch for southeastern Louisiana, including New Orleans and Lake Ponchartrain.



"IT IS NOT OUT OF THE QUESTION THAT KATRINA COULD REACH CATEGORY 5 STATUS AT SOME POINT BEFORE LANDFALL."

"This is not a test," said New Orleans mayor Ray Nagin. Evacuation orders for the city will be issued very soon. Already, nearby Placquemines and St. Bernard parishes have urged people to leave. ("According to the state's plan, New Orleans and Orleans Parish call for evacuations after the low-lying areas to allow people who live south and east of the city to get on the road first and head for safety.") Mayor Nagin urged New Orleanians to "get their supplies, get their medications in order, clean up storm drains and get ready. Because it looks as if we're going to get hit."

The Hurricane Center will likely expand the Hurricane Watches eastward, to cover the Mississippi and perhaps Alabama coastlines as well, later today. It sounds like they did follow my advice and fudge the normal timetable a bit for New Orleans, where hurricane preparedness is a uniquely difficult prospect.

It bears repeating just what we're dealing with here: the potential destruction of a city, and the deaths of many thousands who are unable or unwilling to evacuate. Dr. Jeff Masters puts the odds of this scenario at one in ten:

> I'd hate to be an Emergency Management official in New Orleans right now. Katrina is pretty much following the NHC forecast, and appears likely to pass VERY close to New Orleans. I'm surprised they haven't ordered an evacuation of the city yet. **While the odds of a catastropic hit that would completely flood the city of New Orleans are probably 10%, that is way too high in my opinion to justify leaving the people in the city.** If I lived in the city, I would evactuate NOW! There is a very good reason that the Coroner's office in New Orleans keeps 10,000 body bags on hand. The risks are too great from this storm, and a weekend away from the city would be nice anyway, right? GO! New Orleans needs a full 72 hours to evacuate, and landfall is already less than 72 hours away. Get out now and beat the rush. You're not going to have to go to work or school on Monday anyway. If an evacuation is ordered, not everyone who wants to get out may be able to do so–particularly the 60,000 poor people with no cars.

And it only gets worse. In addition to increasing in strength, Katrina has also substantially increased in **size**, as you can see for yourself here. Hurricane-force winds now extend outward up to 40 miles, and tropical-storm-force winds up to 150 miles, from the center; that's up from 25 and 85 miles, respectively, just 12 hours ago. Katrina "will deliver a widespread damaging blow wherever she comes ashore," says Dr. Masters.

Okay, now for the good news, such as it is. Katrina hasn't strengthened since she reached 115 mph about eight hours ago. She's been going through an eyewall replacement cycle, and it's possible she might weaken a bit this afternoon (though I'm not sure if that's good or bad news, as it might cause people to become dangerously complacent, only to have Katrina blow up into a monster tomorrow). Also, according to the discussion, "There is a possibility that southerly or southwesterly shear could affect Katrina starting at 48 hr…and as always happens in hurricane of this intensity additional concentric eyewall cycles could occur." That would be good… although, 48 hours from now, she'll already have come ashore, won't she? Hmm… HURRY UP, SHEAR!!!

Those two things — wind shear and eyewall replacement cycles — are the only factors that might prevent Katrina from being another Charley, or worse, **another Camille**, at landfall. Water temperatures aren't going to do the trick, as they did with Opal and Dennis. The sea-surface temperatures near the shoreline have warmed since July, there's a patch of water due south of New Orleans that is extremely warm *and* deep; that could easily be the engine that boosts Katrina to Cat. 5 during the final hours before landfall. Which, of course, would be very, very, very bad.

Source: The Irish Trojan's Blog (archive), at http://www.brendanloy.com/wp/2005/08/katrina-cat-3-expected-to-be-145-mph.html

August 27, 2005

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The Irish Trojan's Blog

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Evacuate

Posted by **Brendan Loy** on Friday, August 26, 2005 at 11:22 pm

I'm not a meteorologist. I'm just an amateur weather enthusiast, a law-student blogger who happens to be a hurricane buff. But **if I lived in New Orleans, I would definitely leave at this point. *Tonight.*** Barring a major change in the forecast, I expect the evacuation orders to come tomorrow. That will produce massive traffic jams and general confusion. My advice? Beat the rush; get out now. For it is imperative to get out. Katrina probably won't destroy New Orleans — but it *could*. So if anyone in New Orleans is reading this, I'd personally advise you to get the hell out of dodge.

Source: The Irish Trojan's Blog (archive), at http://www.brendanloy.com/wp/2005/08/evacuate.html

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"The eyewall replacement cycle that began at about 8am this morning has ended….The areal size of the hurricane continues to expand, and Katrina is growing from a medium sized hurricane to a large hurricane. Where the pressure will bottom out after this deepening phase is anyone's guess, and I believe something in the 915 - 925 mb range is most likely, which would make Katrina a strong Category 4 or weak Category 5 hurricane by tomorrow afternoon…

"New Orleans finally got serious and ordered an evacuation, but far too late. There is no way everyone will be able to get out of the city in time, and they may be forced to take shelter in the Superdome, which is above sea level. If Katrina makes a direct hit on New Orleans as a Category 4 hurricane, the levees protecting the city will be breached, and New Orleans, which is 6 - 10 feet below sea level, will fill with water. On top of this 6 feet of water will come a 15 foot storm surge, and on top of that will be 20 foot waves, so the potential for high loss of life is great. Given the current track and intensity forecast, I'd put the odds of this at about 20%."

Jeff Masters, "Eyewall replacement done, Katrina intensifying", Weather Underground, August 28, 2005, at http://www.wunderground.com/blog/JeffMasters/comment.html?entrynum=79&tstamp=200508

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What would you say?

Outline

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- August 27, 2005
- A little about me
- What are CASoS?
- The CASoS problem space
- CASoS in (not so) microcosm: Critical Infrastructure
- Examples of CASoS problems addressed
- Lessons learned from analyzing CASoS
- Where the future lies
- What did I say?

A little about me

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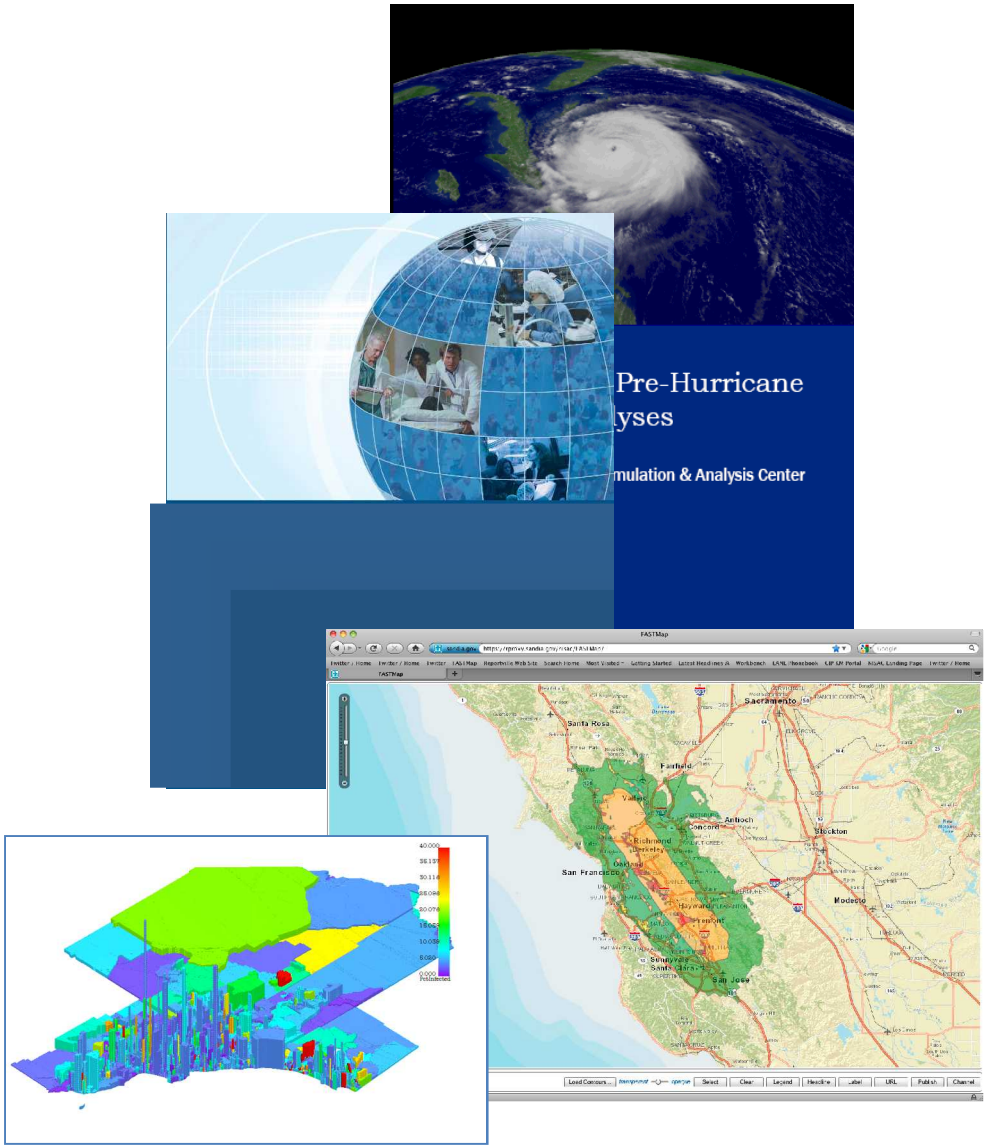
Kevin L. Stamber

- 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 for Incidents (IRAPI)
- Member IIE, INFORMS

A little about me

- NISAC performs a range of infrastructure simulation and analysis tasks for and through US DHS
  - Conducts incident consequence analyses
    - Planned analyses
    - Ad-hoc analyses
  - Provides support for national and regional exercises
  - Conducts capability development to support analysis



Homeland Security

What are CASoS?

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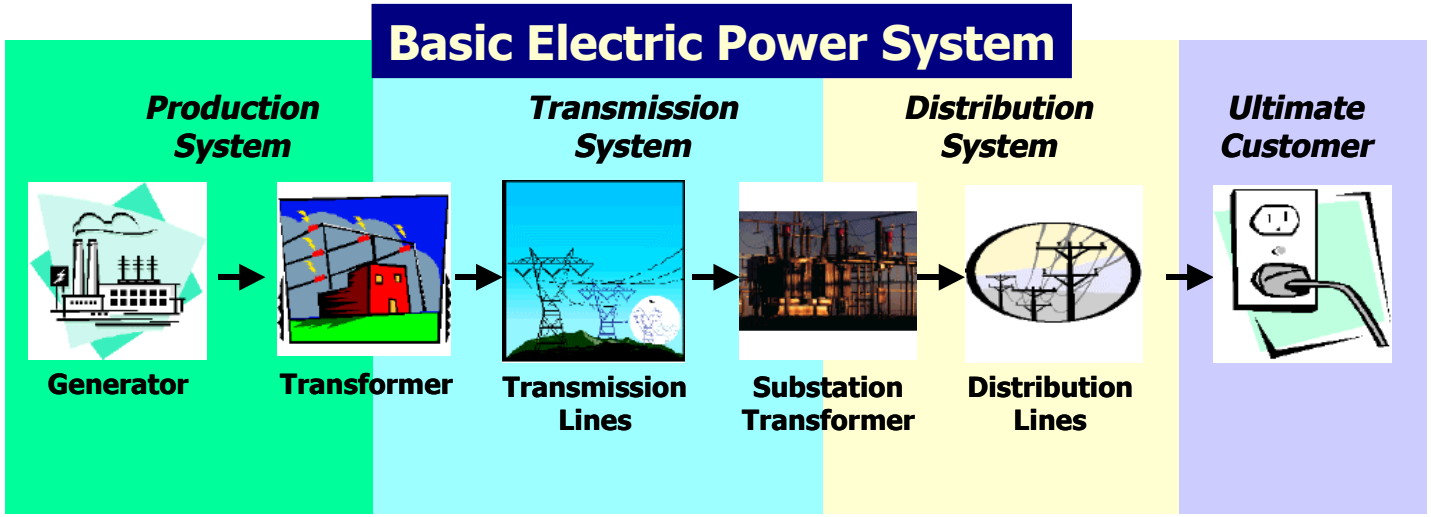
Complex Adaptive System of Systems

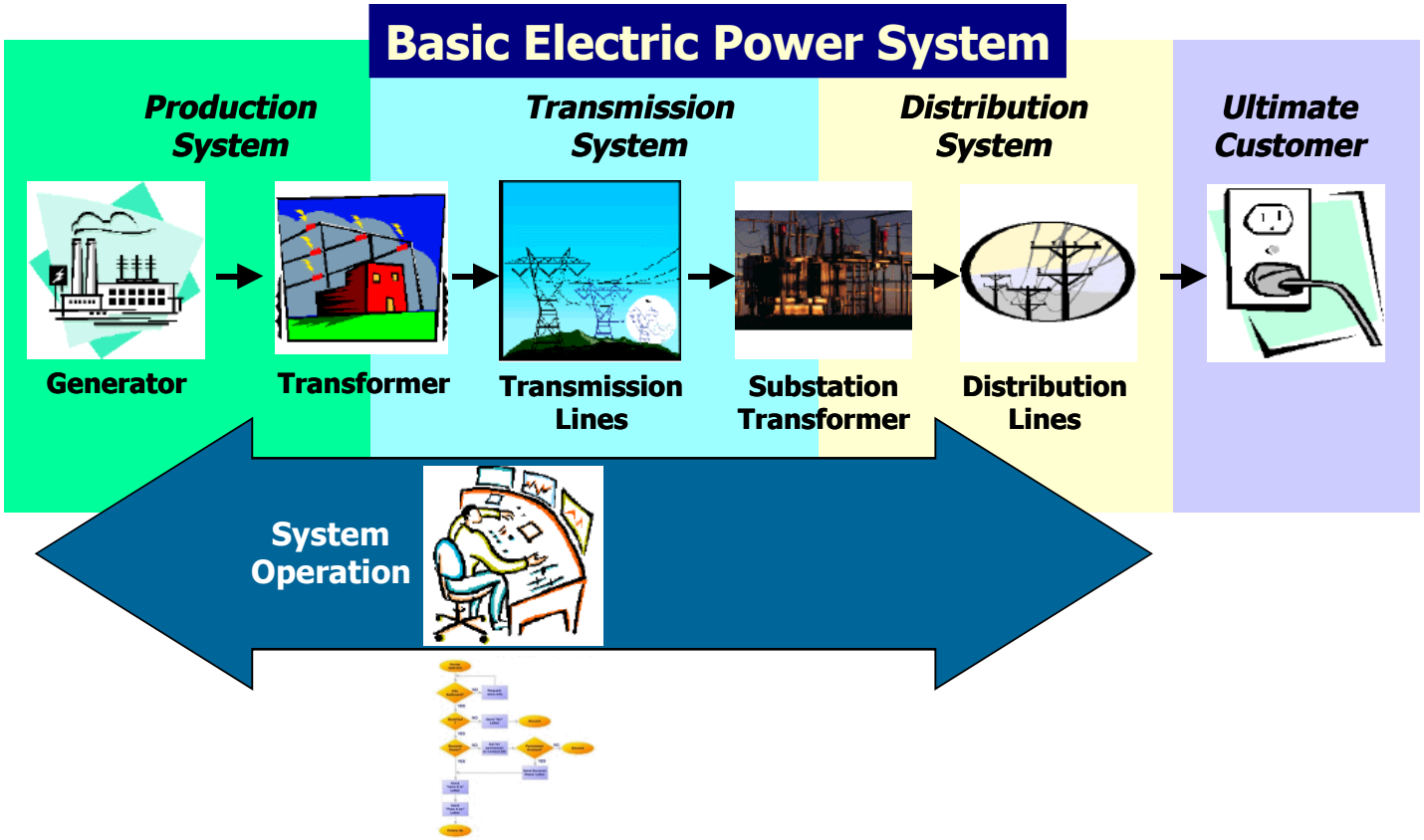
What are CASoS?

- System
  - Webster defines a system as (among other definitions)
    - "a group of related parts that move or work together"
    - "a regularly interacting or interdependent group of items forming a unified whole"
    - "a group of devices or artificial objects or an organization forming a network especially for distributing something or serving a common purpose"



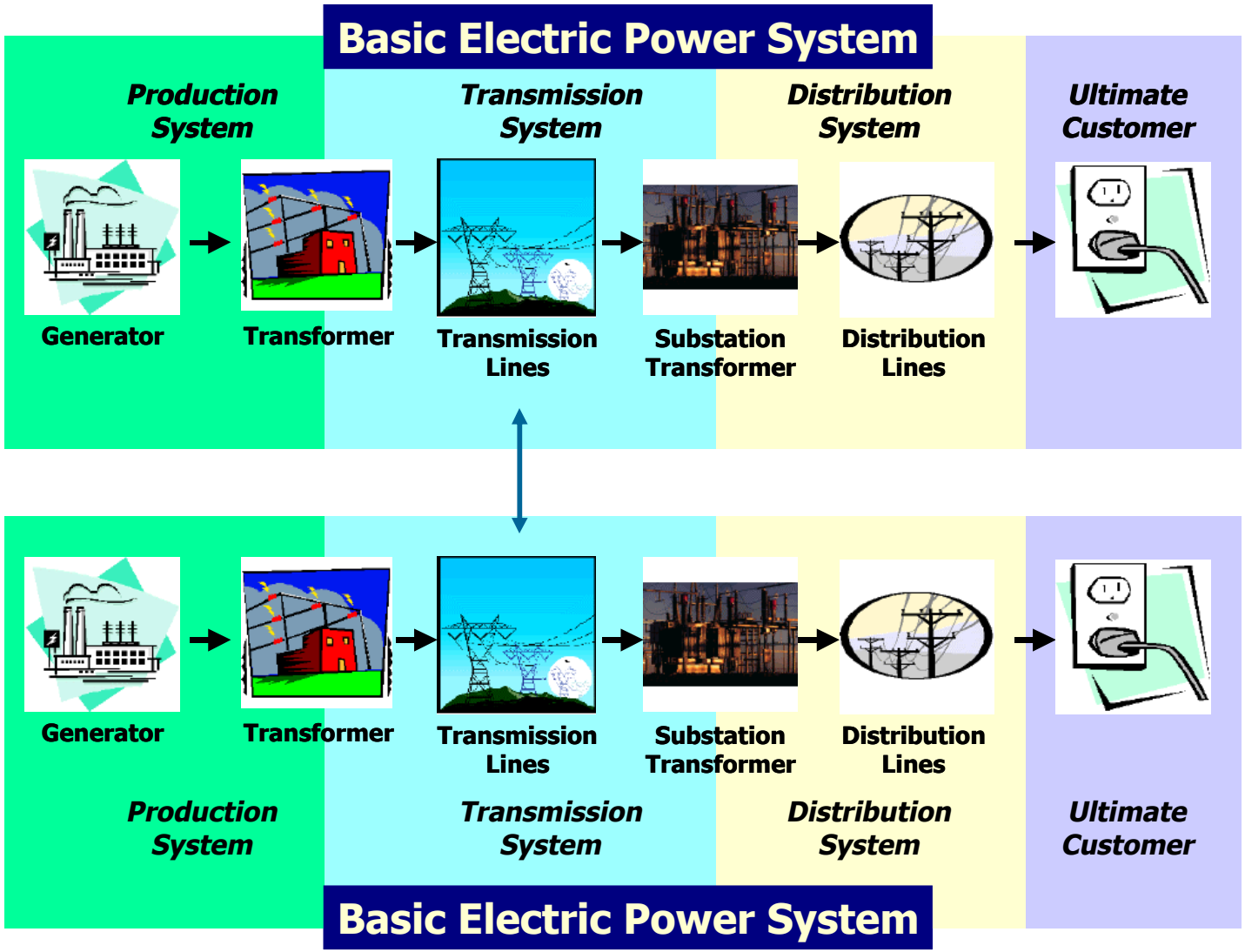
What are CASoS?

- System of Systems



What are CASoS?

- System of Systems



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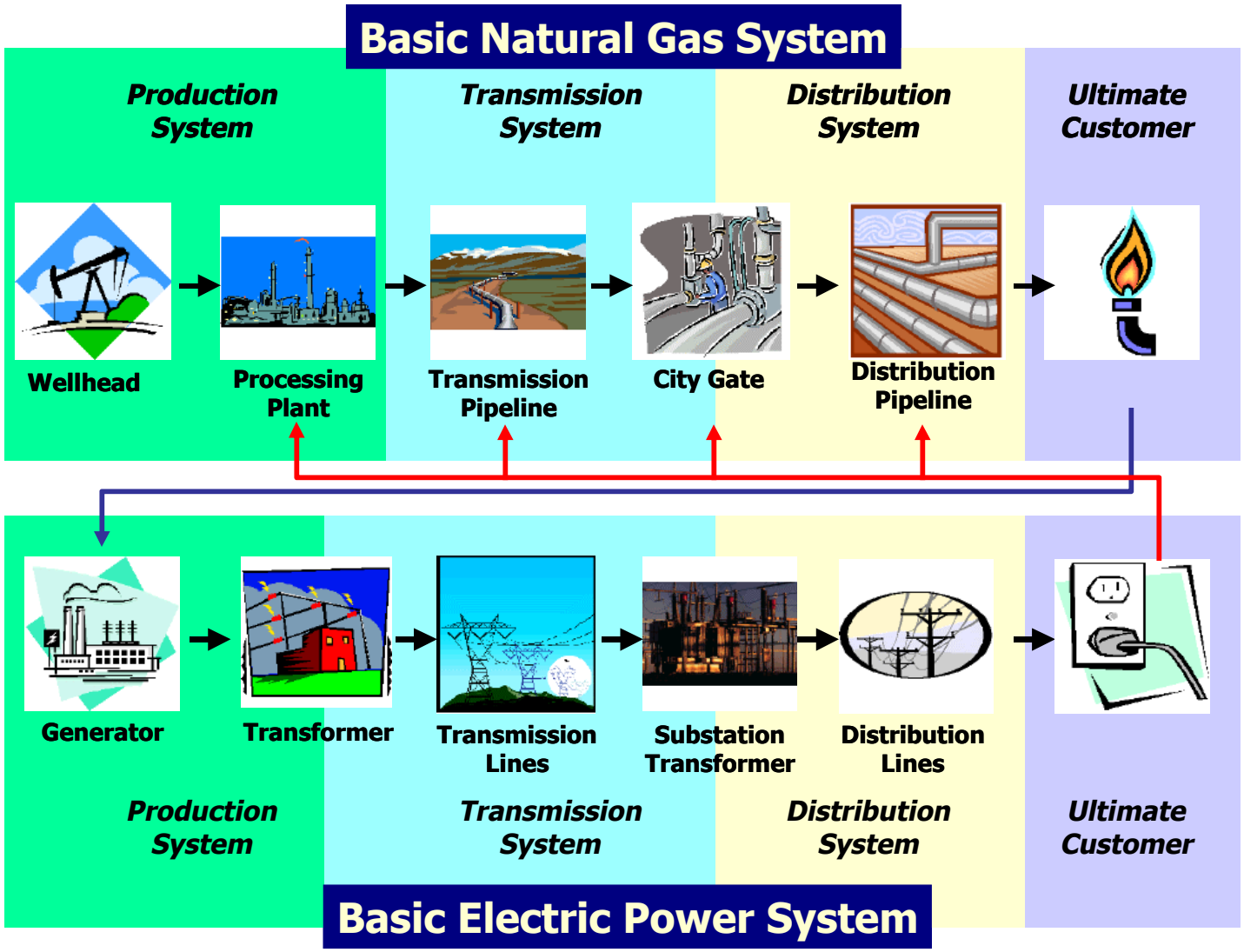
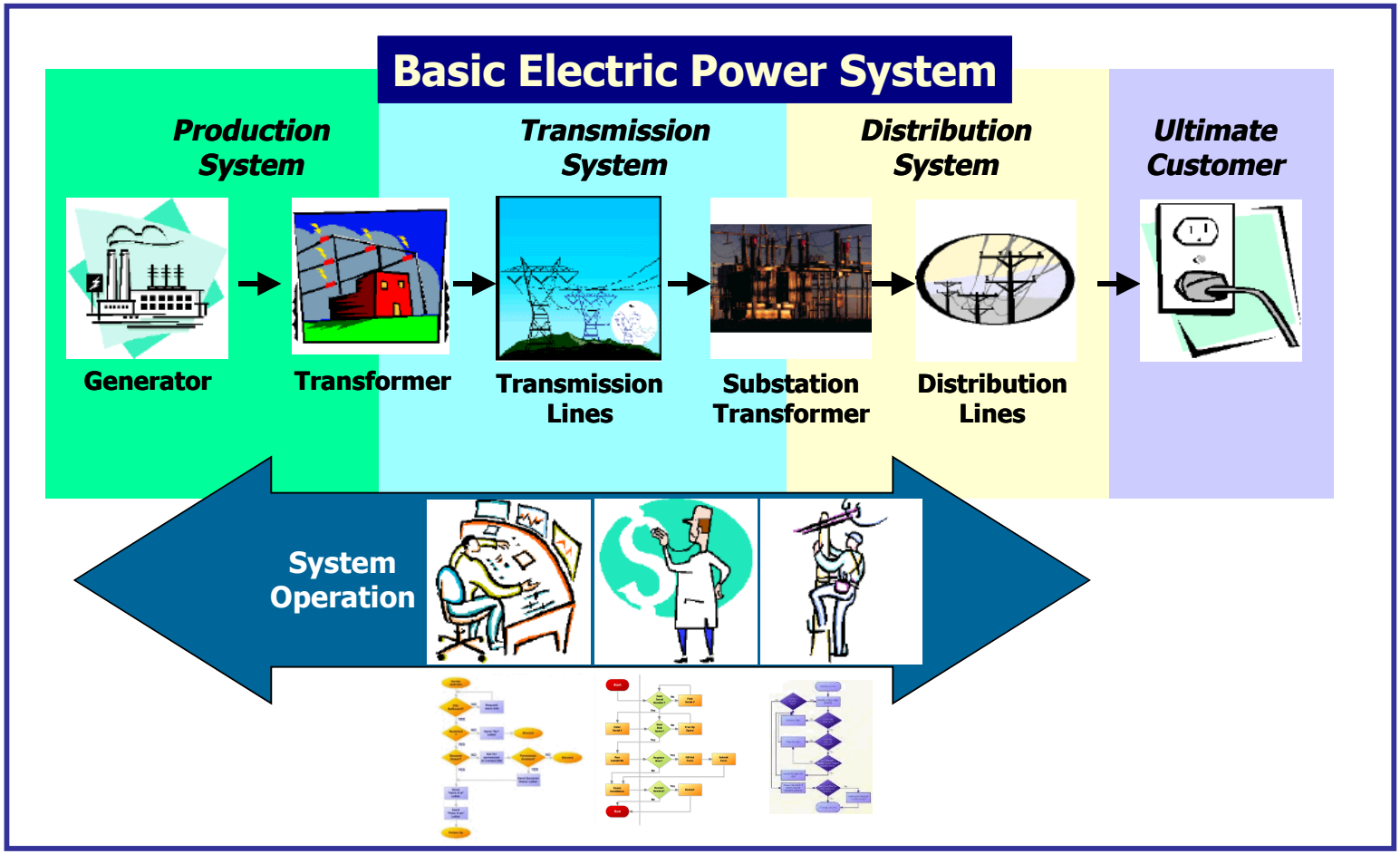
- System of Systems

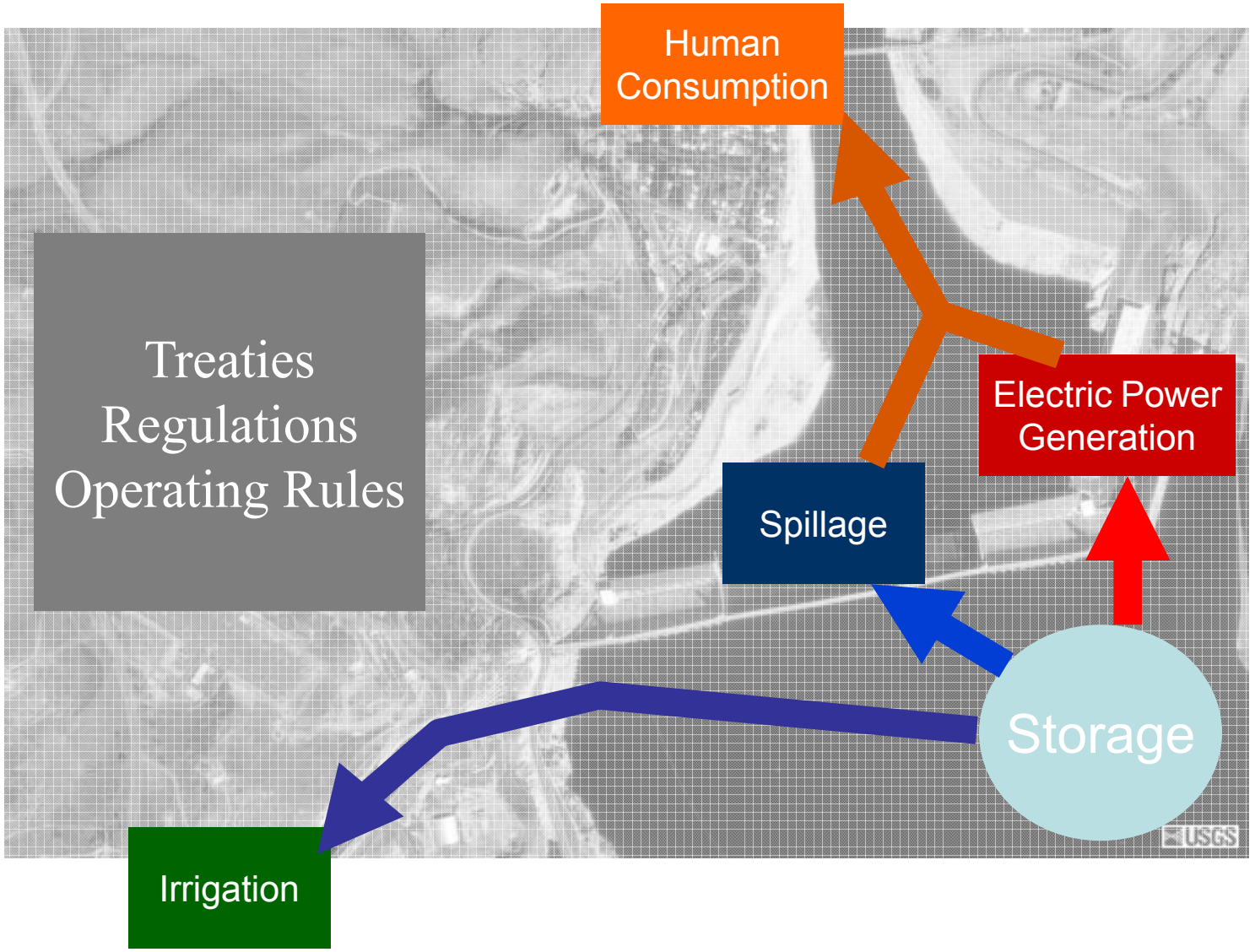


What are CASoS?

- Complex Adaptive System of Systems



What are CASoS?

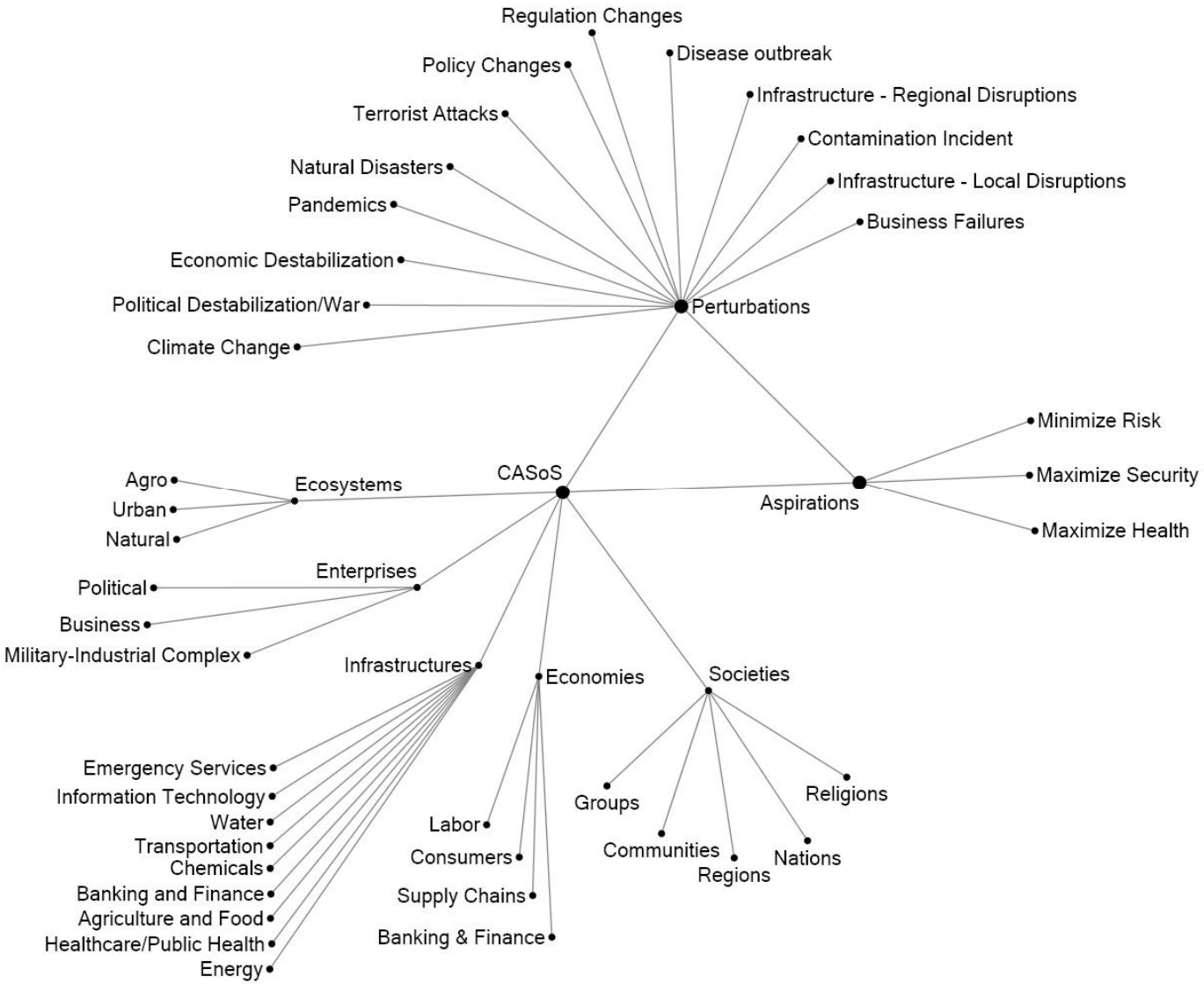


What are CASoS?

- 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)

The CASoS problem space



The CASoS problem space

CASoS in (not so) microcosm: Critical Infrastructure

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CASoS in (not so) microcosm: Critical Infrastructure

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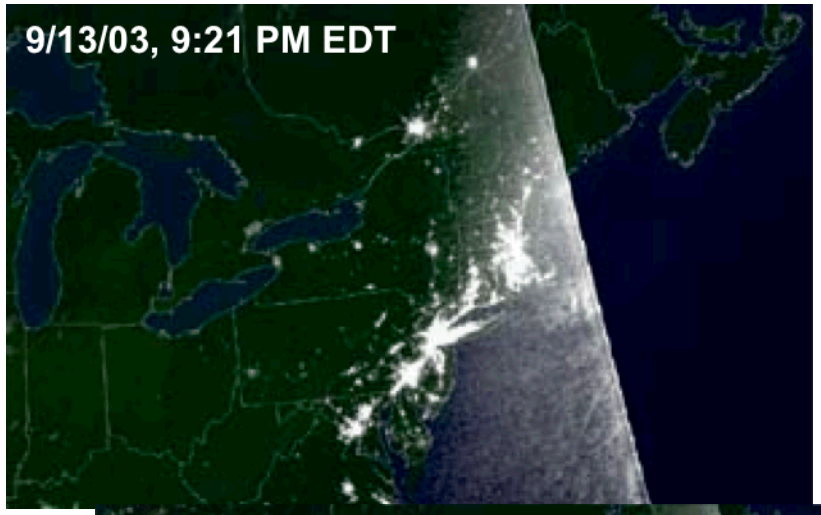
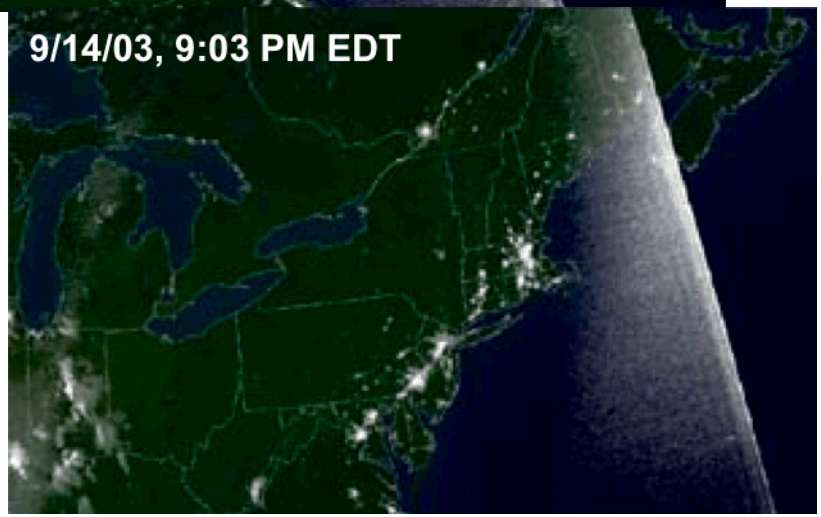
- Interconnections exist
  - Within an infrastructure sector
  - Across infrastructure sectors
- This includes
  - Dependencies
  - Interdependencies
- These dependencies and interdependencies include
  - Humans in the loop
  - Rules and other constraints
    - Functionally specific
    - Geographically specific
    - Treaties, regulations, etc.
- Dependencies and interdependencies can result in
  - Unexpected consequences
  - Cascading failures and impacts
- History is increasingly full of long-tail events





Images: NOAA

Too complex for mental models to be effective decision tools.

CASoS in (not so) microcosm: Critical Infrastructure

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CASoS in (not so) microcosm: Critical Infrastructure

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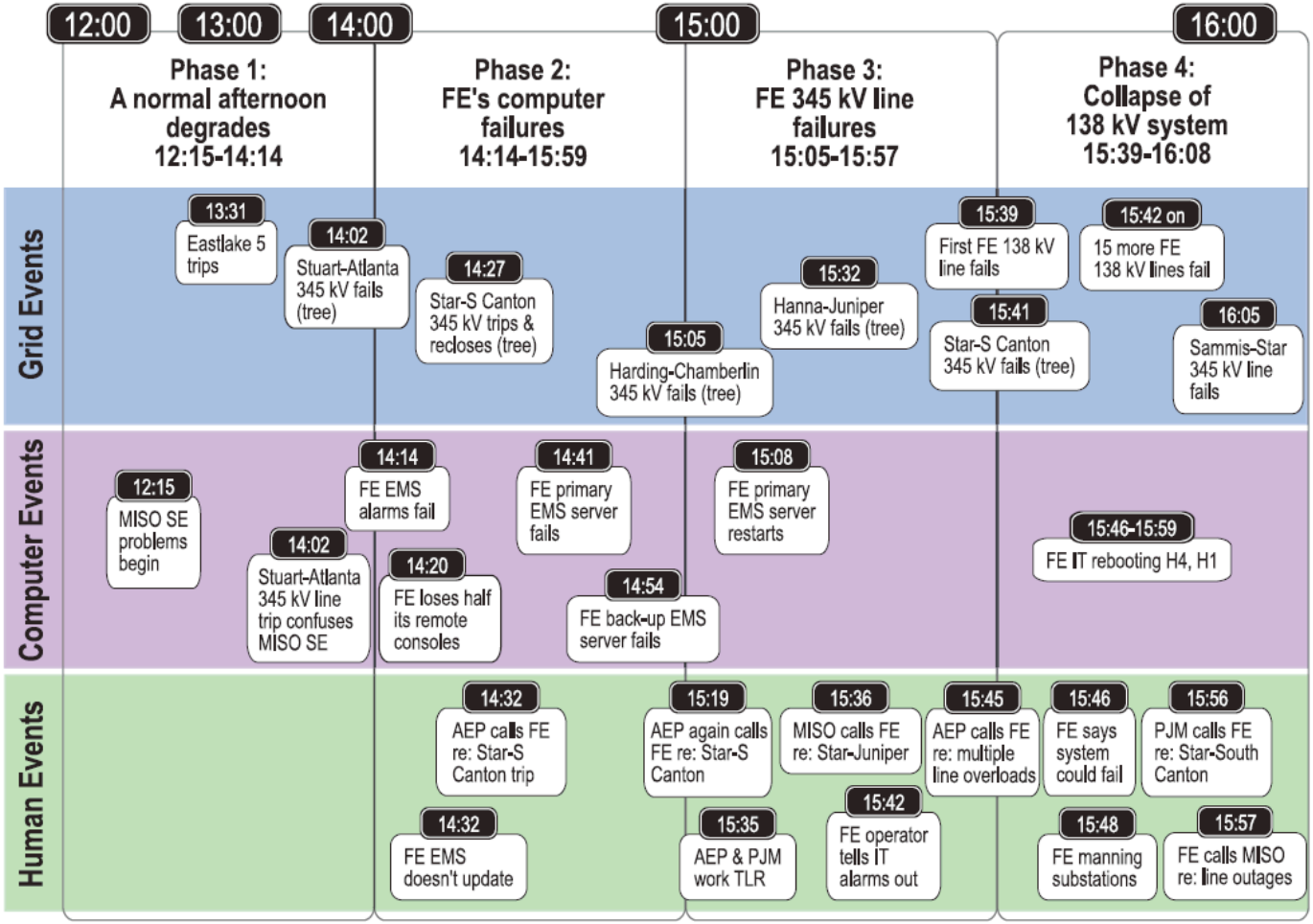
Figure 5.1. Timeline: Start of the Blackout in Ohio



Reference: ***Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations.*** **U.S.–Canada Power System Task Force. April 2004.**

CASoS in (not so) microcosm: Critical Infrastructure

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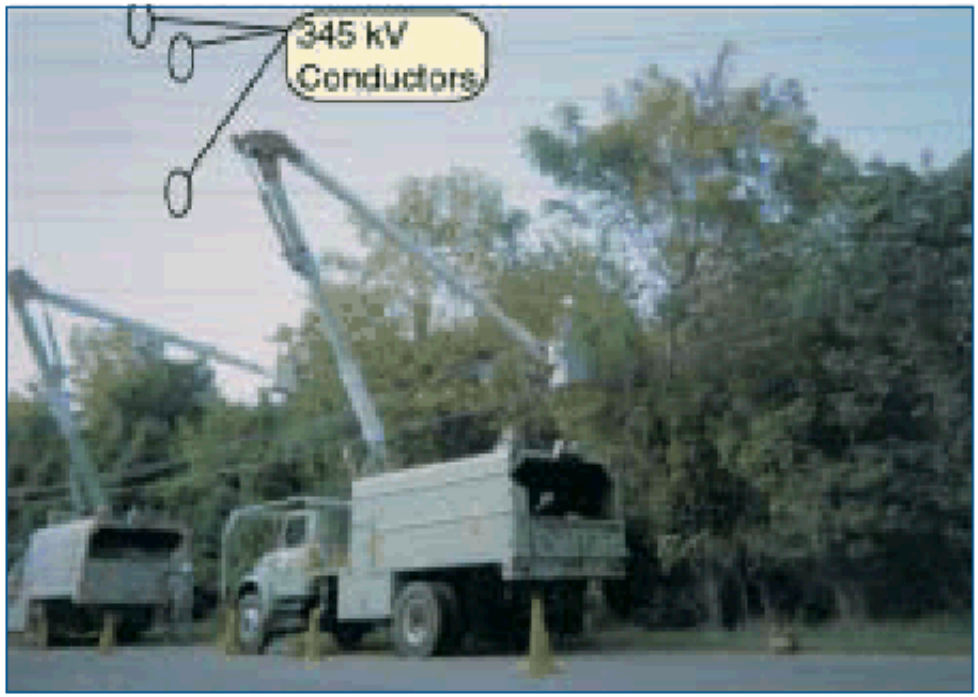
Figure 5.10. Cause of the Hanna-Juniper Line Loss



This August 14 photo shows the tree that caused the loss of the Hanna-Juniper line (tallest tree in photo). Other 345-kV conductors and shield wires can be seen in the background. Photo by Nelson Tree.

- More Phase 2 Events
  - 1542: FE's western transmission operator calls to describe their compromised EMS
    - Control center operators mention their EMS problems to the IT staff
    - More calls to FE control center
  - 1545: A tree-trimming crew reported a tree fault on the Eastlake – Juniper (345kV) line
    - The actual fault was to the nearby Hanna – Juniper line
    - This confused FE more, since the balky EMS accurately showed flow on Eastlake – Juniper
  - 1545: AEP called about the third and last trip of the Star – S. Canton line
    - FE believes them
  - 1546: Perry operator calls back to report imminent trip

CASoS in (not so) microcosm: Critical Infrastructure

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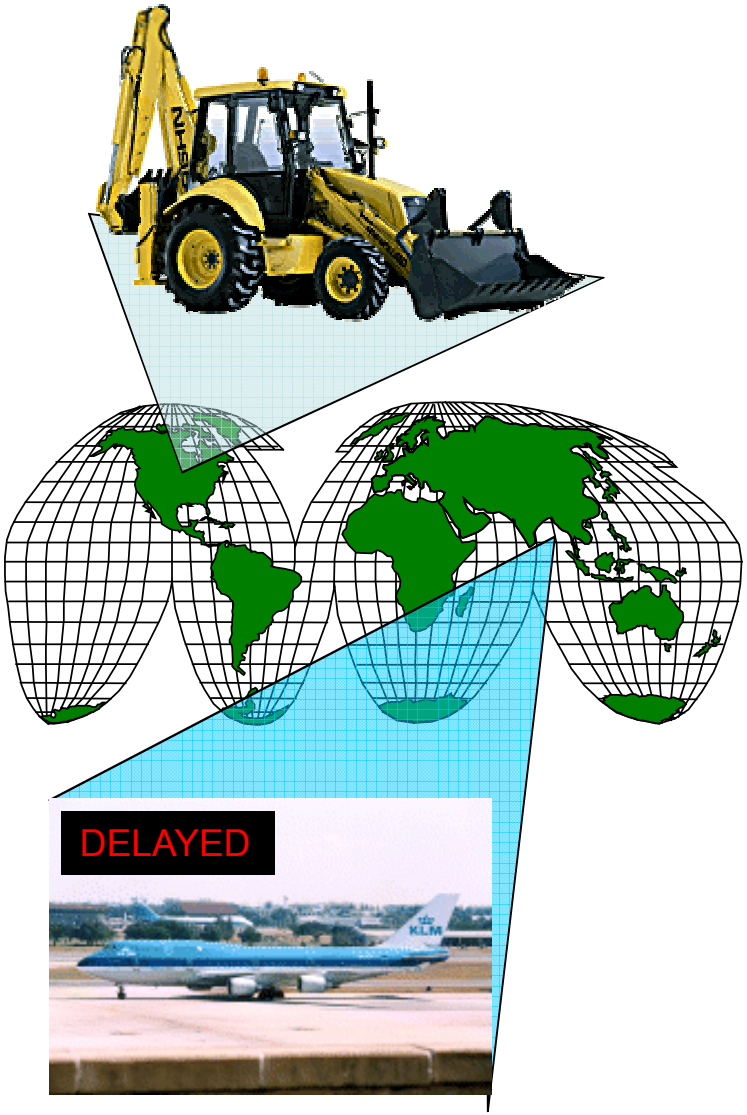

NW Airlines Loses Communication

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

CASoS in (not so) microcosm: Critical Infrastructure

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Fukushima: Rat linked to outage at Japan nuclear plant

A rat may have caused this week's power outage at Japan's tsunami-hit Fukushima nuclear power plant, says the Tokyo Electric Power Co (Tepco).

The company suspects the rodent may have caused a short-circuit in a switchboard, triggering the power cut.

"We have deeply worried the public, but the system has been restored," Tepco spokesman Masayuki Ono was quoted as saying by AFP news agency.

Two years ago a massive quake-triggered tsunami caused meltdowns at the plant.

The plant was brought under control in December 2011 and Monday's crisis was the first time since then that so many facilities had been affected by electrical failure at the same time, Tepco admits.

The power cut shut down cooling systems for four spent fuel ponds at reactors 1, 3 and 4 on Monday evening, although cooling to the reactors themselves was not affected.

The system cooling water which contained spent - but still highly radioactive - nuclear fuel rods failed and it took engineers some 30 hours to repair the damage.

'**Burn marks**'

All cooling systems were operational by early Wednesday morning, Tepco said.

It said it found burn marks on a makeshift power switchboard and a 15cm (six-inch) dead animal nearby.

The company released an image of an apparent rodent carcass inside the switchboard unit.

Correspondents say the incident has highlighted the fragility of the rescue operation at Fukushima two years after the meltdowns caused a major release of radiation.

The Japanese government insists that the reactors are in a "cold shutdown" state and no longer releasing high levels of radiation.

But company officials admit they are still using makeshift power systems as they struggle to decommission - or shut down - down the facility, a process expected to take decades.

BBC News Asia – March 20, 2013, at http://www.bbc.com/news/world-asia-21867705

Examples of CASoS problems addressed

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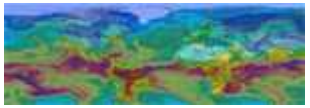
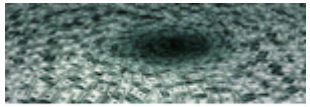
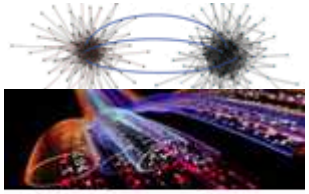
Global Security


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

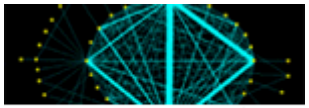

Veterans Health Threats

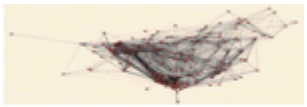

Petrochemical Regulatory Policy

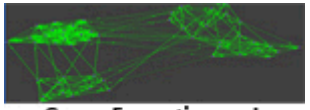

Natural Gas Networks

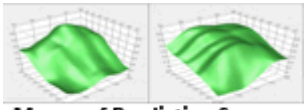

Petroleum Fuels


Livestock Transfer Risks


Congestion and Cascades


Social Network Interventions


Group Formation and Fragmentation


Means of Predicting Success of Interventions

Examples of CASoS problems addressed

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- Pandemic planning
- Port security and productivity modeling

Examples of CASoS problems addressed

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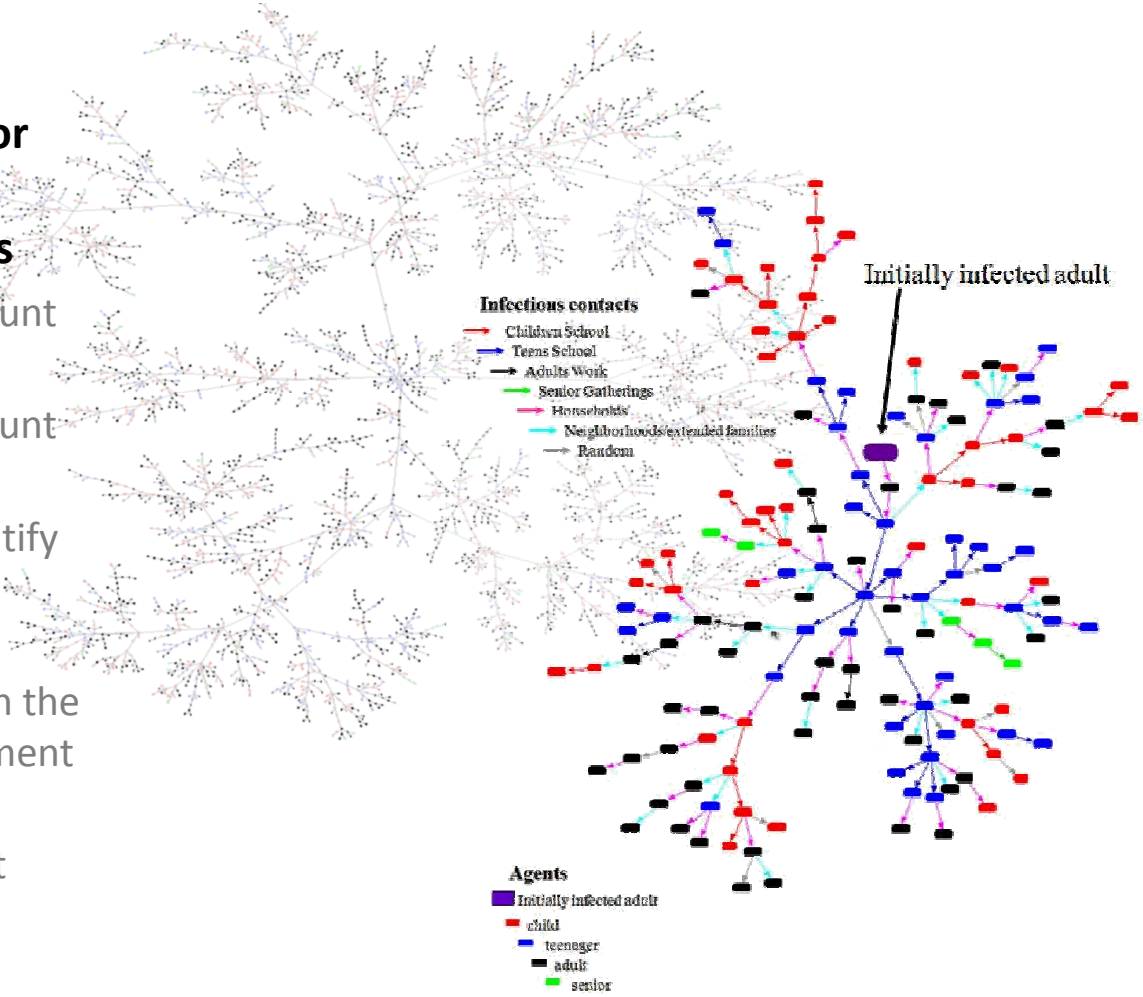
Pandemic planning

- **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

Examples of CASoS problems addressed

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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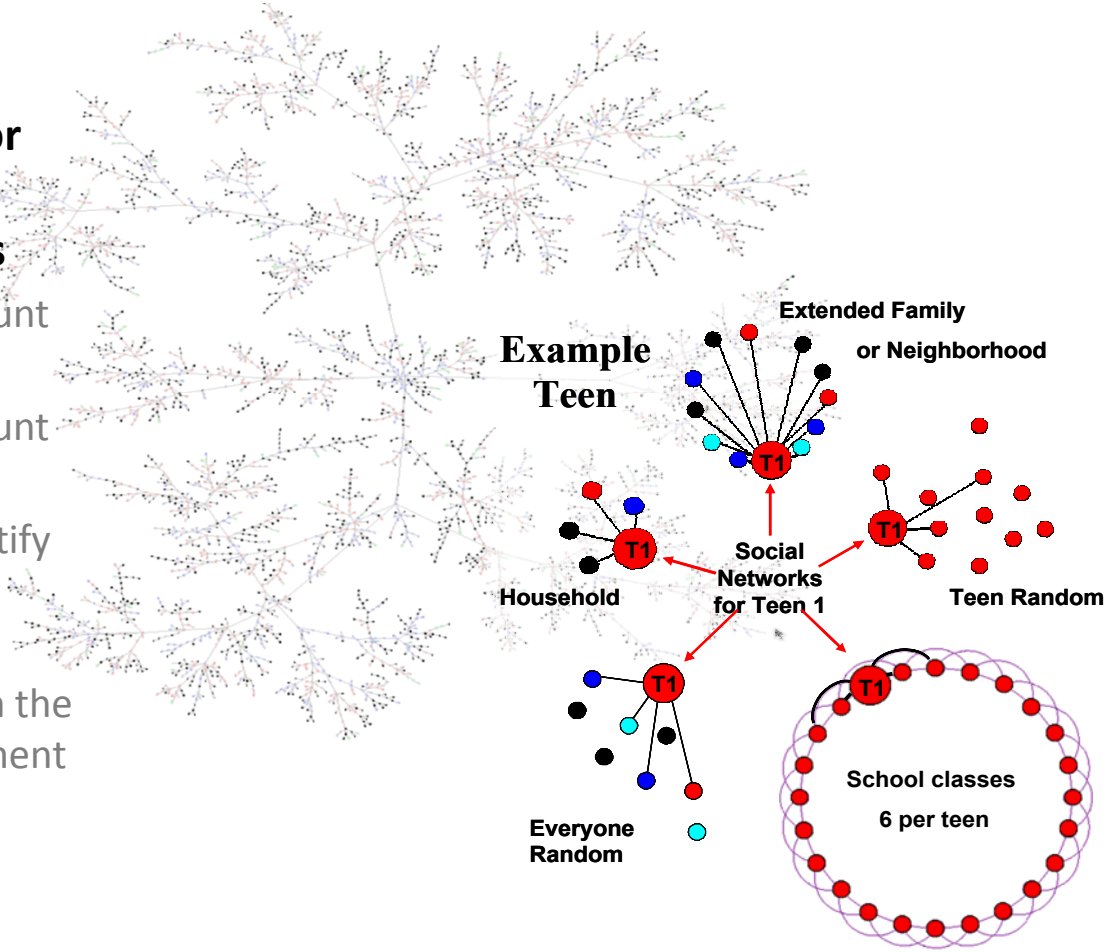

Multiple Social - Networks

Examples of CASoS problems addressed

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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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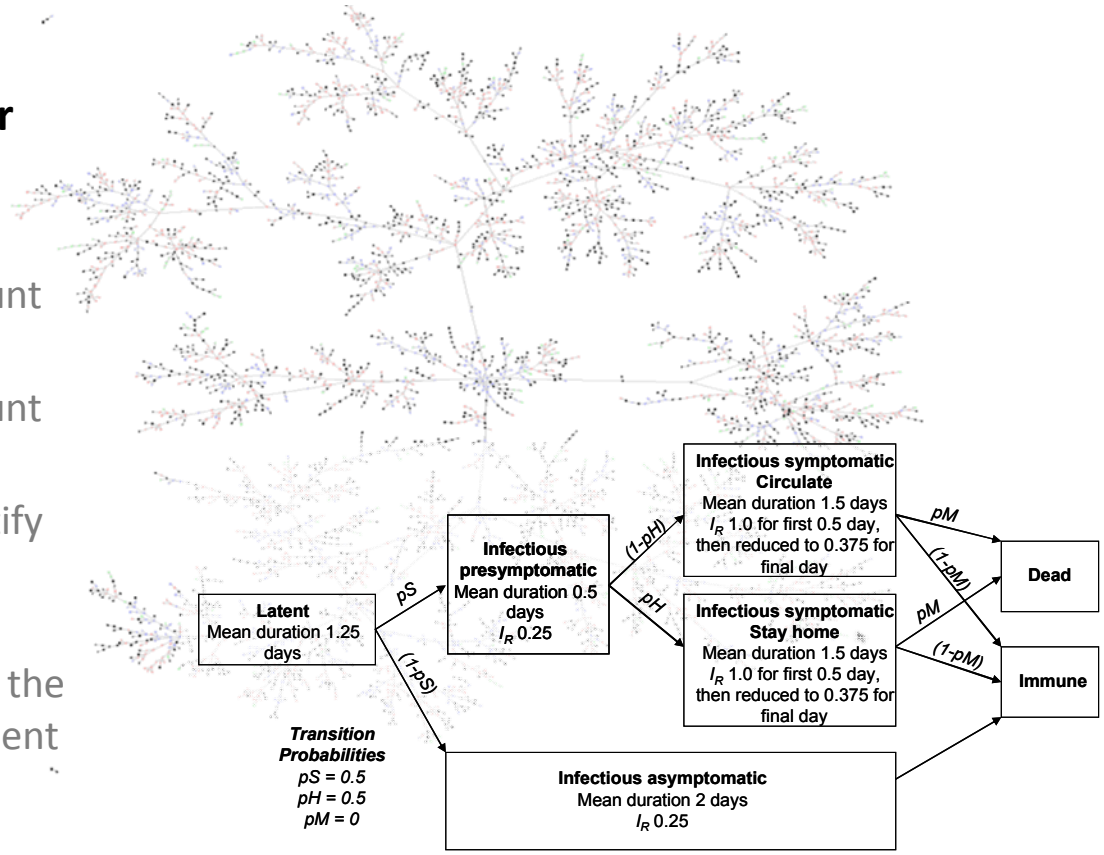

Epidemiological Model (Modified SEIR)

Examples of CASoS problems addressed

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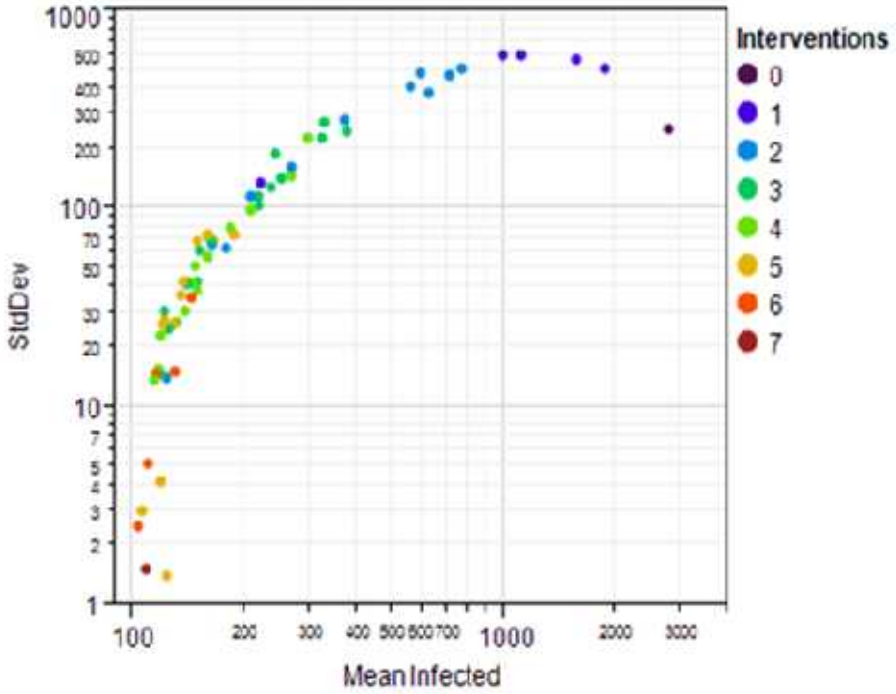
Pandemic planning

- 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



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)

Examples of CASoS problems addressed

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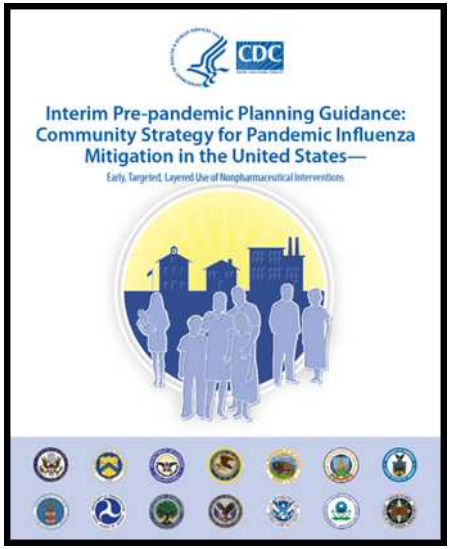
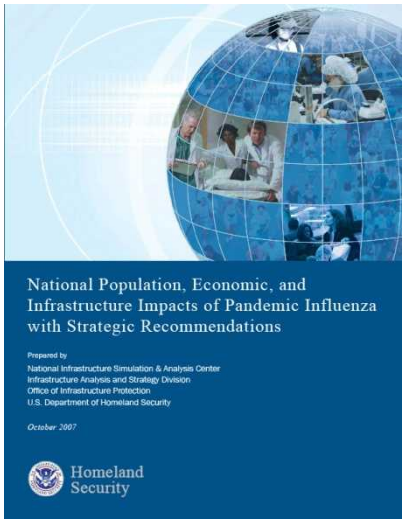
Pandemic planning

- 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**





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.

Examples of CASoS problems addressed

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Port security and productivity modeling

Security solutions to the container shipping challenge should recognize that, in many cases, commerce, including essential national security materials, must continue to flow…

Stifling commerce to meet security needs simply swaps one consequence of a security threat for another – The National Strategy for the Protection of Critical Infrastructures and Key Assets, *February 2003*

Our Goal

- Build a computer model to facilitate finding the right balance between security and economic interests.
- We track:
  - Cargo
  - Costs
- Understanding the robustness of port to disruptions.

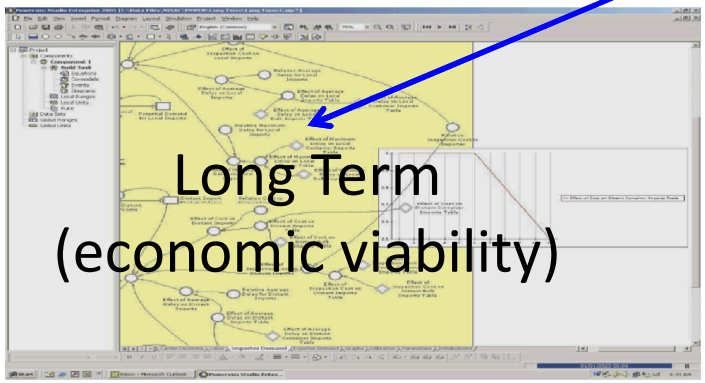
Examples of CASoS problems addressed

Port security and productivity modeling

- Two models for two time scales of interest
  - Short-term (months)
  - Long-term (years)

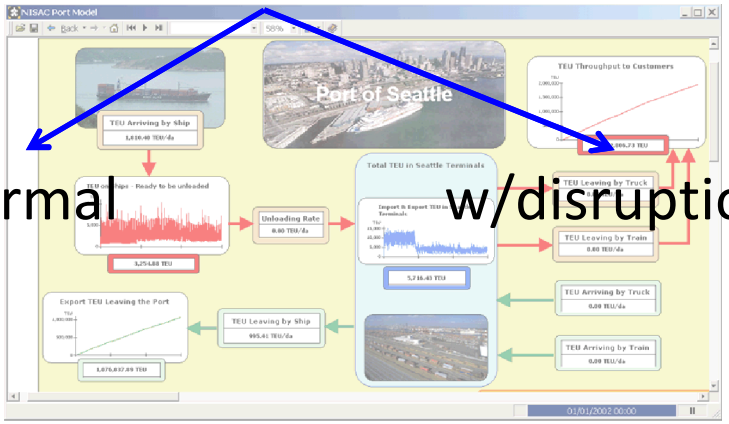
Security Enhancement

Policy



Long Term (economic viability)

Short Term (throughput & costs)



normal

w/disruption

Examples of CASoS problems addressed

Port security and productivity modeling

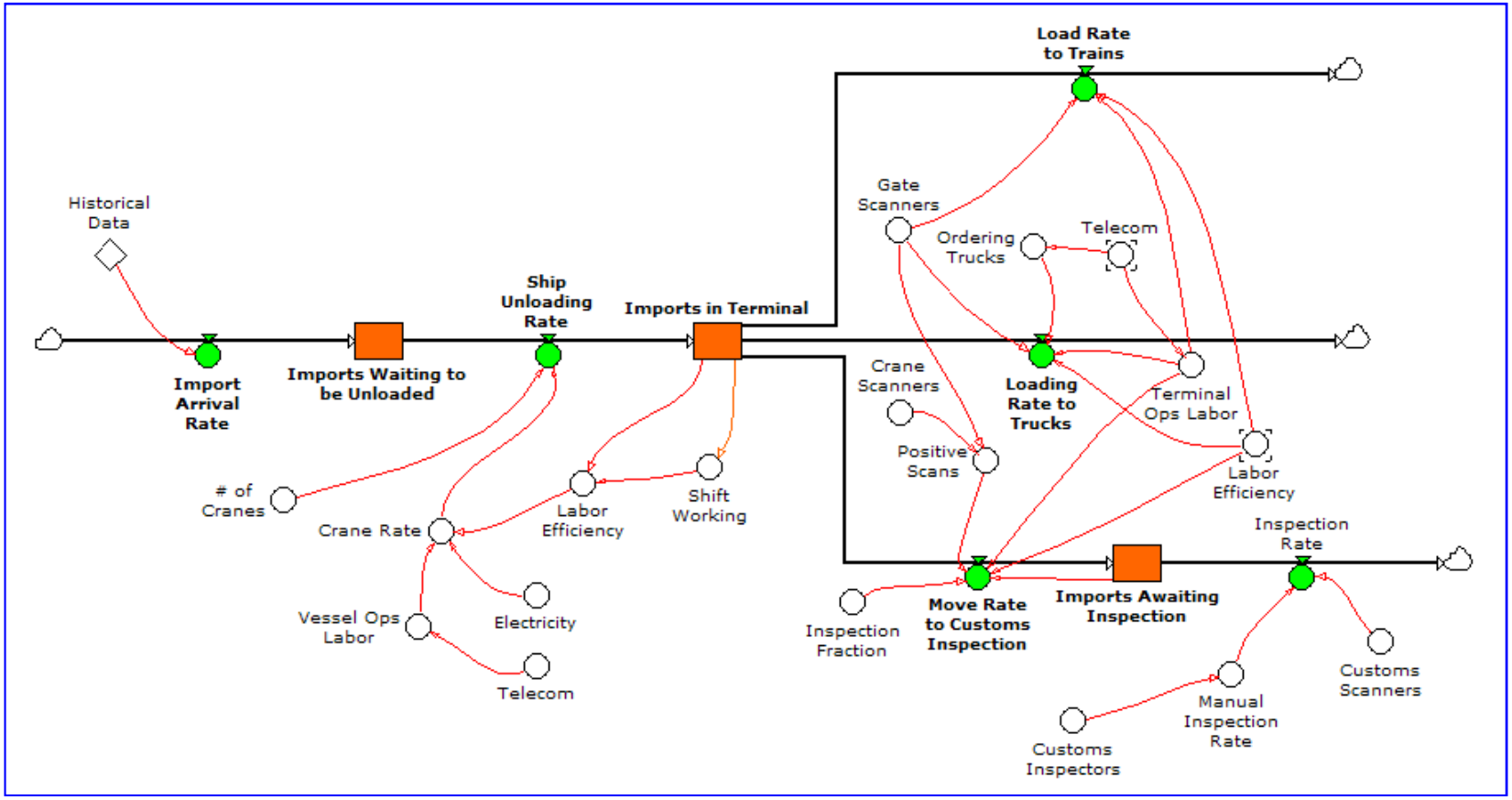
Security policy options

- Increased manual inspections
- Port of departure inspections
- Cargo profiling
  - Early manifest reporting
  - Supply chain assurance (e.g., C-TPAT)
- Container seals
  - Physical
  - Electronic/smart
  - Seals for empties
- Scanners
  - Radiological
  - Chem/bio
- Personnel assurance
  - Background checks
  - Biometric ID

Examples of CASoS problems addressed

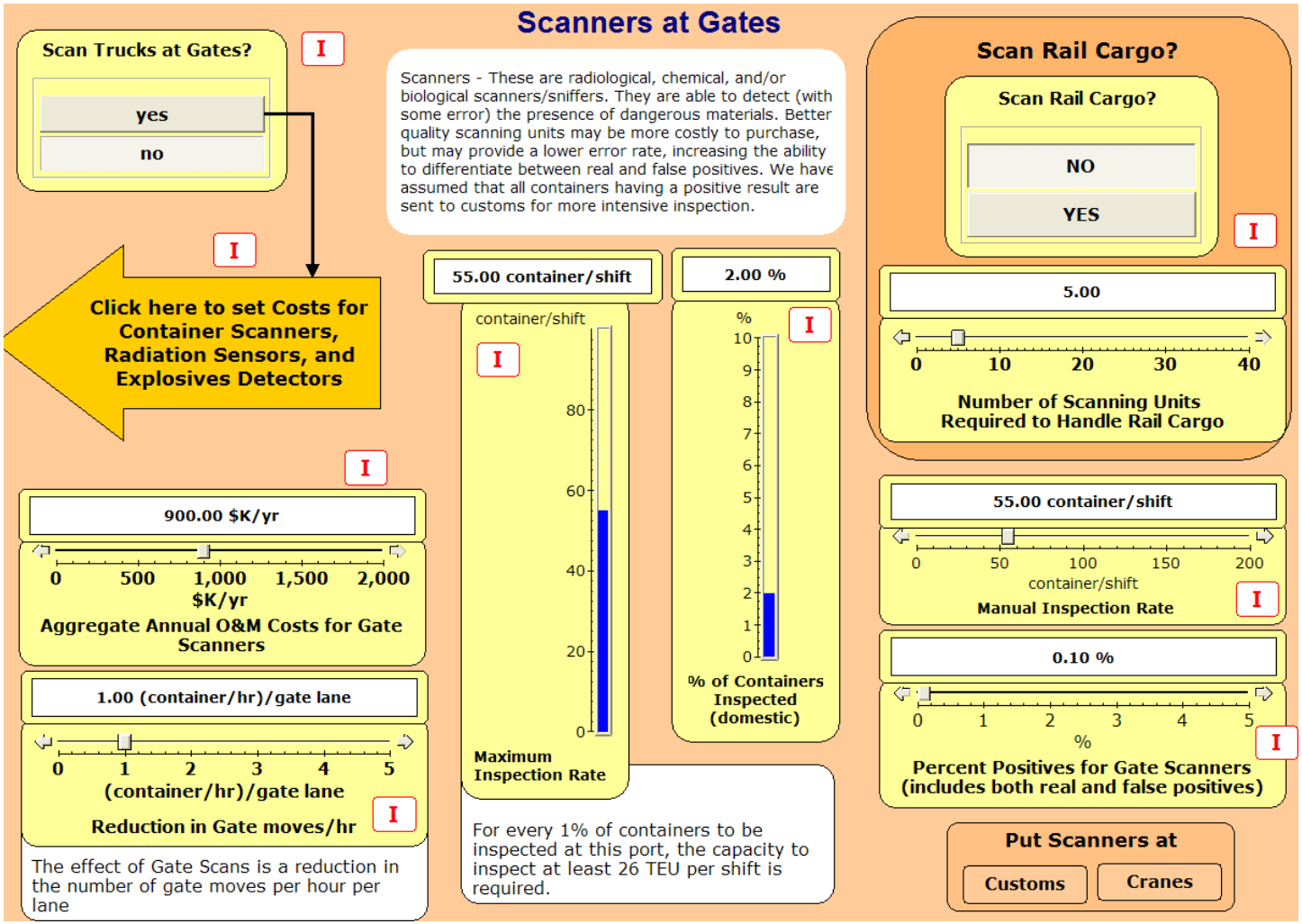
Port security and productivity modeling

Short-Term Cargo Flow Model



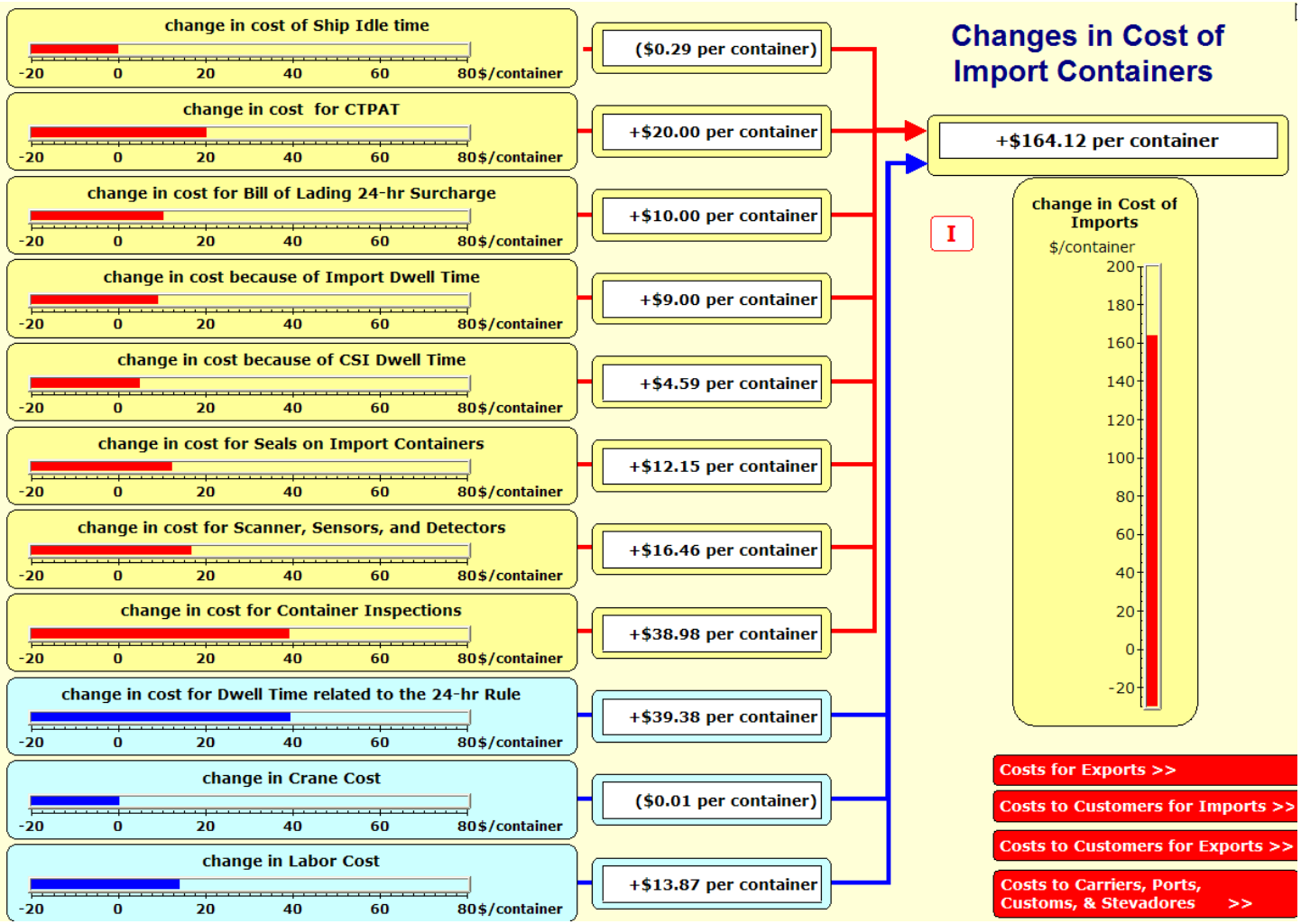
Examples of CASoS problems addressed

Port security and productivity modeling



Examples of CASoS problems addressed

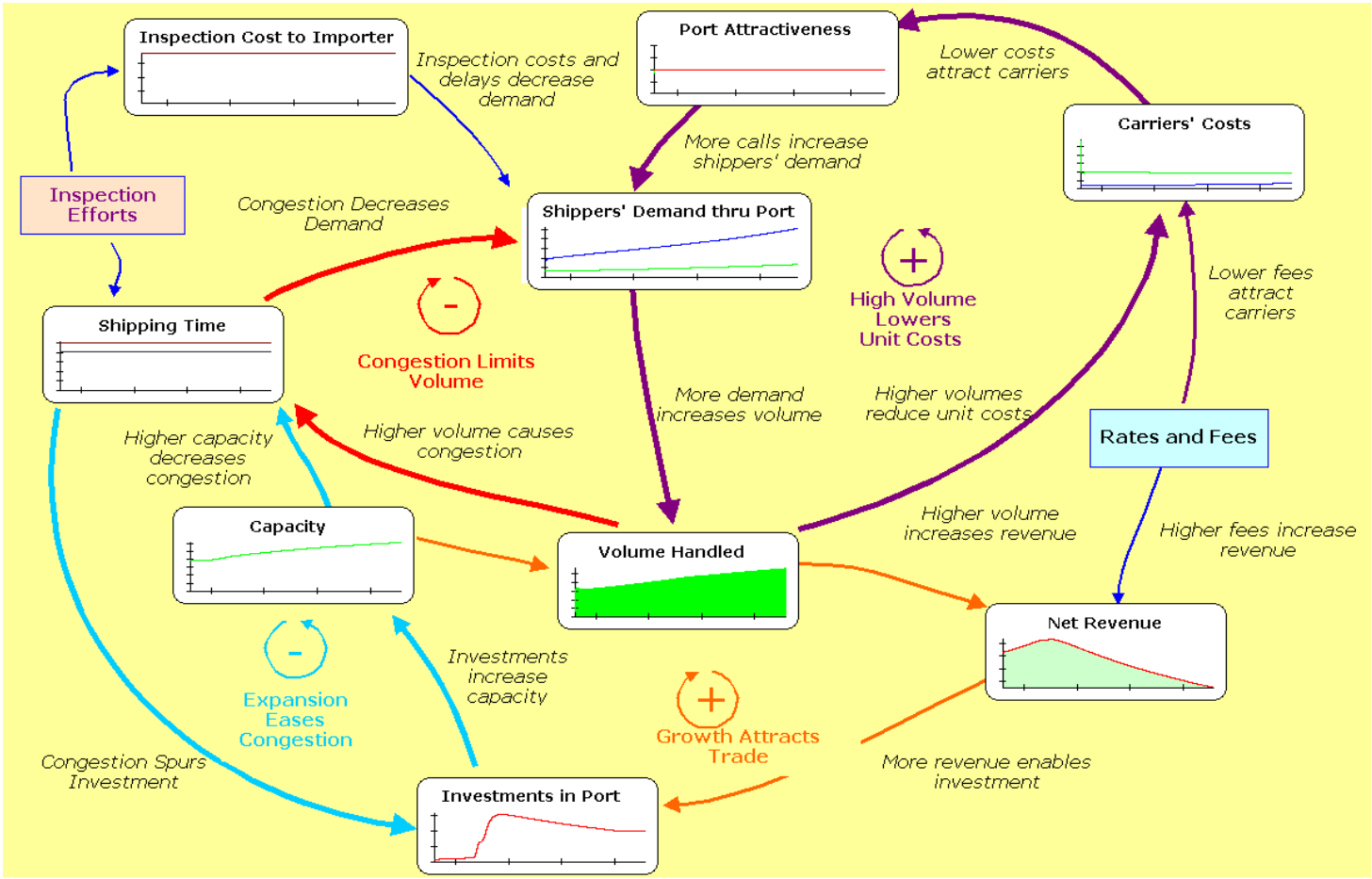
Port security and productivity modeling



Examples of CASoS problems addressed

Port security and productivity modeling

- Long-Term Port Flow Model



Examples of CASoS problems addressed

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Port security and productivity modeling

- Seattle and Portland Workshops

Examples of CASoS problems addressed

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Port security and productivity modeling

Workshop observations

- The short-term operations model provided a tangible grounding for many of the participants
- Some workshop groups developed novel, insightful, dynamic inspection strategies (that we'd have never come up with)
- There is no consensus about what constitutes adequate security: The workshop groups
  - produced a very wide range of comprehensive security policies
  - resisted qualitatively ranking security policies
- Security upgrade decisions seem to be being made by the seat of the pants
  - Nobody really knows how much security they are buying

Examples of CASoS problems addressed

Port security and productivity modeling

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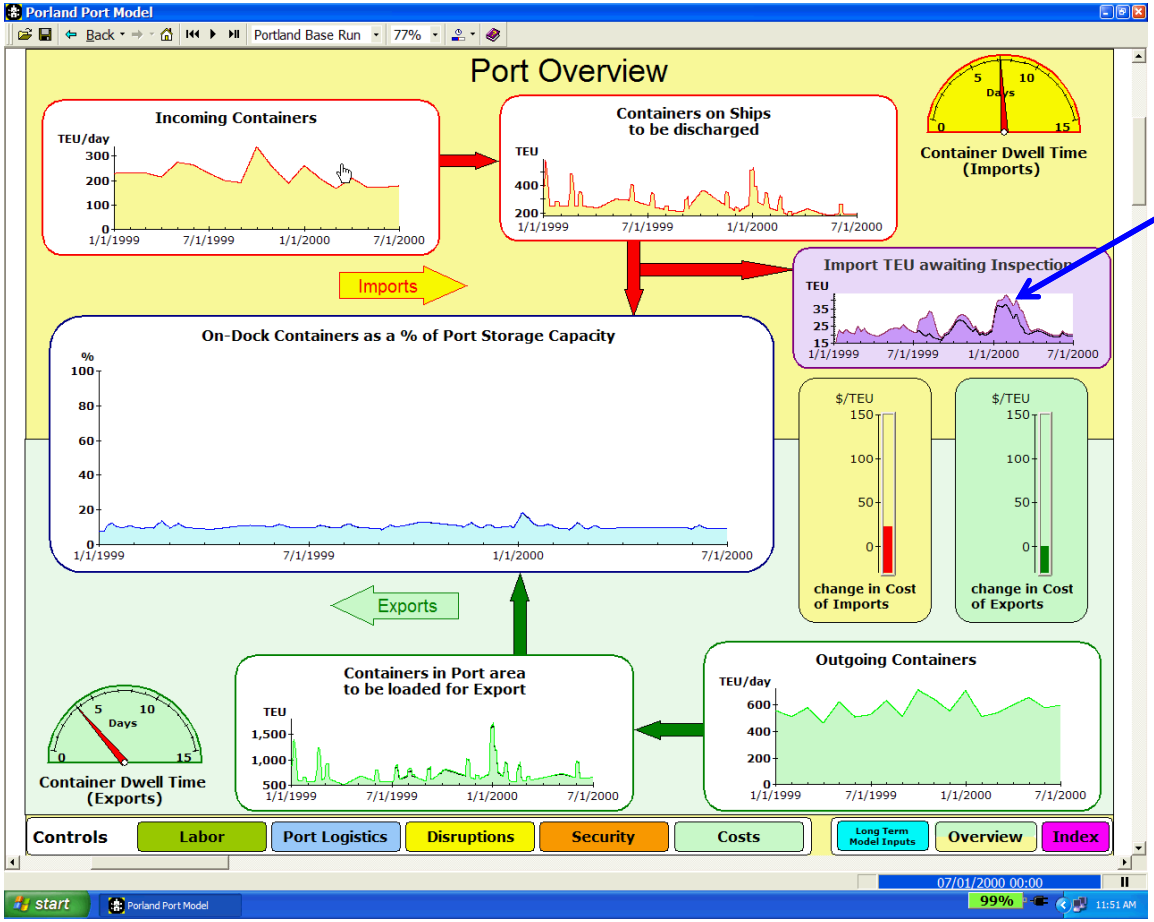
Example from the workshops – Dynamic Security



Using Higher Scanning and Inspection Rate During High Alert and Certain Seasonal Periods

Lessons learned from analyzing CASoS

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- There is no ‘one model’ to solve all problems
  - Perspective drives process
- Getting in front of the question is important
  - as the level of detail you wish to add increases
  - as the time to provide an analytic product that is actionable decreases
- Validation is difficult but important

Lessons learned from analyzing CASoS

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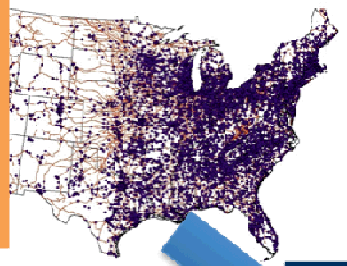
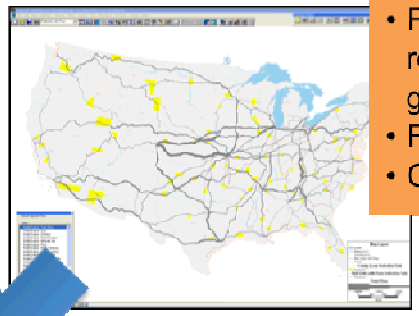
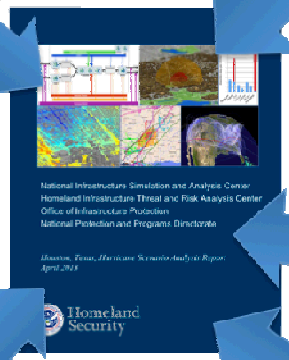
Perspective Drives Process

Spatial/Physical
- Location of key infrastructure assets
- Asset Characteristics
- Co-location

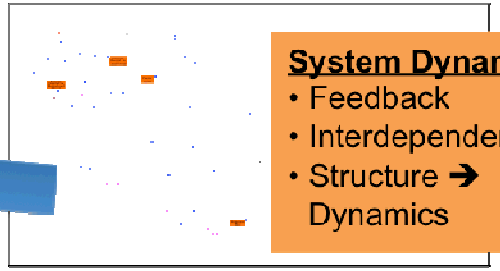


Network
- Flow of resources and goods
- Flow Capacity
- Critical Nodes

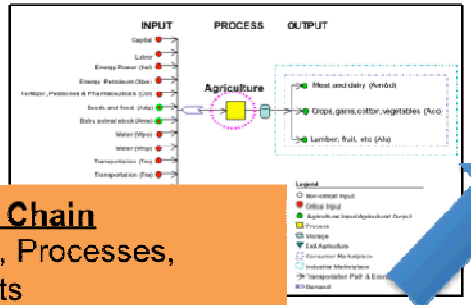




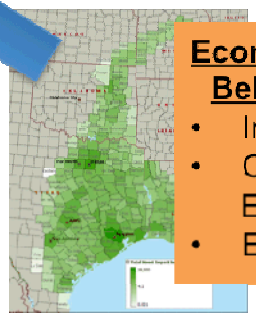
System Dynamics
- Feedback
- Interdependencies
- Structure ➔ Dynamics



Supply Chain
- Inputs, Processes, Outputs
- Process ➔ Infrastructure
- Dependencies

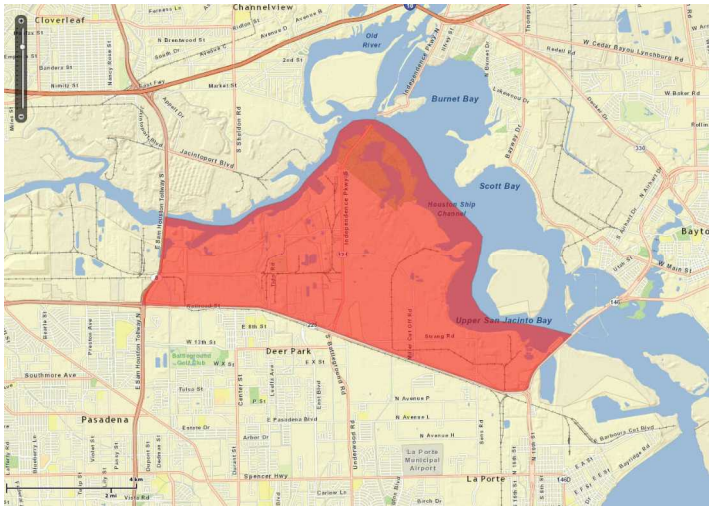


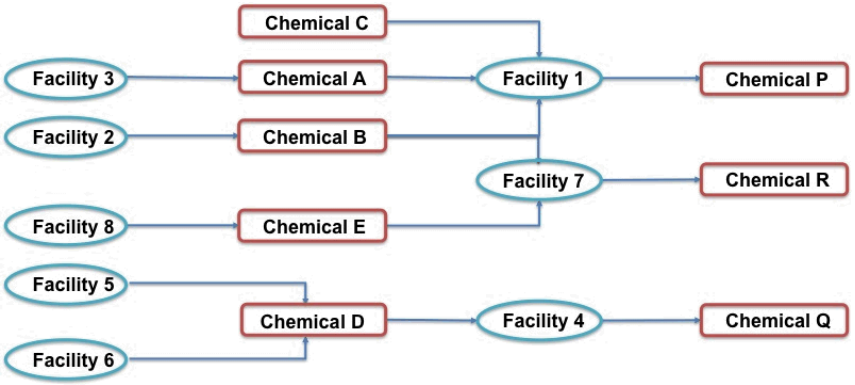
Economics/Human Behavior
- Input-Output modeling
- Computable General Equilibrium modeling
- Evacuation



Lessons learned from analyzing CASoS

- Study of road transportation of chemicals in Houston Ship Channel area
  - Texas Transportation Institute at Texas A&M University did field data collection
    - 107 hours
    - 21611 trucks
    - 2470 HazMat placarded trucks
  - Sandia did analysis of manufacturers and infrastructure in footprint
    - 26 manufacturers
    - Over 100 chemicals produced
  - Identified and quantified truck movements based on annual data well within order of magnitude of field data





Where the future lies

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- 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 understanding with stakeholders on the right ways to use CASoS models
- Building a community of practice

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QUESTIONS & ANSWERS

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What did I say?

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The Washington Post

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White House Got Early Warning on Katrina

By Joby Warrick
Washington Post Staff Writer
Tuesday, January 24, 2006

In the 48 hours before Hurricane Katrina hit, the White House received detailed warnings about the storm's likely impact, including eerily prescient predictions of breached levees, massive flooding, and major losses of life and property, documents show.

A 41-page assessment by the Department of Homeland Security's National Infrastructure Simulation and Analysis Center (NISAC), was delivered by e-mail to the White House's "situation room," the nerve center where crises are handled, at 1:47 a.m. on Aug. 29, the day the storm hit, according to an e-mail cover sheet accompanying the document.

The NISAC paper warned that a storm of Katrina's size would "likely lead to severe flooding and/or levee breaching" and specifically noted the potential for levee failures along Lake Pontchartrain. It predicted economic losses in the tens of billions of dollars, including damage to public utilities and industry that would take years to fully repair. Initial response and rescue operations would be hampered by disruption of telecommunications networks and the loss of power to fire, police and emergency workers, it said.

In a second document, also obtained by The Washington Post, a computer slide presentation by the Federal Emergency Management Agency, prepared for a 9 a.m. meeting on Aug. 27, two days before Katrina made landfall, compared Katrina's likely impact to that of "Hurricane Pam," a fictional Category 3 storm used in a series of FEMA disaster-preparedness exercises simulating the effects of a major hurricane striking New Orleans. But Katrina, the report warned, could be worse.

The hurricane's Category 4 storm surge "could greatly overtop levees and protective systems" and destroy nearly 90 percent of city structures, the FEMA report said. It further predicted "incredible search and rescue needs (60,000-plus)" and the displacement of more than a million residents.

The NISAC analysis accurately predicted the collapse of floodwalls along New Orleans's Lake Pontchartrain shoreline, an event that the report described as "the greatest concern." The breach of two canal floodwalls near the lake was the key failure that left much of central New Orleans underwater and accounted for the bulk of Louisiana's 1,100 Katrina-related deaths.

The documents shed new light on the extent on the administration's foreknowledge about Katrina's potential for unleashing epic destruction on New Orleans and other Gulf Coast cities and towns. President Bush, in a televised interview three days after Katrina hit, suggested that the scale of the flooding in New Orleans was unexpected. "I don't think anybody anticipated the breach of the levees. They did anticipate a serious storm," Bush said in a Sept. 1 interview on ABC's "Good Morning America."