U.S. DEPARTMENT OF ENERGY

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A Retrospective of 10 years of Infrastructure Modeling, Simulation, and Analysis

Daniel Horschel

Actionable Knowledge Solutions

Sandia National Laboratories

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National Nuclear Security Administration

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Outline

- **What is NISAC (Our Pedigree)**
- **The Right ~~Tool~~ Question**
  - Use the right model
  - Starting small
  - Monolithic models can be inflexible and difficult to tailor to a specific question
- **Data**
  - Often you need to work in a data sparse environment
  - Ownership/Sharing
  - Feedback loops (running models during an event, improving the models)
  - Models can also point out where it is useful to get more data
- **It's not the Tool, It's the Analyst (and the team)**
  - The importance of a cadre of tools and approaches
  - The importance of SMEs (V&V)
  - The emergence of a new type of SME
  - Those that can take Action
- **Developing Trust in the Models/Analysts**
  - Would you change a system/policy based on the analysis?
  - V&V is not possible, How do you develop trust?
  - A "pull" from an end user is needed
  - Broadening around just the "event"
- **Getting Right People Together**
  - From Academic peer-reviewed documents to stop-light fact-sheets and a BB message
  - … With Trust in the Analyst's products, communications can be tailored to the end user

National Infrastructure Simulation and Analysis Center

INFRASTRUCTURE

PEDIGREE

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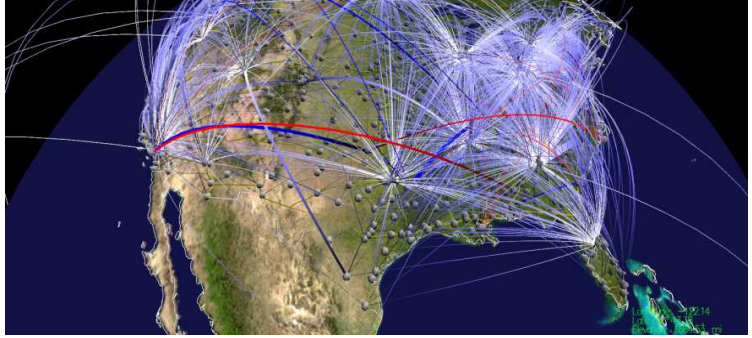
NISAC History & Mission

- **Patriot Act identified NISAC as the center for Critical Infrastructure Interdependency Modeling, Simulation, and Analysis.**
- **Provide a common, comprehensive view of U.S. infrastructure and its response to disruptions.**
- **Operationally-tested DHS rapid-response capability.**
  - 24/7 crisis action analysis
- **Devolution site for DHS/HITRAC**



NISAC is a critical component in DHS/NPPD/IP's analytical capability

NISAC Structure

- Department of Homeland Security Program, jointly executed by Sandia and Los Alamos National Laboratories
- Draws upon the expertise of 40-50 individuals located across the two sites

- Uses the unequalled and extensive reachback capabilities of Sandia and Los Alamos National Laboratories as premier United States National Security Laboratories

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What We Want to Know About Infrastructures and Their Interdependencies

- Are certain systems, networks, supply chains, parts of the country more at risk than others? Why?
- Have interdependencies increased the risks or have they changed them?
  - What conditions have to exist to cause cascading failures?
  - What size of event has to occur to initiate cascading failures?
- Are there trends in the evolution of the infrastructures toward more vulnerable conditions or configurations?
- Are we repeating any mistakes from the past or have we really learned from them?
- How do the risks to infrastructures impact national security?
- How can we reduce the risks to infrastructures?
  - Can we afford to reduce those risks?
  - Over what timeframe?

This is a Hard Problem

- Need to enhance preparedness, protection, response, recovery, and mitigation activities
- Quantifying / Qualifying interactions of political, health, social, economic and technical systems including uncertainties
- Coupling socio-systems (power networks, societies, etc.) to physical systems (climate, weather, CBRNE, …)
- Empirically-based computational social science does not exist
- Large, complex data; data poor environments
- Calibration, Verification, Validation
- Multiple simultaneous scales and resolutions
- Attribute-based assessments cannot capture non-local, non-intuitive or interdependency effects
- Operationalize confidence and trust in decision support

Why we model

- **The domains in which we work are:**
  - Large
  - Complex
  - Dynamic
  - Adaptive
  - Nonlinear
  - Behavioral

August 14, 2003 Northeast Power Outage

- **Too complex for mental models to be effective decision tools**
- **Identify when/where things break, and any cascading effects**
- **Quantifying consequences of disruptions in very complex systems**
  - **Loss of a single asset or node within a particular system due to a directed attack**
  - **Regional disruptions due to a natural disasters or large scale attacks**
- **The rational choice is to…**

  Experiment with models, *not* the system

  Gain expert operational insight through modeling

FY12 NISAC Activities

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- **Capability Development**
  - Global Financial
  - Global Oil
  - Flooding
  - Electric Power
  - Economics
  - Chemical Supply Chain
  - Healthcare
  - Prioritization
  - Water
  - WME Fragility Modeling
  - Food & Agriculture
- **Planned Analysis**
  - Hurricanes
    - Houston
    - Corpus Christi
    - New Orleans
  - Regional Resilience
  - Salt Lake City Earthquake
  - Retail Payment System
  - Cyber
  - Pandemic
- **Crisis Action**
- **Support Activities**
  - Models
  - Systems
  - Data
  - Deployed tools
  - V&V
  - Science Advisor

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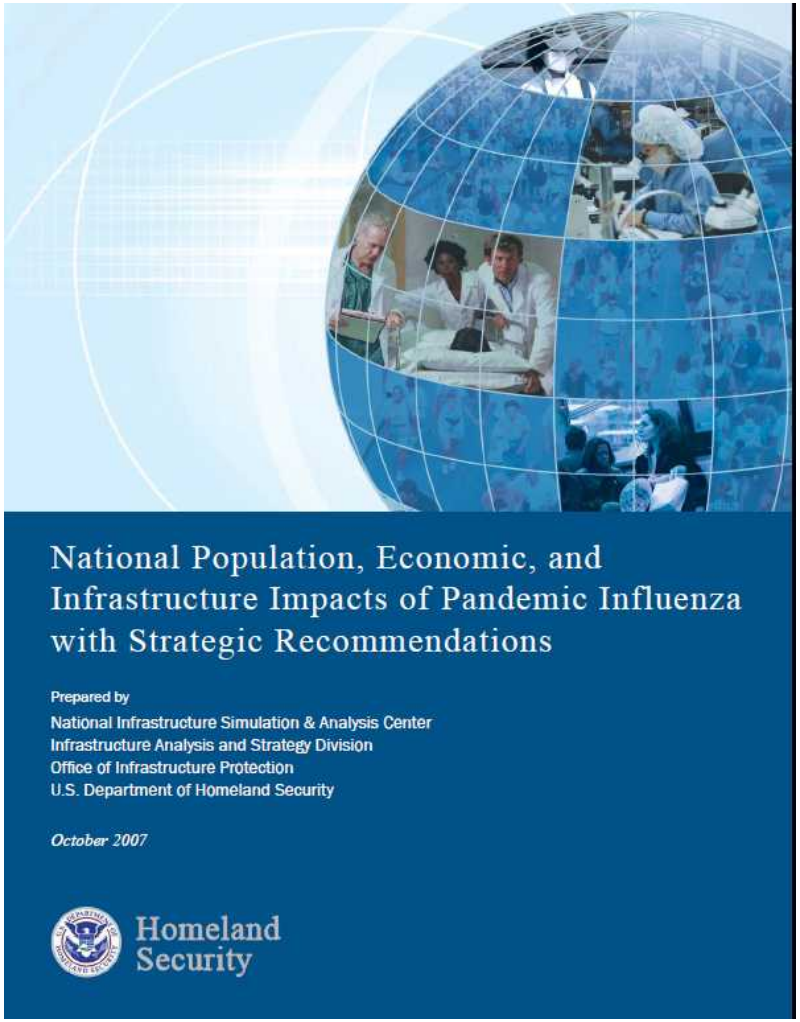
All Adages are True, You Just Need to Know When

The early bird gets the worm.

The second mouse gets the cheese.

Thoughts and Examples

- Thoughts
  - Sandia's analysts/model developers were queried. They have been with NISAC for many years, most since the beginning. They are our Subject Matter Experts. (…And some of mine own as a manager in the group for several years.)
- Examples
  - To provide specific examples, an Avian Influenza Pandemic Influenza study is dovetailed into each section.




The Right ~~Tool~~ Question

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THE RIGHT ~~MODEL~~ QUESTION

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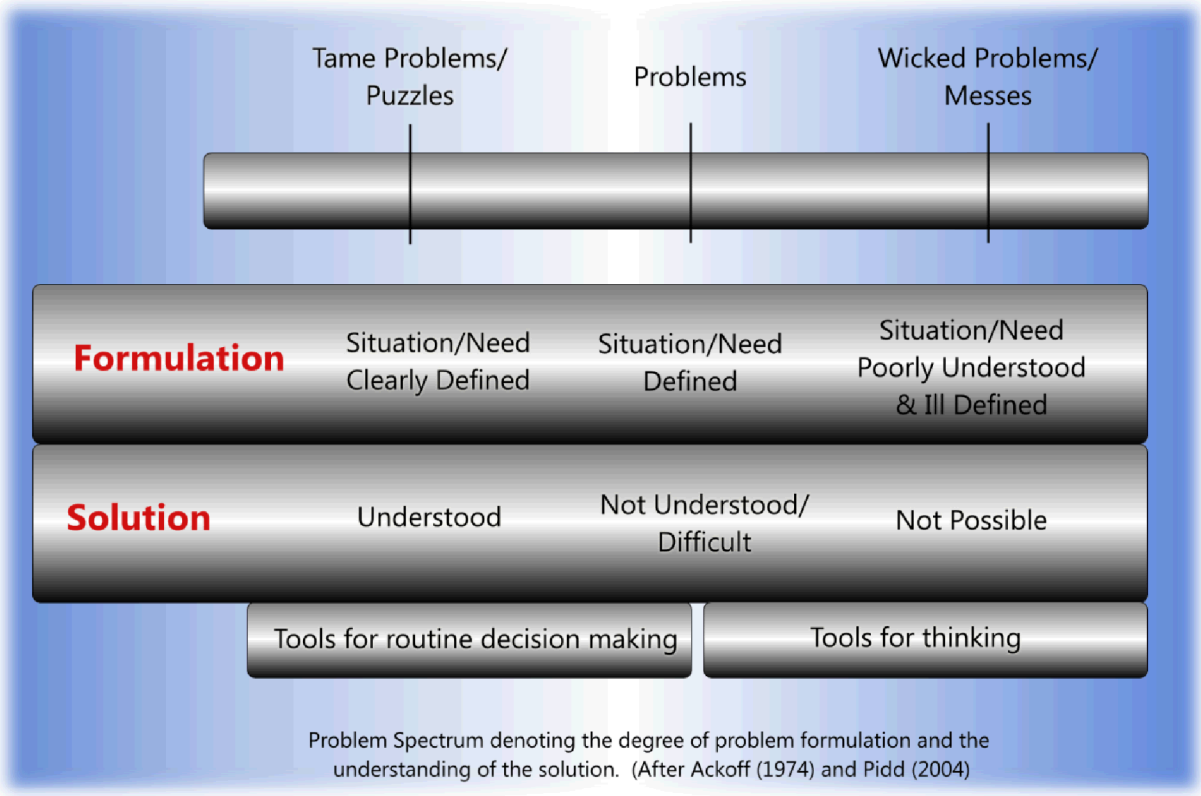
Model Regimes Determines the Modeling Approach

Many of the problems DHS wants answered are "wicked problems and messes"



Problem Spectrum denoting the degree of problem formulation and the understanding of the solution. (After Ackoff (1974) and Pidd (2004)

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Range of Capabilities Are Necessary

Realistic → **Abstract**

Decreasing detail, computation and development time

Data on system elements	**High-fidelity models - individual infrastructure elements**	**Systems models of aggregate supply - demand dynamics**	**Generic, highly abstracted network models**
Only know what is measured or monitored - limited to specific set of conditions *For existing systems only*	**Detailed simulation of changes in conditions or behaviors** *For complex systems and detailed phenomenology*	**Effects of conditions and limitations on system operation** *For trade-studies and planned systems*	**Simulation and identification of vulnerabilities of different network topologies to disruptions** *For quick-turnaround answers*

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MSA

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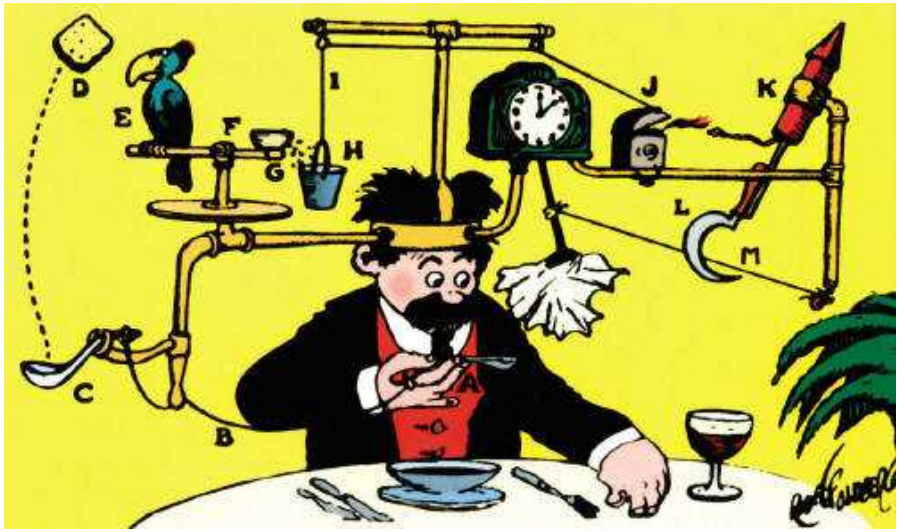
Spiral Development of Question and Model

- Start simple and build
- Multiple tools and approaches
- What data is available?
- A tool for “everything” is difficult to validate and understand, difficult to tailor to “today’s” question

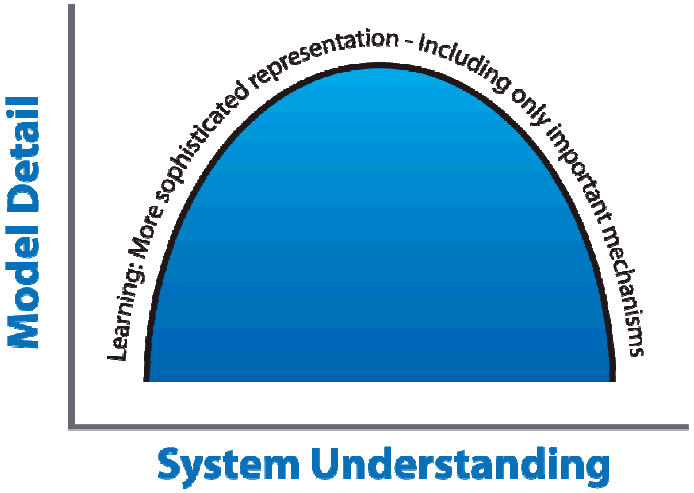


Source: Amazon.com

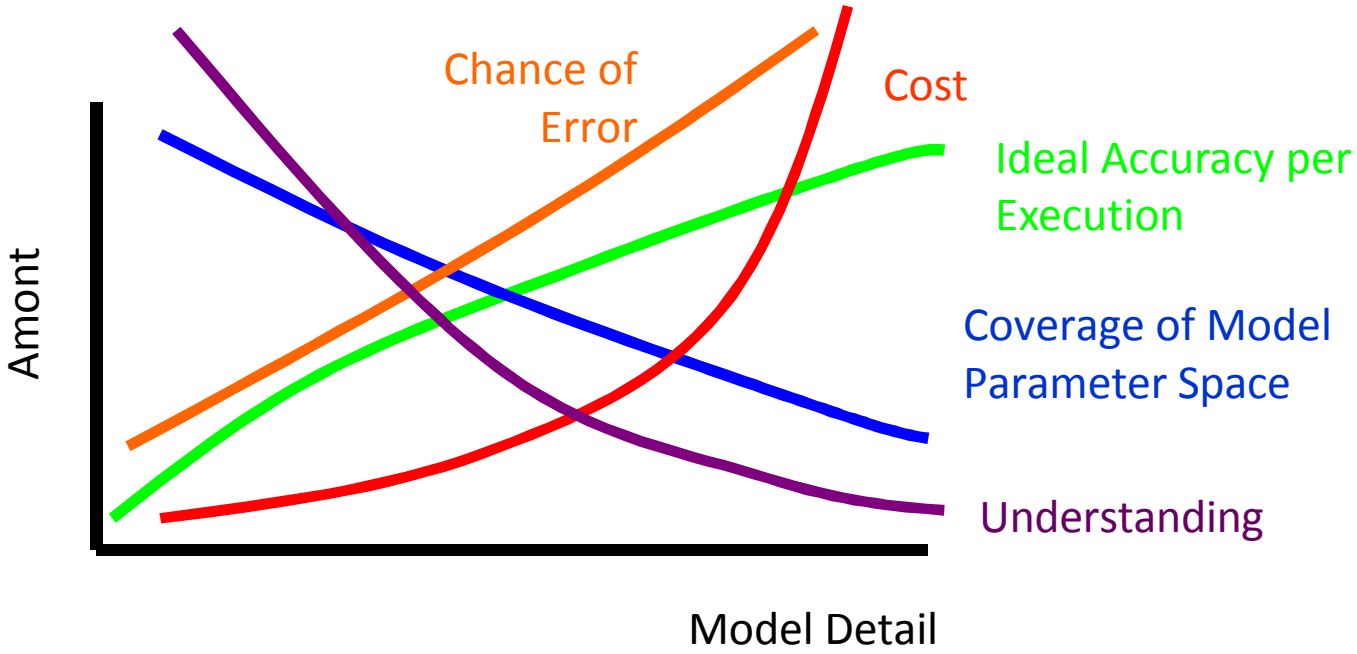
Detail of Models and Analysts' Understanding

Why simplification of models and increased understanding is needed

- Our questions and therefore our models must extend beyond design basis for engineered systems to include abnormal, even catastrophic events
- From past observation, large models exhibited relatively simple behaviors
- Verification & validation become more difficult as the size/detail of the model increases
- Models can become so complex they are difficult to understand



Detail : More can be less



1. Recognize the tradeoff
2. Characterize the uncertainty with every model
3. Buy detail when and where it's needed

Detail of Models and Analysts' Understanding

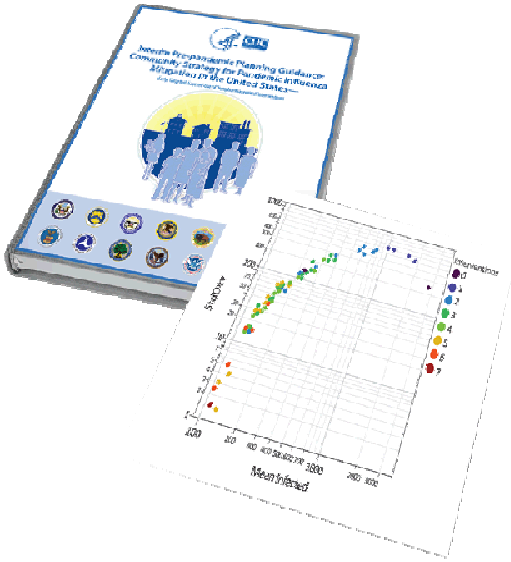
Everything that can be counted does not necessarily count;

Everything that counts cannot necessarily be counted.

William Bruce Cameron

Pandemic Example the Initial Study

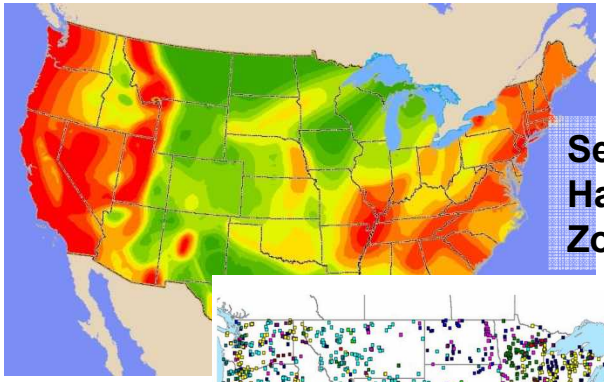
- There was no customer call: initiated by NISAC staff to look at events that could have impacts similar to 9/11
- Simple dynamic simulation models: SEIR; simple network models to look at disease propagation, contacts at CDC
- Used some Health System modelers and CDC staff as SMEs.
- Well received at DHS and shared relatively broadly for a “study”



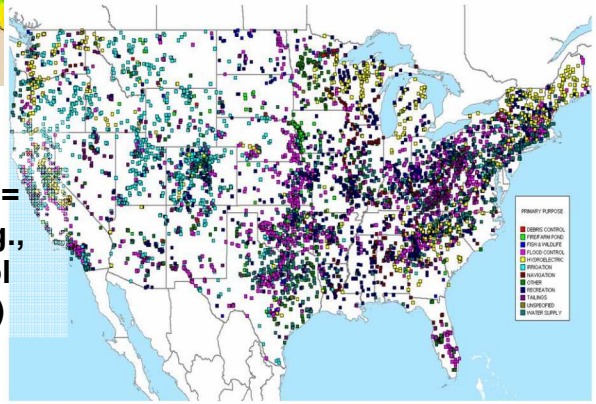
Example

U.S. Hazards Assessment: Preliminary Report. October 18, 2005

October 4, 2005: NISAC was tasked by ASIP to do a systematic evaluation of the US to identify scenarios with high likelihood and severe consequences.



Seismic Hazard Zones



Dams
(Color code = purpose; e.g., flood control hydroelect,)

Agriculture/Food:
- Foot & Mouth
- Disease
- Food-borne illness

Banking and Finance:
- Distress of banks (Re)insurance Disruption
- Financial contagion and currency shocks
- Loss of confidence in markets

Dams

Economics:
- China
- Demographics of Aging
- Poverty

Emergency Response:
- Desertion by emergency personnel
- Destruction of hospitals
- Need for specialized resources

Energy:
- EHV transformers
- Control Centers
- Natural Gas
- World Oil
- Refining Capacity
- Powder River Coal

Natural Disasters:
- Climate Change
- Earthquake
- Tsunamis
- Volcanism
- Landslides
- Meteorological

Public Health:
- Pandemics

Telecommunications

Transportation:
- Major metropolitan outage
- Distributed simultaneous outages
- Persistent terrorist events

Set agenda for research in FY06: Evaluate policies designed to offset infrastructure disruptions of:
- •LNG, NG supply, storage, pipeline capacity)
- •EHV transformer reserves
- •Pharmaceutical stockpiles
- •Refined petroleum product reserves

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NISAC

Data

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DATA

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Data Poor-The Way things Are

- The data you need is never available… you often work in a data sparse environment
- The private sector owns most of the infrastructure data
- Some very useful government data are collected

Data Poor-The Way Things Are

- Commercial Sources of Data
  - Extremely helpful
  - Not always correct; correcting data, updating and re-synchronizing needs to be an ongoing process

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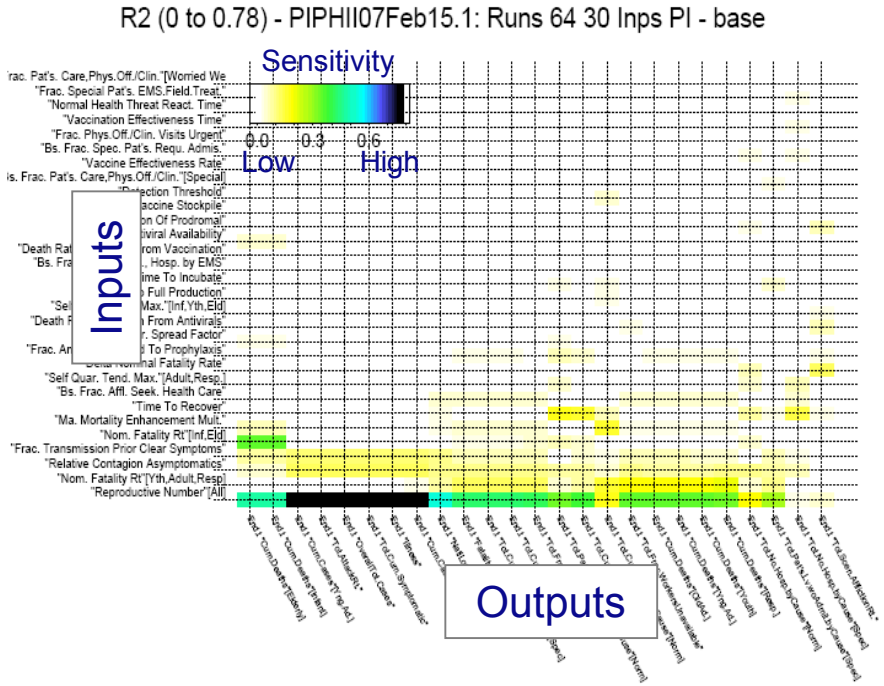
Example

Key Findings – Sensitivity

- Parameters that contribute significantly to variance
  - **Reproductive number (R_0)**
  - **Proportion of transmission occurring prior to symptoms**
  - Time to recover
  - Fraction of infected people that are asymptomatic
  - Relative contagion of asymptomatics
  - *Contact tracing effectiveness*
  - Case fatality rate
  - *Antiviral production rate*



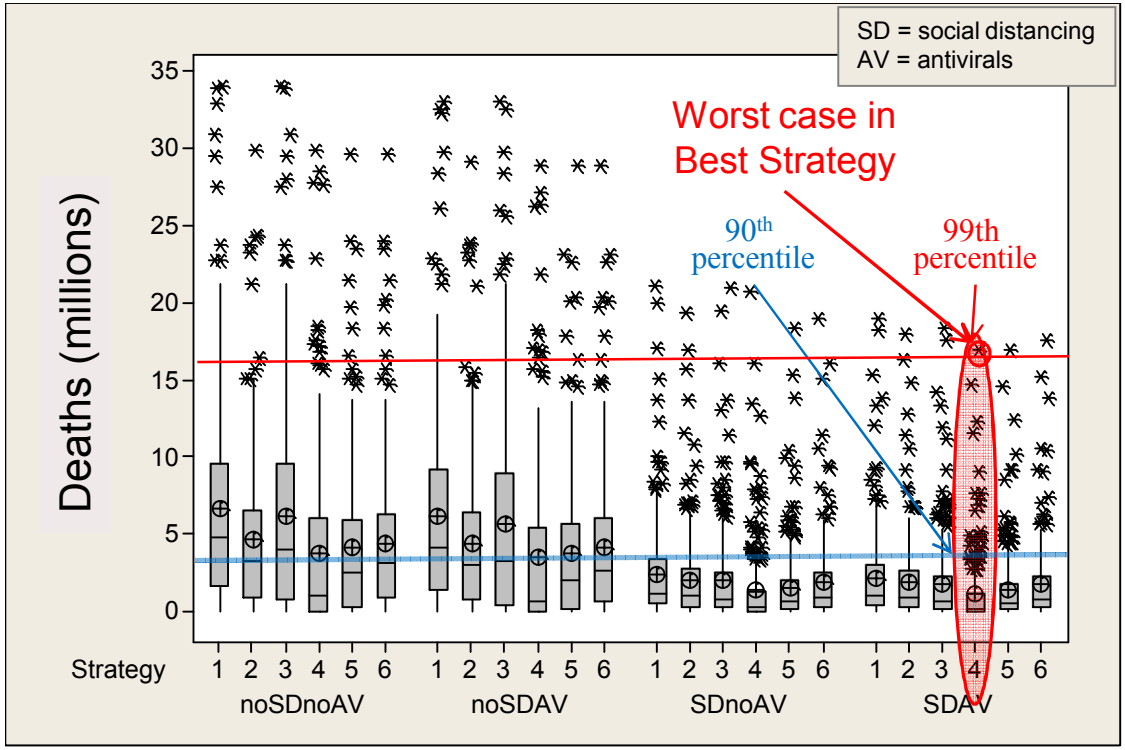
So what?

- These are things to measure or improve early in a pandemic to optimize response

Example

Key Findings – Variability in Results

- High variability due to uncertainty in inputs
- Even the best mitigation strategy has a wide range of outcomes
  - Up to 16 million deaths in the worst case using the best intervention strategy



So what?

- High variability in results: worst case could be 20 times the average case

Shaded boxes show the interquartile range[1] (IQR)
Horizontal bar in box is median
Circle with "+" depicts average value
Whisker extends to min(max value, 1.5 * IQR)

[1] IQR is the distance that spans the middle 50 percent of the data.


It's Not the Tool

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IT'S NOT THE TOOL

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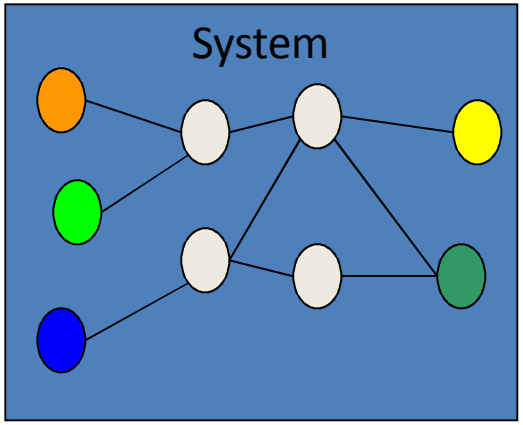
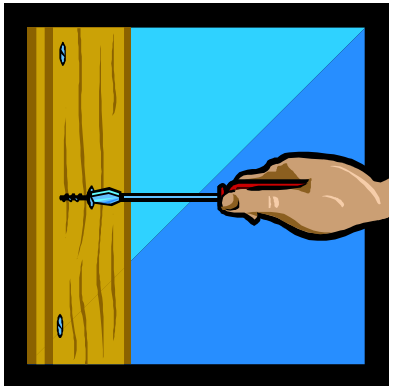
Finding the right model

- **There is no general-purpose model of any system**
- **A model describes a system for a purpose**

What to we care about?



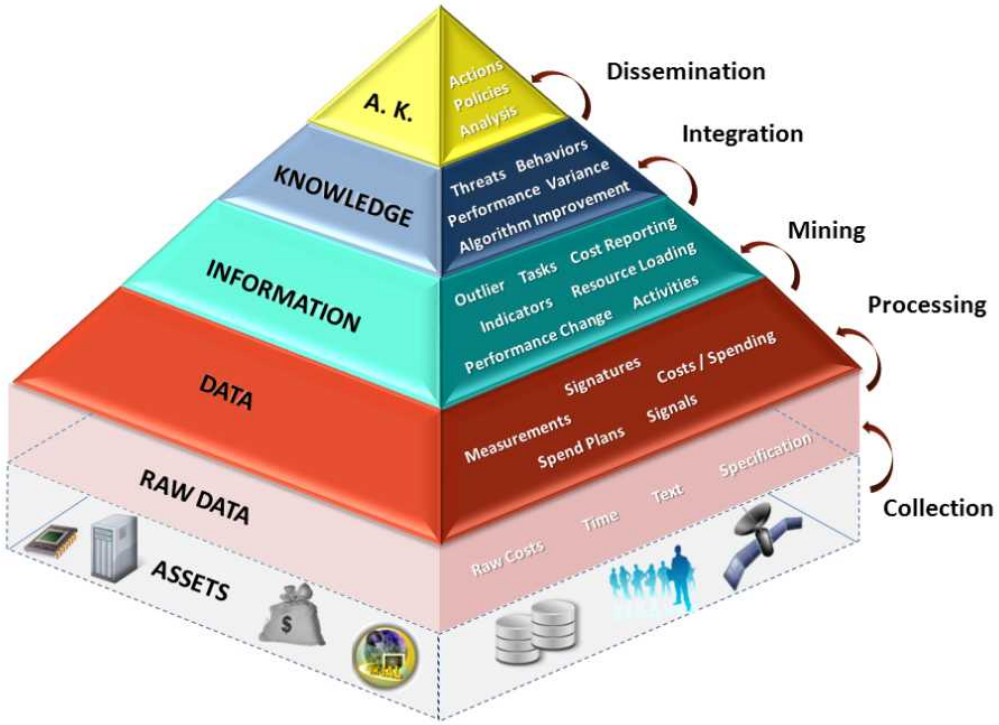
What can we do?



Additional structure and details added *as needed*

From Data to Actionable Knowledge

- Moving from data to models to analyst to decisions maker is the means to turn data into actionable knowledge.
- The “Holy Grail” we all seek.




Trust

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TRUST

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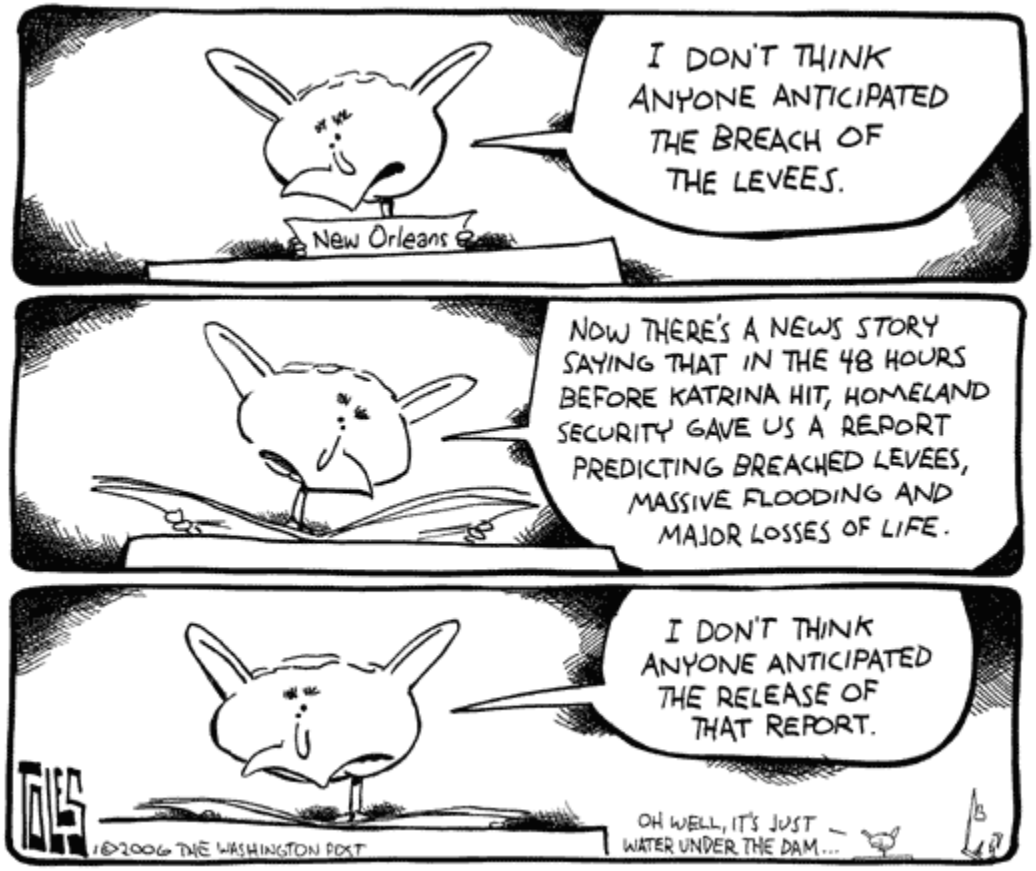
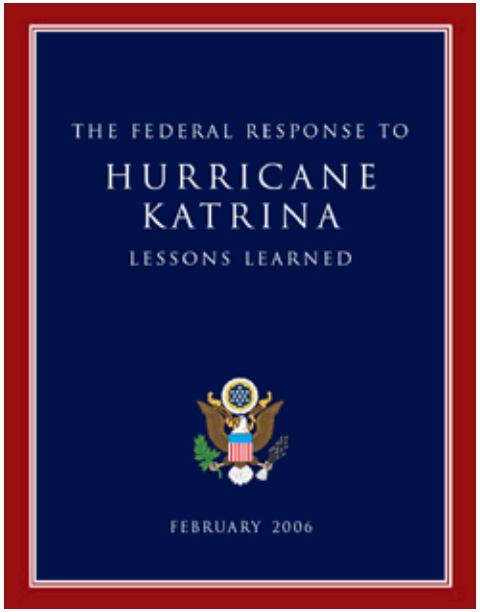
Our Tipping Point for Trust



Washington Post, January 25, 2006



Recommendation # 82:

"DHS should expand the National Infrastructure Simulation and Analysis Center's (NISAC) Modeling and Analysis capability to allow more robust and accurate systems modeling."

White House Report, February 2006

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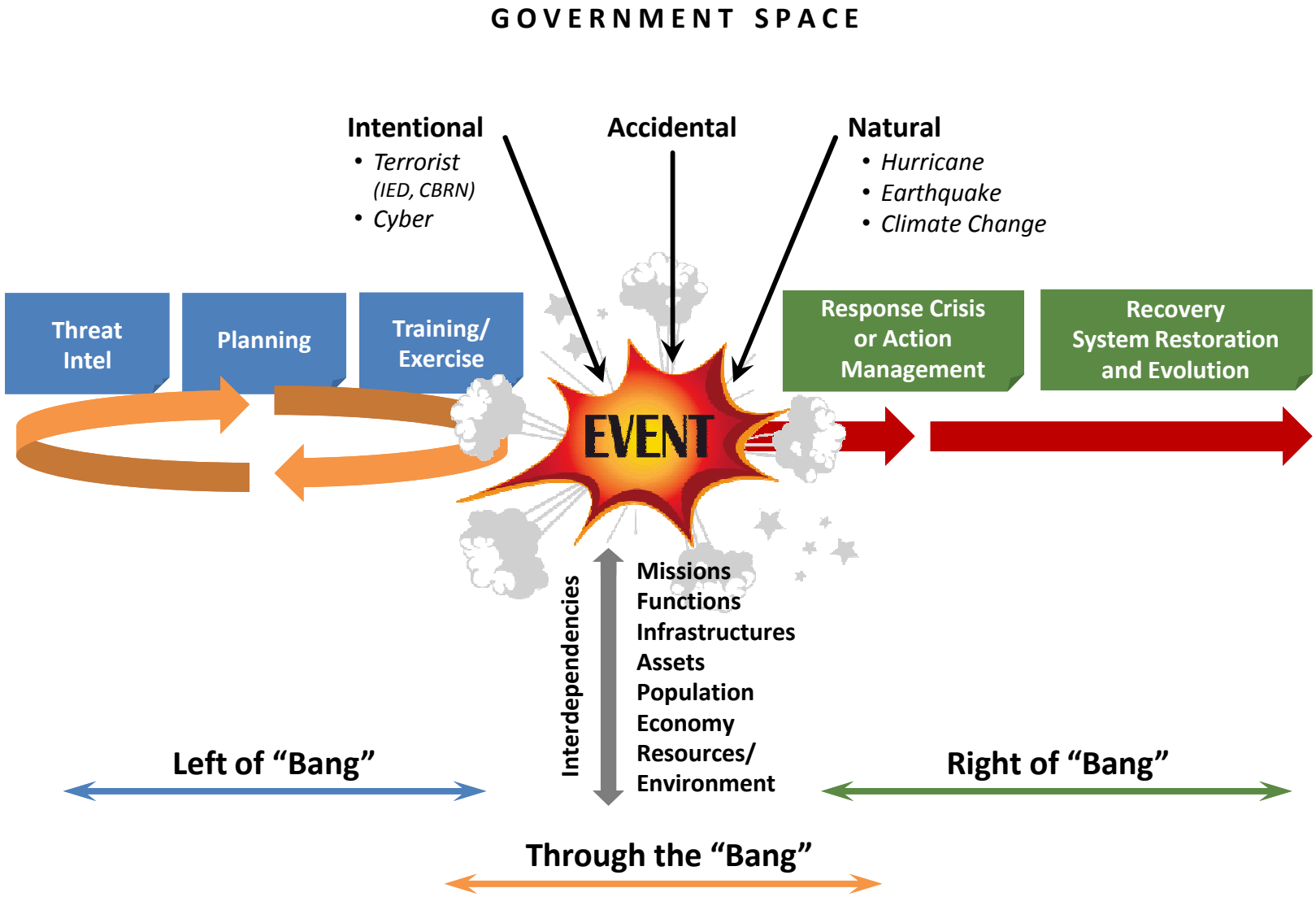
Trust Changed The Game and Our Impact

- **Decision Makers could**
  - Ask what if questions
  - Plan and make preparations for events
  - Change policy
- **The Rest of the story**
  - Pres. Bush read a book on the Spanish Flu of 1912
  - His desire to prepare the country Pandemic led him to NISAC and the formal study that has been used as an example in this presentation

The Event Lifecycle



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Infrastructures Lifecycle

OWNER/OPERATOR SPACE

- NISAC today rarely gets to look at the problem and make recommendations/analyses on the infrastructure before the threat is imminent
- Infrastructure security and resilience can be most effectively managed when considering the entire suite of actions that can be taken over the lifecycle of infrastructures
- By developing capability and expertise for each potential intervention stage, Modeling, Simulation and Analysis could provide a more comprehensive portfolio of infrastructure protection analysis and more effective resilience recommendations

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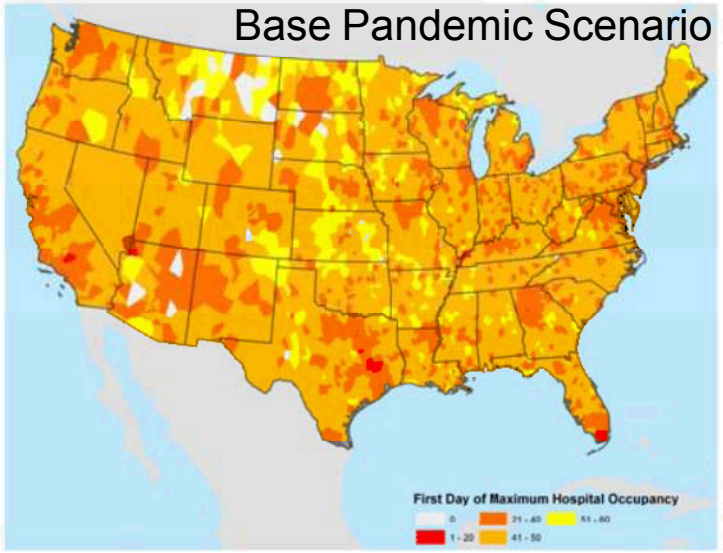
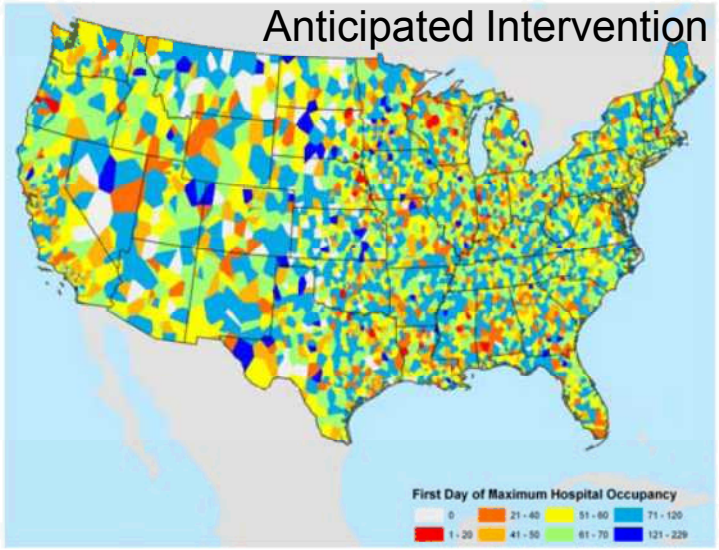
Pandemic Influenza Study

Example

Key Findings – Healthcare





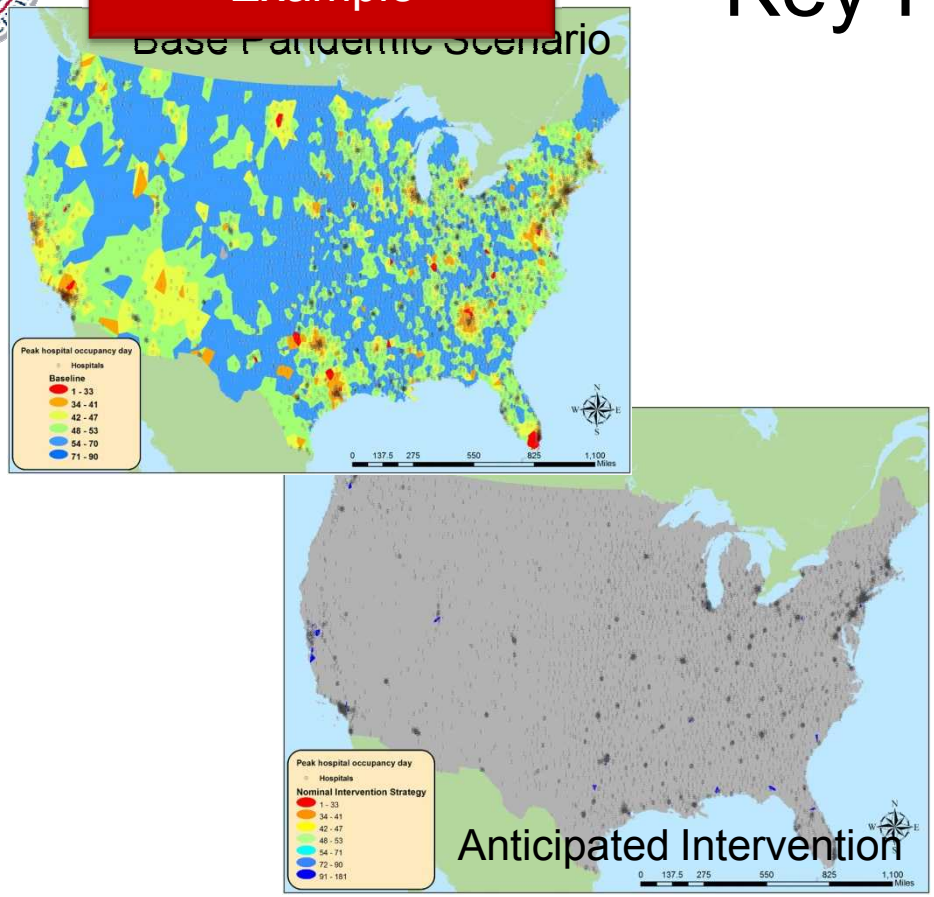
- In severe pandemic, periods of peak occupancy in neighboring communities overlap for several weeks
  - Worker exchange is not possible
  - Entire Nation is affected almost simultaneously
- In mild pandemic or effectively mitigated pandemic, peak effects are spread over several months and worker exchange is possible

So what?

- Geographic worker substitution may not be possible

Example

Key Findings - Healthcare



- Hospitals reach full occupancy *prior to the peak* of the pandemic
  - With no government-directed intervention, overflow duration is 3-6 weeks
  - With government-directed interventions hospital overflow can be limited to a few hospitals that operate at capacity for a few weeks

So what?

- Effective intervention strategy can minimize but not eliminate healthcare impacts
- Impacts in large metro areas, even in best case

Example

gs & Policy Recommendations

- Plan to deal with high fraction of sick & dead among un/underinsured families
- Household quarantine is effective at reducing illness
- Fortify high attack rate areas
- Note: same areas lack adequate normal healthcare capacity
- Ultimate goal is an effective vaccine
- Effective monitoring and good distribution network are necessary for antiviral strategy to work
- Produce and stockpile antivirals
- Promote development of new vaccine technology to prevent significant loss of life and GDP
- Use pre-pandemic vaccine for critical workers first
- Investigate true effectiveness of face masks
- Manufacture & stockpile good face masks
- Distribute masks to critical workers & train them
- Don't close borders to goods
- Study trade-off of natural & forced reduction of business & tourism through border control
- Close schools before 1% of population becomes infected
- Keep schools closed until vaccine is available
- Plan to deal with hourly wage workers when closing schools
- Policy tradeoff: Combinations of pharmaceutical and non-pharmaceutical interventions can balance the impact of the medical and economic outcomes
- A list of things was created to measure or improve early in a pandemic to optimize response
- Plan for and exercise multi-component interventions

Example

gs & Policy Recommendations

- Have a Production, stockpile & distribution plan
- Reasonable effective interventions exist
- Voluntary absenteeism is likely to be larger than medical absenteeism
- Impact not uniform: pre-position supplies appropriately Infrastructures important in pandemic response are at greatest risk from workforce absenteeism
- Top priorities for planning & mitigation
- Workforce reduction similar across the country
- Facilities in some counties will have higher absenteeism
- Most-impacted assets and counties vary by scenario
- Plan for healthcare costs of $2B to $80B, depending on intervention effectiveness
- Day of peak death rate could change by 1-2 months depending on intervention strategy
- Geographic healthcare worker substitution may not be possible
- Health care system will be overloaded
- Temporary treatment facilities are needed
- Natural disasters further increase overload
- Effective intervention strategy can minimize healthcare impacts, but not completely
- No power outages are expected
- Some generating plants may have workforce continuity issues at the peak of the pandemic
- Telecommunication system will maintain operation with telecommuting
- Occasional redialing may occur in major metropolitan areas
- Telecommunications system will not become damaged

Example

gs & Policy Recommendations

- Rail transport: widespread congestion and significant delays beginning at 10% absenteeism (2-3 times annual average)
- Impacts are specific to terminals
- Terminal 6 at the Port of Los Angeles should consider strong mitigation measures, and/or encourage customers to make arrangements with other ports
- Milk supply is expected to continue
- Food sector is probably robust to worst expected absenteeism
- Simple food mitigation: stockpile at locations up & down supply chain
- Mutual Aid agreements unlikely to be effective
- Cross-training of staff and support contracts with local engineering firms are needed
- Water & Wastewater
  - Mutual Aid agreements unlikely to be effective
  - Cross-training of staff and support contracts with local engineering firms are needed
- Workforce continuity
  - Requires planning well in advance at facility level
  - Requires cognizance of critical workers and training/certification time
  - Educate/train existing workforce to prevent panic
  - Address safety limitations & logistical/scheduling limits
- Short-term economic impacts are driven by demand decrease, and about $100B (Katrina-like)
- Long-term economic impacts are driven by fatalities
- Plan exercises to refine execution

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THE IMPORTANCE OF A TEAM

NISAC Success is a Diverse Team

- Depending on where you sit “your team” is obvious. For example, for me it is the model developers, analysts, data manager, and etc.
- We focused on the physical sciences initially
- We understand the importance of other elements; e.g. social sciences.
- Key is a stakeholder/ customer that can use the information. This information “pull” challenges the analysts and allows them to refine their processes.
- Working together and developing a common lexicon takes time, but is essential for quick response.

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Capturing Complex Interdependencies

Integration of Multidisciplinary Skill Sets and Expertise

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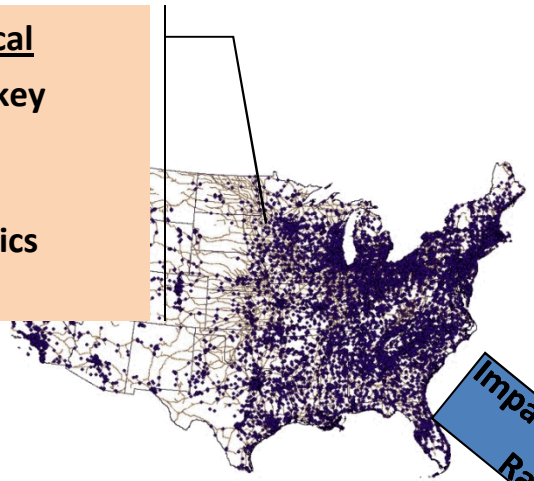
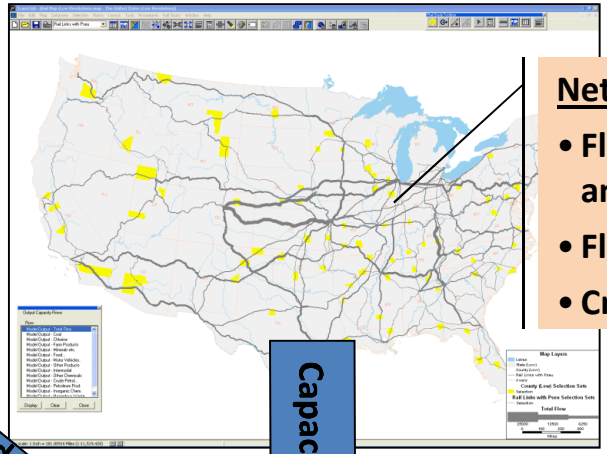
Spatial/Physical

- Location of key assets
- Asset Characteristics
- Co-location



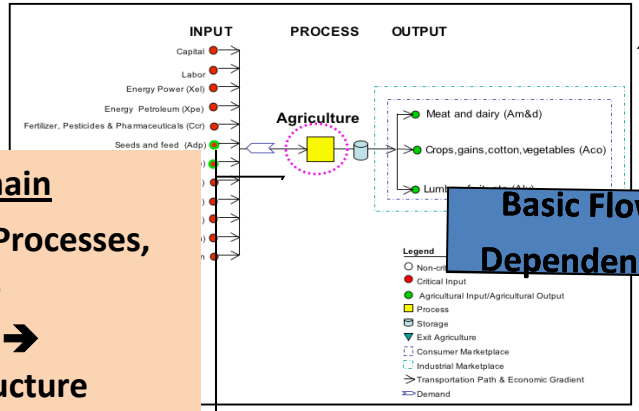


Network

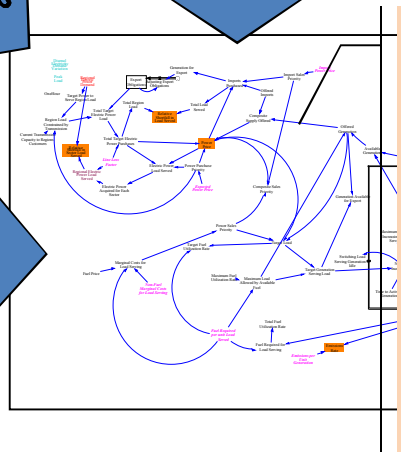
- Flow of resources and goods
- Flow Capacity
- Critical Nodes

Impacted Assets Ratios

Capacities



Basic Flows Dependencies



System Dynamics

- Stocks/Flows
- Feedback Loops
- Interdependencies
- Structure ➔ Dynamics

- Interacting Networks

Supply Chain

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

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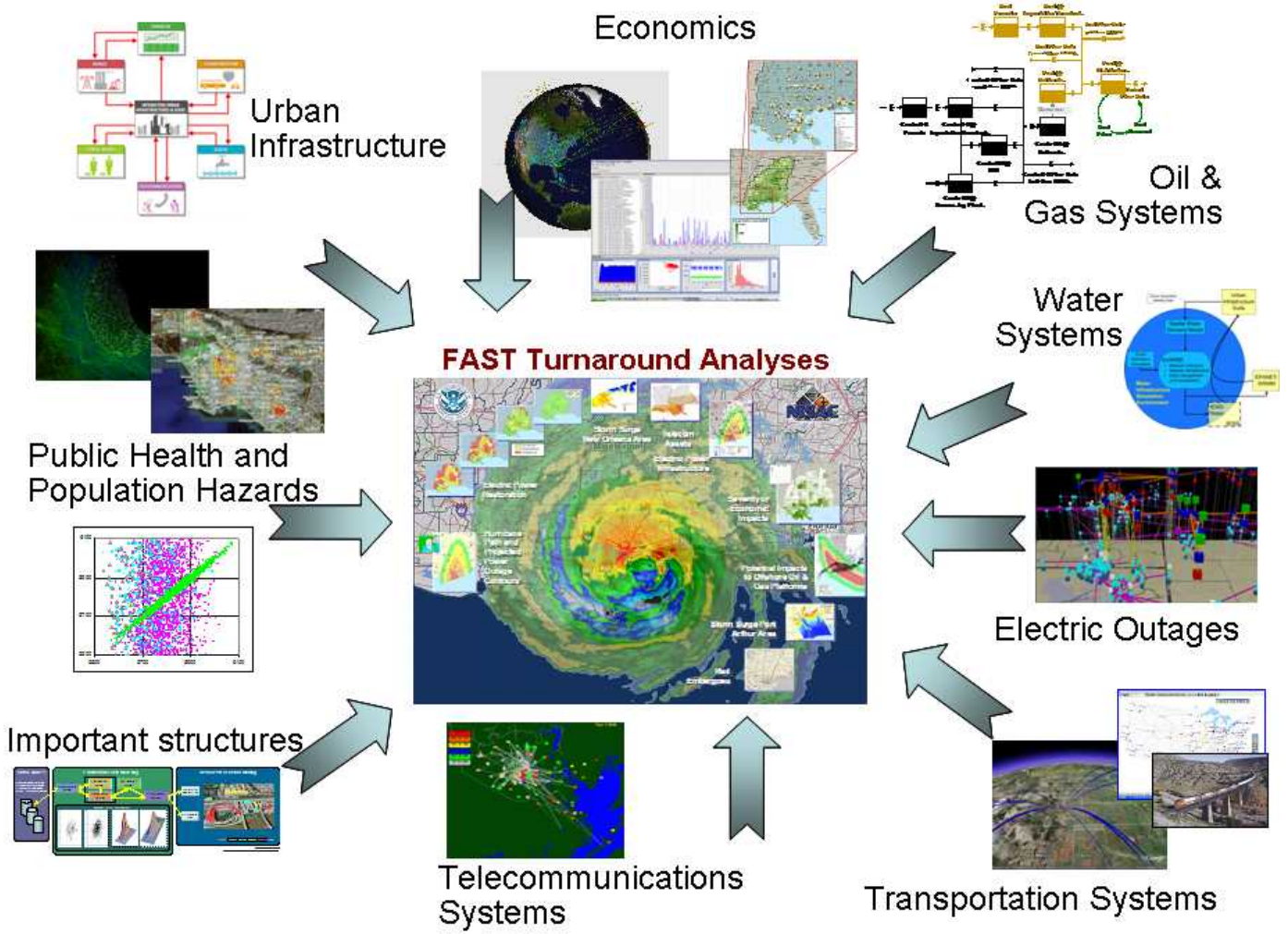
Integration of Multidisciplinary Skill Sets and Expertise



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Lexicon-Understanding-Communication

- **Different backgrounds and training result in opportunities for mis-communications**

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Conclusions

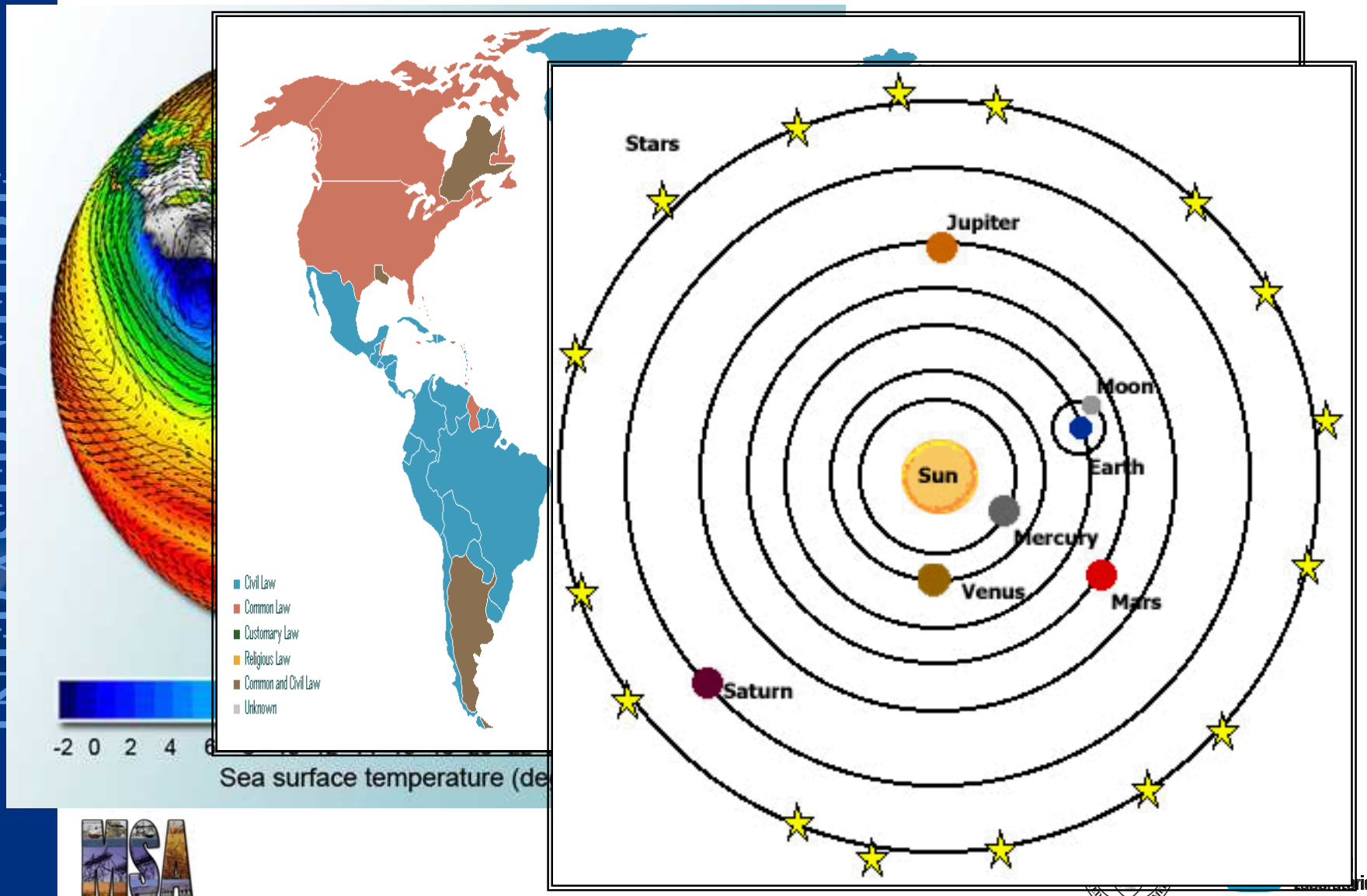
- Understand the purpose and need of the model; What needs to be answered
- Start small; seek understanding; build capacity and tool as needed
- A large cadre of tools are needed; no one approach will meet all needs.
- Having the right data, at the right time has proved illusive; be able to answer questions with incomplete data
- Information pull and a decision maker that trusts/uses the information is a game changer
- A Diverse team is critical, though challenging the rewards are worth the effort
- CUSP has a unique starting point and envionrmnt and has great opportunity for success.

INFRASTRUCTURE

BACKUP SLIDES

Sandia
National
Laboratories

Modeling the World



Modeling and Analysis of Infrastructure Dependencies

- **Purpose of the analysis will determine modeling needs/fit**
  - Time frame of concern
  - Capacity to absorb/respond/adapt/restore/recover = Resilience
  - Risk management (threat management (security; consequence management (design for n-1 failures; design for resilience to specified threats; plan for restoration/recovery); risk mitigation)
- **Experiment on models**
- **Engineer solutions for complex adaptive systems and dynamic conditions**
- **Improve understanding of risks and solutions to aid decision making**
- **Cyber/physical domain work**