



# Defining & Evaluating Threats and Designing Mitigation Strategies for VA Healthcare

Robert Glass, Thomas Moore, Walter Beyeler, Arlo  
Ames, Louise Maffitt, Patrick Finley  
Sandia National Laboratories

Ronald Norby  
Veterans Health Administration  
10N/VISN 22

Victoria Davey  
Veterans Health Administration  
Office of Public Health and Environmental Hazards



# The Problem

- VA has had substantial experience facing both natural and man-made threats
  - Earthquakes
  - Hurricanes
  - Severe Acute Respiratory Syndrome (SARS)
  - Avian influenza/ H1N1 influenza
  - Acts of terrorism
- Many questions and concerns based on these events
  - What if we had done things differently?
  - How could we better prepare?
  - If 'X' happens, what approaches lead us to 'Y<sub>1</sub> + Y<sub>2</sub> + Y<sub>3</sub>' (the outcomes we want)?



# Computational Modeling as an Approach to consider a multitude “what if’s”

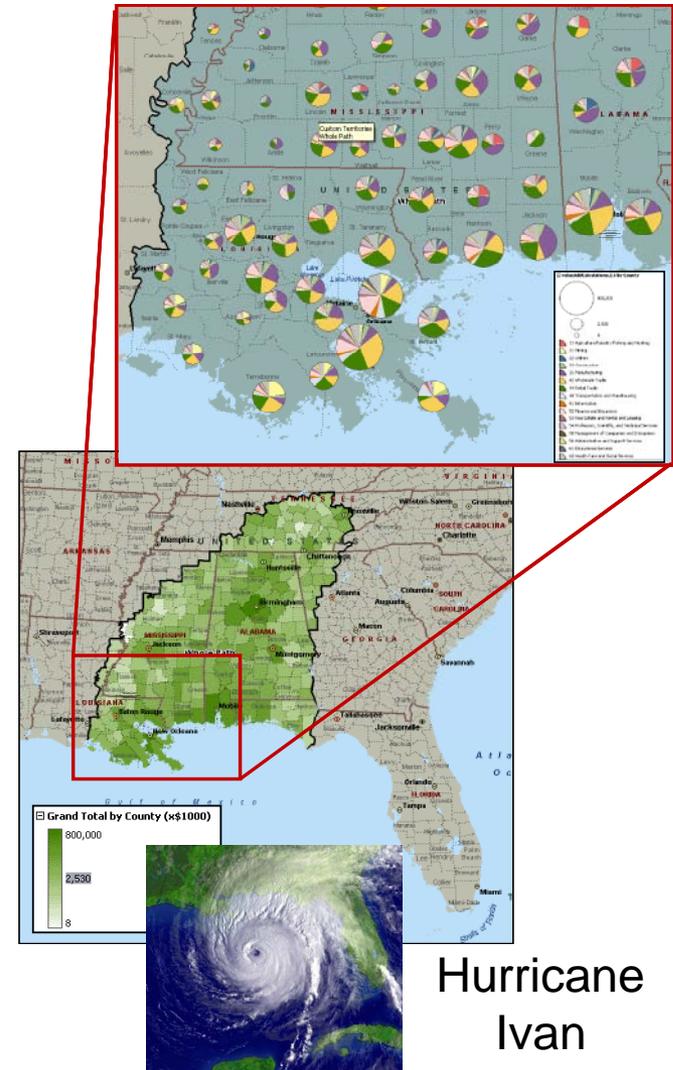
- We will use advanced computational models of real-world threats and potential disasters in order to provide options for policy, interventions, actions.
- A 5-year project
  - model the complex system of VA health care within communities
  - simulate various natural or manmade threats (H1N1 influenza, an earthquake)
  - select key aspects that might be averted, mitigated, improved
  - simulate, re-define, re-simulate, apply in exercises, evaluate, prepare, use



# National Infrastructure Simulation and Analysis Center

## Analyses:

- Damage areas, severity, duration, restoration maps
- Projected economic damage
  - Sectors, dollars
  - Direct, indirect, insured, uninsured
  - Economic restoration costs
- Affected population
- Affected critical infrastructures
- Propagating supply chain effects



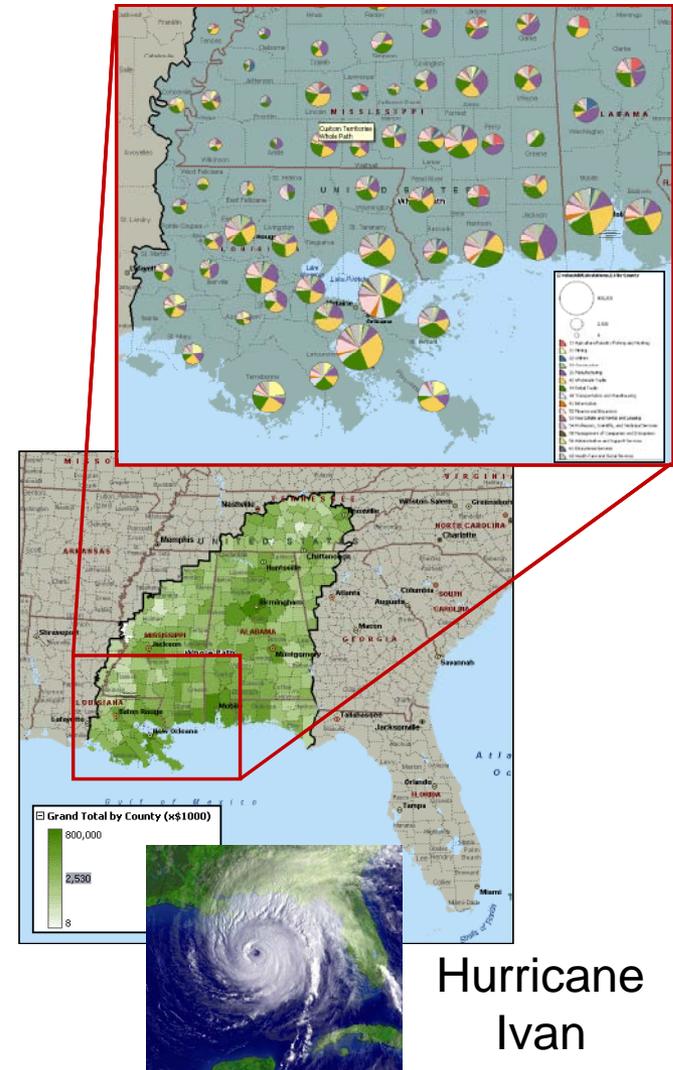
Hurricane Ivan

## Analyses:

- Damage areas, severity, duration, restoration maps
- Projected economic damage
  - Sectors, dollars
  - Direct, indirect, insured, uninsured
  - Economic restoration costs
- Affected population
- Affected critical infrastructures
- Propagating supply chain effects

## Focus of research:

- Comprehensive evaluation of Threats
- Design of Robust Mitigation
- Evolving Resilience



Hurricane Ivan



## 2002: Advanced Methods and Techniques Investigations (AMTI)

### 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**”



<http://www.sandia.gov/nisac/amti.html>



## 2002: Advanced Methods and Techniques Investigations (AMTI)

### 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  
or CASoS**

<http://www.sandia.gov/nisac/amti.html>





# Complex Adaptive Systems of Systems (CASoS) Engineering

Complex Adaptive Systems of Systems (CASoS) are vastly complex physical-socio-technical systems which we must understand to design a secure future for the nation.

CASoS include people, organizations, cities, infrastructure, government and ecosystems. Many of humanity's largest problems such as Global Climate Change and Conflict End Games involve CASoS.

While the problems are disparate, the theories, technologies, tools, and approaches to enable effective engineering efforts focused on the solution of CASoS problems are consistent.

CASoS Engineering Aspirations:

Predict  
Prevent or Cause  
Recover or Change

Monitor  
Prepare  
Control

## Infrastructures as Complex Adaptive Systems

Complexity science provides methods and a framework for simulation and analysis of general infrastructure and infrastructure interdependencies. These methods help us understand how and why some infrastructures will fail and the question that a given infrastructure must answer is: Is it possible to reduce the probability of failure?

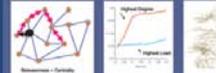
An infrastructure is a network that can be represented as a series of entities, connected to each other by some form of interaction. Nodes occur in:  
Power grids, transforming power grid users  
Complexity and models of the internet  
Infrastructure in a financial network  
Transportation (air, ground)  
Telecommunications hubs  
People in a social network



## Congestive Failure in Power Grid and Fedwire

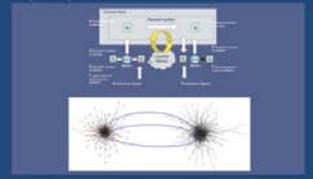
NSAC synthesized and extended the large variety of abstract models and applied them to very different power infrastructure: the high voltage electric power transmission system and Fedwire.

For the hybrid electric power grid, initial simulations demonstrated that the addition of geographically unconnected windfarm transactions can eventually result in grid-to-grid failure, thus increasing the likelihood that actions of unconnected power markets (without proper security coordination on market actions) can undermine large scale system stability. Network topology also greatly influences system robustness.



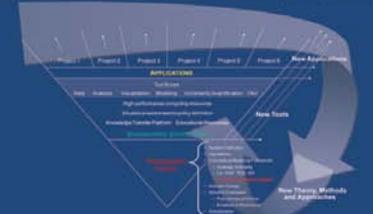
## Congestion and Cascades in Payment Systems

For the Banking and Finance infrastructures, the CASoS framework and modeling tools were applied first to payment systems. Then extended to analysis of liquidity and credit risks in the context of inter-bank and inter-bank payment systems and foreign exchange. The work has attracted the interest and collaboration of the Federal Reserve, the European Central Bank, and international researchers. Modeling results have identified unanticipated interdependencies arising from foreign exchange.



## CASoS Engineering Framework

The high level structure of the CASoS Engineering framework has its basis in methodological theory which evolves as it is applied to projects and real-world problems. The Workbench of tools and approaches evolves as projects continue to develop as they through the influence of new capabilities and understanding. Implementation leads to discovery which improves theory.



## Global Financial Systems

NSAC's focused capability development for the Global Financial System (GFS) integrates knowledge gained from analysis of financial institutions, institutions and markets conducted over the past four years with advanced systems engineering philosophy and methodology.

NSAC's goal is to elucidate how the large recurrent instabilities on financial systems might arise, how they might be controlled, and how those controls might influence economic growth or shift the pattern of regional growth rates.

A multi-year project, the initial NSAC GFS model represents interconnecting financial, industry, commercial, and government entities within an interactive dynamic environment where entities have demonstrated the flexibility to respond in a plausible way to changing environments.



## Petrochemical and Natural Gas Networks

The modeling toolkit was configured to analyze the impact of disruptions within the chemical sector and other sectors on petrochemical production and supply.

The natural gas sector was then modeled to determine the impact of changes within the natural gas system on natural gas transmission and locality.

The tool models are used in conjunction to examine condition-dependent behaviors and capacities in the petrochemical supply chain.



## Pandemic Influenza Containment Strategy

To identify an effective disease containment strategy, NSAC used a networked, agent-based model of a community of individual, multi-environmental local contact networks. Model agents represent individual people who are linked to each other within and among groups to form a contact network reflective of a multi-environment, structured community using either fully connected, random, or ring networks for each group.

Eight containment strategy and numerous disease manifestations were analyzed. The strategy identified by NSAC analysis as most effective and robust to changing conditions was subsequently incorporated in the Center for Disease Control's National Pandemic Influenza Containment Strategy 2009.



## General infrastructures



Contact: Robert J. Glass, Senior Scientist  
Sandia National Laboratories  
rgu@sandia.gov

<http://www.sandia.gov/casos/>





# Complex Adaptive Systems of Systems (CASoS) Engineering

Complex Adaptive Systems of Systems (CASoS) are vastly complex physical-socio-technical systems which we must understand to design a secure future for the nation.

CASoS include people, organizations, cities, infrastructure, government and ecosystems. Many of humanity's largest problems such as Global Climate Change and Conflict End Games involve CASoS.

While the problems are disparate, the theories, technologies, tools, and approaches to enable effective engineering efforts focused on the solution of CASoS problems are consistent.

CASoS Engineering Aspirations:

Predict  
Prevent or Cause  
Recover or Change

Monitor  
Prepare  
Control

## Infrastructures as Complex Adaptive Systems

Complexity science provides methods and a framework for simulation and analysis of general infrastructure and infrastructure interdependencies. These methods help us understand how and why infrastructure systems will fail and the question that a given infrastructure must answer for itself is: "What is the minimum level of service that can be maintained in a network that can be maintained as a series of smaller, interconnected, but not necessarily identical, parts?"

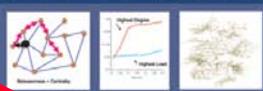
Needs could be:  
Power grids, transportation, power grid users  
Complexity and robustness of the network  
Resilience in a financial network  
Transportation for a given network  
Telecommunications hubs

Characteristics of such networks:  
Connectivity  
Complexity  
Path length (or degree of separation)

## Congestion in Power Grid and Fedwire

NGAC synthesized and tested the large variety of abstract models and applied them to many different power infrastructures; the high voltage electrical power transmission system and Fedwire.

For the hybrid electric power grid, initial simulations demonstrated that the addition of renewable resources without transmission can eventually result in grid congestion, thus increasing the likelihood that actions of uncoordinated power markets (without proper security coordination on market actions) can undermine large scale system stability. Network topology and capacity influence system robustness.



## Congestion and Cascades in Payment Systems

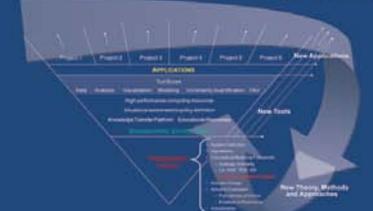
For the Banking and Finance infrastructures, the CASoS framework and modeling tools were applied first to payment systems. Then extended to analysis of liquidity and credit risks in the context of inter-bank and inter-city payment systems and foreign exchange. The work has attracted the interest and collaboration of the Federal Reserve, the European Central Bank, and international researchers. Modeling results have identified unanticipated interdependencies arising from foreign exchange.



The Funding of Interest Payment Model (FIPM) 1992-2002, Report 1, 20, 2001, Lawrence Livermore National Laboratory, Lawrence Livermore National Laboratory, 2001.

## CASoS Engineering Framework

The high level structure of the CASoS Engineering framework has its basis in methodological theory which evolves as it is applied to projects and real-world problems. The Workbench of tools and approaches evolves as projects continue to develop as they progress through the interface of new capabilities and understanding. Implementation leads to discovery which inspires theory.



CASoS Engineering Framework and the Process of Its Evolution, Volume 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100.

## Global Financial Systems

NGAC's focused capability development for the Global Financial System (GFS) integrates knowledge gained from analysis of financial systems, institutions and systems combined over the past four years with advanced systems engineering philosophy and methodology.

NGAC's goal is to structure how the large recurrent instabilities in financial systems might arise, how they might be controlled, and how those controls might influence economic growth or shift the pattern of regional growth rates.

A multi-year project, the initial NGAC GFS model represents interconnecting financial, industry, commercial, and government entities within an interactive dynamic environment where entities have demonstrated the flexibility to respond in a plausible way to changing environments.



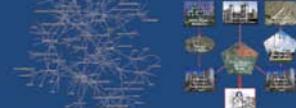
Global Financial System (GFS) Analysis, Appendix, International Model (GFS) and the Global Financial System (GFS), Volume 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100.

## Petrochemical and Natural Gas Networks

The modeling toolkit was configured to analyze the impact of disruptions within the chemical sector and other sectors on petrochemical production and supply.

The natural gas sector was then modeled to determine the impact of changes within the natural gas system on natural gas transmission and supply.

The tool models are used in conjunction to examine condition-dependent behaviors and capacities in the petrochemical supply chain.



Global Financial System (GFS) Analysis, Appendix, International Model (GFS) and the Global Financial System (GFS), Volume 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100.

## Pandemic Influenza Containment Strategy

To identify an effective disease containment strategy, NGAC used a networked, agent-based model of a community of individual, multi-overlapping local contact networks. Model agents represent individual people who are linked to each other within and among groups to form a contact network reflective of a multiply overlapping, structured community with either fully connected, random, or ring networks for each group.

Eight containment strategy and numerous disease manifestations were analyzed. The strategy identified by NGAC analysis as most effective and robust to changing conditions was subsequently incorporated in the Center for Disease Control's National Pandemic Influenza Containment Strategy 2009.



Global Financial System (GFS) Analysis, Appendix, International Model (GFS) and the Global Financial System (GFS), Volume 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100.

# Examples

- General infrastructures
- Congestive Failure
  - Power Grids
  - Payment systems (Fedwire: financial transfer system)



Contact: Robert J. Glass, Senior Scientist  
Sandia National Laboratories  
rgl@snl.sandia.gov  
<http://www.sandia.gov/hoac/eng>





# Complex Adaptive Systems of Systems (CASoS) Engineering

Complex Adaptive Systems of Systems (CASoS) are vastly complex physical-socio-technical systems which we must understand to design a secure future for the nation.

CASoS include people, organizations, cities, infrastructure, government and ecosystems. Many of humanity's largest problems such as Global Climate Change and Conflict End Games involve CASoS.

While the problems are disparate, the theories, technologies, tools, and approaches to enable effective engineering efforts focused on the solution of CASoS problems are consistent.

CASoS Engineering Aspirations:

Predict  
Prevent or Cause  
Recover or Change

Monitor  
Prepare  
Control

## Infrastructures as Complex Adaptive Systems

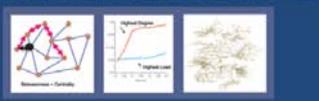
Complexity science provides methods and a framework for simulation and analysis of complex infrastructure and infrastructure interdependencies. These methods help us understand how infrastructure systems behave and how they fail and the question that a given infrastructure must answer is: "Is it possible to include a variety of factors?"

Examples of infrastructure systems include:  
Power grids  
Transportation networks  
Telecommunications  
Water distribution

Characteristics of such networks:  
Connectivity  
Density  
Path length (or degree of separation)

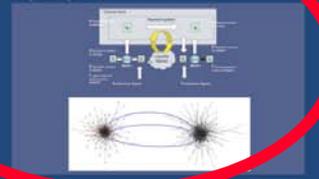
## Congestive Failure in Power Grid and Fedwire

NGAC synthesized and extended the large variety of abstract models and approaches to study energy delivery and infrastructure systems. The high voltage electrical power transmission system and Fedwire.



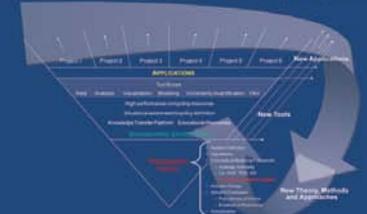
## Congestion and Cascades in Payment Systems

Payment and Finance infrastructures, the core of the market and modeling could well be applied first to payment systems. Both extensive issues of flexibility and credit risk in the context of inter-bank and inter-market energy exchange. The work has attracted the interest and collaboration of Federal Reserve, the European Central Bank, and international researchers.



## CASoS Engineering Framework

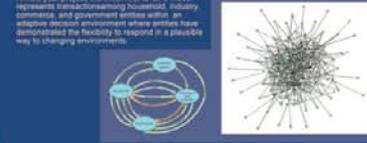
The high level structure of the CASoS Engineering framework has its basis in methodological theory which evolves as it is applied to projects and real-world problems. The Workbench of tools and approaches evolves as projects continue to develop as they progress through the interface of new capabilities and understanding. Implementation leads to discovery which inspires theory.



## Global Financial Systems

NGAC's focused capability development for the Global Financial System (GFS) integrates knowledge gained from analysis of financial systems, infrastructure and systems conducted over the past four years with advanced systems engineering philosophy and methodology.

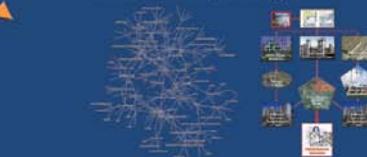
NGAC's goal is to structure how the large recurrent instabilities in financial systems might arise, how they might be controlled, and how those controls might influence economic growth or shift the pattern of regional growth rates.



## Petrochemical and Natural Gas Networks

The modeling toolkit was configured to analyze the impact of disruptions within the chemical sector and other sectors on petrochemical production and supply.

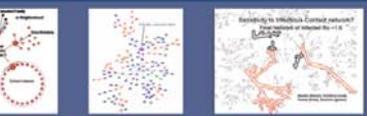
The natural gas sector was then modeled to determine the impact of changes within the natural gas system on natural gas transmission and supply.



## Pandemic Influenza Containment Strategy

To identify an effective disease containment strategy, NGAC used a networked, agent-based model of a community of individual, multi-overlapping local contact networks. Model agents represent individual people who are linked to each other within and among groups to form a contact network reflective of a multiply overlapping, structured community using either fully connected, random, or ring networks for each group.

Eight containment strategy and numerous disease manifestations were analyzed. The strategy identified by NGAC emerged as most effective and novel to changing conditions was subsequently incorporated in the Center for Disease Control's National Pandemic Influenza Containment Strategy 2009.



# Examples

- General infrastructures
- Congestive Failure
  - Power Grids
  - Payment systems (Fedwire: financial transfer system)
- Coupled payment systems (Fedwire: FX market: Target)



Contact: Robert J. Glass, Senior Scientist  
Sandia National Laboratories  
rglass@sandia.gov  
<http://www.sandia.gov/ngac/>





# Complex Adaptive Systems of Systems (CASoS) Engineering

Complex Adaptive Systems of Systems (CASoS) are vastly complex physical-socio-technical systems which we must understand to design a secure future for the nation.

CASoS include people, organizations, cities, infrastructure, government and ecosystems. Many of humanity's largest problems such as Global Climate Change and Conflict End Games involve CASoS.

While the problems are disparate, the theories, technologies, tools, and approaches to enable effective engineering efforts focused on the solution of CASoS problems are consistent.

CASoS Engineering Aspirations:

Predict  
Prevent or Cause  
Recover or Change

Monitor  
Prepare  
Control

## Infrastructures as Complex Adaptive Systems

Complexity science provides methods and a framework for simulation and analysis of complex infrastructure and infrastructure interdependencies. These methods help us understand how infrastructure systems behave and how they fail and the question that a given infrastructure must answer is: Can it be fixed? Is it a network that can be restructured as a series of smaller, interconnected sub-networks?

Networks can be:  
Power grids, transportation, power grid users  
Complexity and robustness of the network  
Resilience in a financial network  
Transportation (for example)  
Telecommunications hubs  
People in a social network

Characteristics of such networks:  
Connectivity  
Complexity  
Path length (or degree of separation)

## Congestive Failure in Power Grid and Fedwire

NSAC synthesized and extended the large variety of abstract models and applied them to very different real infrastructure: the high voltage electric power transmission system and Fedwire.

For the hybrid electric power grid, initial simulations demonstrated that the addition of non-synchronous wind turbines can eventually result in a grid to cascading failure, thus increasing the likelihood that actions of uncoordinated power markets (without proper security coordination on market actions) can undermine large scale system stability. Network topology also greatly influences system robustness.

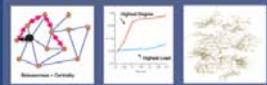


Figure 1: Network Topology, Dynamics, and Resilience. (a) Network Topology: A graph showing nodes and edges. (b) Network Dynamics: A line graph showing network behavior over time. (c) Network Resilience: A graph showing network performance under stress.

## Congestion and Cascades in Payment Systems

For the Banking and Finance infrastructures, the CASoS framework and modeling tools were applied first to payment systems. Then extended to analyses of liquidity and credit risks in the context of inter-bank network payment systems and foreign exchange. The work has attracted the interest and collaboration of the Federal Reserve, the European Central Bank, and international researchers. Modeling results have identified unsuspected interdependencies arising from foreign exchange.

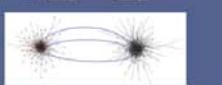


Figure 2: Congestion and Cascades in Payment Systems. (a) Network Topology: A graph showing nodes and edges. (b) Network Dynamics: A line graph showing network behavior over time. (c) Network Resilience: A graph showing network performance under stress.

## CASoS Engineering Framework

The high level structure of the CASoS Engineering framework has its basis in methodological theory which evolves as it is applied to projects and real-world problems. The Workbench of tools and approaches evolves as projects continue to develop as time through the influence of new capabilities and understanding. Implementation leads to discovery which inspires theory.

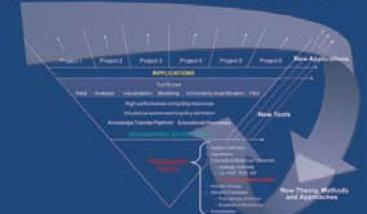


Figure 3: CASoS Engineering Framework and the Process of Its Evolution. (a) Project 1: Initial analysis and planning. (b) Project 2: Data collection and analysis. (c) Project 3: Model development and simulation. (d) Project 4: Validation and verification. (e) Project 5: Implementation and monitoring.

## Global Financial Systems

NSAC's focused capability development for the Global Financial System (GFS) integrates knowledge gained from analyses of financial markets, institutions and systems combined over the past four years with advanced systems engineering philosophy and methodology.

NSAC's goal is to structure how the large recurrent instabilities in financial systems might arise, how they might be controlled, and how those controls might influence economic growth or shift the pattern of regional growth rates.

A multi-year project, the initial NSAC GFS model represents interconnecting financial, industry, commercial, and government entities within an interactive dynamic environment where entities have demonstrated the flexibility to respond in a plausible way to changing environments.



Figure 4: Global Financial System. (a) Network Topology: A graph showing nodes and edges. (b) Network Dynamics: A line graph showing network behavior over time. (c) Network Resilience: A graph showing network performance under stress.

## Petrochemical and Natural Gas Networks

The modeling toolkit was configured to analyze the impact of disruptions within the chemical sector and other sectors on petrochemical production and supply.

The natural gas sector was then modeled to determine the impact of changes when the natural gas system on natural gas transactions and supply. The tool models are used in conjunction to examine condition-dependent behaviors and capacities in the petrochemical supply chain.



Figure 5: Petrochemical and Natural Gas Networks. (a) Network Topology: A graph showing nodes and edges. (b) Network Dynamics: A line graph showing network behavior over time. (c) Network Resilience: A graph showing network performance under stress.

## Pandemic Influenza Containment Strategy

To identify an optimal disease containment strategy, NSAC used a networked, agent-based model of a population of individuals, with a focus on the role of social contacts in the spread of disease. Model agents represent individual people who are interacting with other agents in a network. The network is composed of nodes representing individuals and edges representing social contacts. The network is dynamic, with nodes and edges appearing and disappearing over time.

High-resolution network data and numerous disease manifestations were analyzed. The strategy identified by NSAC was the most effective and robust to changing conditions was subsequently incorporated in the Center for Disease Control and Prevention's National Pandemic Influenza Containment Strategy 2009.



Figure 6: Pandemic Influenza Containment Strategy. (a) Network Topology: A graph showing nodes and edges. (b) Network Dynamics: A line graph showing network behavior over time. (c) Network Resilience: A graph showing network performance under stress.

# Examples

- General infrastructures
- Congestive Failure
  - Power Grids
  - Payment systems (Fedwire: financial transfer system)
- Coupled payment systems (Fedwire: FX market: Target)
- Pandemics



# Complex Adaptive Systems of Systems (CASoS) Engineering

Complex Adaptive Systems of Systems (CASoS) are vastly complex physical-socio-technical systems which we must understand to design a secure future for the nation.

CASoS include people, organizations, cities, infrastructure, government and ecosystems. Many of humanity's largest problems such as Global Climate Change and Conflict End Games involve CASoS.

While the problems are disparate, the theories, technologies, tools, and approaches to enable effective engineering efforts focused on the solution of CASoS problems are consistent.

CASoS Engineering Aspirations:

Predict  
Prevent or Cause  
Recover or Change

Monitor  
Prepare  
Control

## Infrastructures as Complex Adaptive Systems

Complexity science provides methods and a framework for simulation and analysis of complex infrastructure and infrastructure interdependencies. These methods help us understand how infrastructure systems behave and how we can predict and prevent a given infrastructure from failing. An infrastructure is a network that can be represented as a series of nodes connected to each other by some form of interaction.

Nodes could be:  
Power plants, transforming power grid users  
Computers and routers in the internet  
Hospitals in a financial network  
Transportation hubs (airports)  
Telecommunications hubs  
People in a social network

Characteristics of such networks:  
Connectivity  
Complexity  
Path length (or degree of separation)

## Congestive Failure in Power Grid and Fedwire

NSAC synthesized and extended the large variety of abstract models available and applied them to many different types of infrastructures; the high voltage electrical power transmission system and Fedwire.

For the hybrid electric power grid, initial simulations demonstrated that the addition of powerplants connected without transformers can eventually result in grid cascading failure, that is, the total collapse of the system. The addition of transformers (which provide security coordination on market actions) can maintain large scale system stability, network topology and greatly influence system robustness.

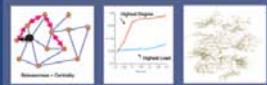


Figure 1: Network Characteristics, Topology, and Robustness. (Source: [unintelligible])

## Congestion and Cascades in Payment Systems

For the Banking and Finance infrastructures, the CASoS framework and modeling tools were applied first to payment systems. Then extended to analysis of liquidity and credit risks in the context of interbank and intercountry payment systems and foreign exchange. The work has attracted the interest and collaboration of the Federal Reserve, the European Central Bank, and international researchers. Modeling results have identified unsuspected interdependencies arising from foreign exchange.

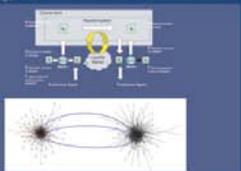


Figure 2: Congestion and Cascades in Payment Systems. (Source: [unintelligible])

## CASoS Engineering Framework

The high level structure of the CASoS Engineering framework has its basis in methodological theory which evolves as it is applied to projects and real-world problems. The Workbench of tools and approaches evolves as projects continue to develop as they progress through the lifecycle of new capabilities and understanding. Implementation leads to discovery which inspires theory.

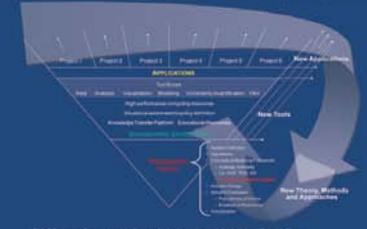


Figure 3: CASoS Engineering Framework and the Process of its Evolution. (Source: [unintelligible])

## Global Financial Systems

NSAC's focused capability development for the Global Financial System (GFS) integrates knowledge gained from analysis of financial institutions, infrastructure and systems conducted over the past four years with advanced systems engineering philosophy and methodology.

NSAC's goal is to elucidate how the large recurrent instabilities in financial systems might arise, how they might be controlled, and how those controls might influence economic growth or shift the pattern of regional growth rates.

A multi-year project, the initial NSAC GFS model represents interconnecting financial, industry, commercial, and government entities within an interactive dynamic environment where entities have demonstrated the flexibility to respond in a plausible way to changing environments.



Figure 4: Global Financial System. (Source: [unintelligible])

## Petrochemical and Natural Gas Networks

The modeling toolkit was configured to analyze the impact of disruptions in the chemical sector and other sectors on petrochemical production and export. The natural gas sector was then modeled to determine the impact of change when the natural gas system or natural gas transportation and locally. The two models are used in conjunction to examine condition-dependent behaviors and capacities in the petrochemical supply chain.



Figure 5: Petrochemical and Natural Gas Networks. (Source: [unintelligible])

## Pandemic Influenza Containment Strategy

To identify an effective disease containment strategy, NSAC used a networked, agent-based model of a community of individual, multi-overlapping local contact networks. Model agents represent individual people who are linked to each other within and among groups to form a contact network reflective of a multiply overlapping, structured community using either fully connected, random, or ring networks for each group.

Eight containment strategy and numerous disease manifestations were analyzed. The strategy identified by NSAC analysis as most effective and robust to changing conditions was subsequently incorporated in the Center for Disease Control's National Pandemic Influenza Containment Strategy 2009.



Figure 6: Pandemic Influenza Containment Strategy. (Source: [unintelligible])

# Examples

- General infrastructures
- Congestive Failure
  - Power Grids
  - Payment systems (Fedwire: financial transfer system)
- Coupled payment systems (Fedwire: FX market: Target)
- Pandemics
- Petrochemicals and Natural gas networks



Contact: Robert J. Glass, Senior Scientist  
Sandia National Laboratories  
rglass@sandia.gov  
<http://www.sandia.gov/hiac/hiac.html>





# Complex Adaptive Systems of Systems (CASoS) Engineering

Complex Adaptive Systems of Systems (CASoS) are vastly complex physical-socio-technical systems which we must understand to design a secure future for the nation.

CASoS include people, organizations, cities, infrastructure, government and ecosystems. Many of humanity's largest problems such as Global Climate Change and Conflict End Games involve CASoS.

While the problems are disparate, the theories, technologies, tools, and approaches to enable effective engineering efforts focused on the solution of CASoS problems are consistent.

CASoS Engineering Aspirations:

Predict  
Prevent or Cause  
Recover or Change

Monitor  
Prepare  
Control

## Infrastructures as Complex Adaptive Systems

Complexity science provides methods and a framework for simulation and analysis of general infrastructure and infrastructure interdependencies. These methods help us understand how systems behave and how they will fail and the question that a given infrastructure must answer is: Is it capable to include variability of its behavior?

Key research areas in a network that can be represented as a series of nodes connected to each other by some form of interaction:

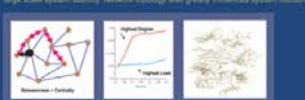
Networks used by:  
Power grids, transforming power grid users  
Transportation and traffic in the internet  
Supply chains in a financial network  
Transportation for a government  
Telecommunications hubs  
People in a social network

Characteristics of such networks:  
Connectivity  
Density  
Path length (or degree of separation)

## Congestive Failure in Power Grid and Fedwire

NSA/CSS synthesized and extended the large variety of abstract models and applied them to many different real world infrastructures; the high voltage electric power transmission system and Fedwire.

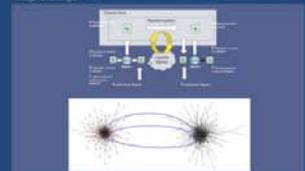
For the hybrid electric power grid, initial simulations demonstrated that the addition of non-synchronous windfarm transactions can eventually result in grid to cascading failure, thus increasing the likelihood that actions of unconnected power markets without proper security coordination on market actions can undermine large scale system stability. Network topology and gravity influences system robustness.



## Congestion and Cascades in Payment Systems

For the Banking and Finance infrastructures, the CASoS framework and modeling tools were applied first to payment systems. Then extended to analyses of liquidity and credit risks in the context of interbank network payment systems and foreign exchange. The work has attracted the interest and collaboration of the Federal Reserve, the European Central Bank, and international researchers.

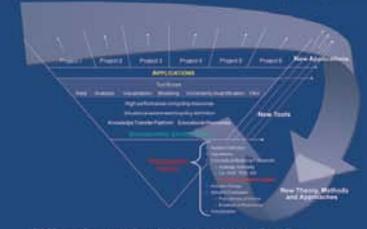
Modeling results have identified unanticipated interdependencies arising from foreign exchange.



The Funding of Interest Payment Model (FIPM) 1992-2002. Copyright © by Sandia. Licensed to FEMA and the National Science Foundation under the NSF Grant Number: 00-35389-0001.

## CASoS Engineering Framework

The high level structure of the CASoS Engineering framework has its basis in methodological theory which evolves as it is applied to projects and real-world problems. The Workbench of tools and approaches evolves as projects continue to develop as they progress through the interaction of new capabilities and understanding. Implementation leads to discovery which inspires theory.



## Global Financial Systems

NSA/CSS advanced capability development for the Global Financial System (GFS) integrates knowledge from analyses of financial institutions, infrastructure and systems combined over the past 10 years with advanced systems engineering philosophy and methodology.

NSA/CSS's goal is to structure how the large recurrent instabilities in financial systems might arise, how they might be controlled, and how those controls might influence economic growth or shift the pattern of regional growth rates.

A multi-year project, the initial NSA/CSS GFS model represents interconnecting financial, industry, commercial, and government entities within an interactive dynamic environment where entities have demonstrated the flexibility to respond in a plausible way to changing environments.

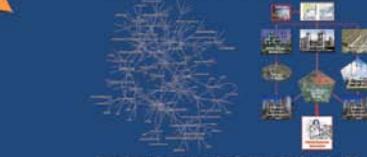


## Petrochemical and Natural Gas Networks

The modeling toolkit was configured to analyze the impact of disruptions within the chemical sector and other sectors on petrochemical production and supply.

The natural gas sector was then modeled to determine the impact of changes when the natural gas system or natural gas transactions and locally.

The tool models are used in conjunction to examine condition-dependent behaviors and capacities in the petrochemical supply chain.



## Pandemic Influenza Containment Strategy

To identify an effective disease containment strategy, NSA/CSS used a networked, agent-based model of a community of individual, multi-overlapping local contact networks. Model agents represent individual people who are linked to each other within and among groups to form a contact network reflective of a multi-layered, structured community using either fully connected, random, or ring networks for each group.

Eight containment strategy and numerous disease manifestations were analyzed. The strategy identified by NSA/CSS analysis as most effective and robust to changing conditions was subsequently incorporated in the Center for Disease Control's National Pandemic Influenza Containment Strategy 2005.



Visual Systems Strategies for Pandemic Influenza. Copyright © by Sandia. Licensed to FEMA and the National Science Foundation under the NSF Grant Number: 00-35389-0001.

# Examples

- General infrastructures
- Congestive Failure
  - Power Grids
  - Payment systems (Fedwire: financial transfer system)
- Coupled payment systems (Fedwire: FX market: Target)
- Pandemics
- Petrochemicals and Natural gas networks
- Global Financial Systems



Contact: Robert J. Glass, Senior Scientist  
Sandia National Laboratories  
rglass@sandia.gov  
<http://www.sandia.gov/hsac/hsac.html>

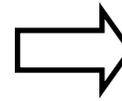




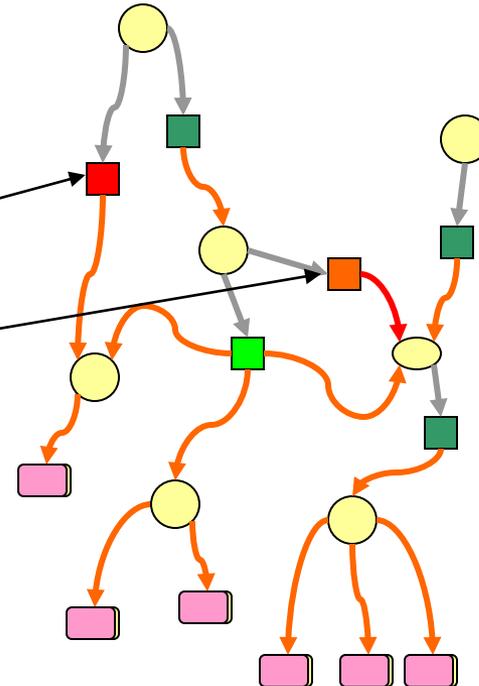
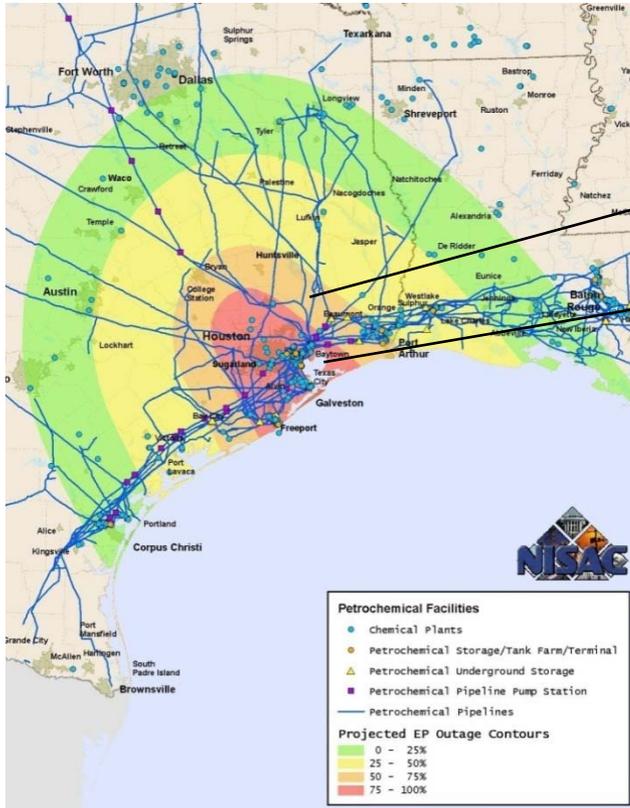
# In a CASoS such as the VHA...

Everything is connected  
*skilled workers-utilities-  
transportation-  
structures-supplies-  
emergency services*

In a threat like a  
hurricane, if  
components are  
disrupted...



**Reduced health care  
capacity**



**Increased morbidity  
Decreased preventive services  
Diminished health status**

# Modeling Threats to VA Health Care System

- What are the threats?
- How important is each system component?
- How can threats be prevented or mitigated?

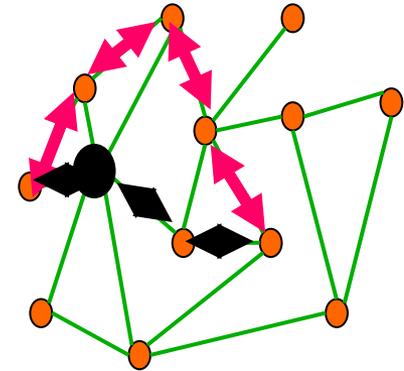
## Define

- Complex system of systems (e.g. VA health care)
- Apply appropriate methods and theories (e.g. analogy, percolation theory, game theory, network theory...)
- Create computational model and populate with required data to address problem (e.g. population, # clinics, personnel, beds, ventilators, supply chains, trucks, etc)

## Design and Test Solutions

- Determine feasible, real-world options for mitigation (helicopters vs. trucks)
- Discover how robust these options are to uncertainties in assumptions (e.g. weather, who comes to work), and
- Establish critical enablers that increase system resilience (e.g. nothing works without water)

## Implement Solutions within the Real World





## Elicitation of VISN 22

Began the process of:

- Learning about people and their roles under normal and stressed conditions within a VISN (including veterans for whom the system cares)
- Understanding roles and interrelationships within individual facilities
- Understanding interrelationships between facilities within a VISN and with other non VHA facilities in the surrounding community or region
- Understanding the interrelationships between individual VISNs and national VHA and VA administration
- Identifying data to inform models at both small scale high-resolution (individual hospital-community) and large scale low-resolution (facilities within regions and the nation)
- Identifying surprises – surprising scarce resources, surprising interactions, surprising reliances



# Perceived Threats VISN 22

## Summary of Categories

- Physical Security
- Unpredictable human behavior
- Infrastructure
- Too much demand to meet
- Disasters
- Diseases
- Staffing
- Patients
- Community Relationships
- Organizational Issues
- Disaster Preparedness
- Distractions



# Perceived Threats VISN 22

## Summary of Categories

- Physical Security
- Unpredictable human behavior
- Infrastructure
- Too much demand to meet
- Disasters
- Diseases
- Staffing
- Patients
- Community Relationships
- Organizational Issues
- Disaster Preparedness
- Distractions

## Conclusions:

- Threats perceived as Local
- Thus our concern is raised to the system level or **Systemic Risk**
  - Response to national disasters
  - Normal operations weighted down by mandates



# Perceived Threats VISN 22

## Summary of Categories

- Physical Security
- Unpredictable human behavior
- Infrastructure
- Too much demand to meet
- Disasters
- Diseases
- Staffing
- Patients
- Community Relationships
- Organizational Issues
- Disaster Preparedness
- Distractions

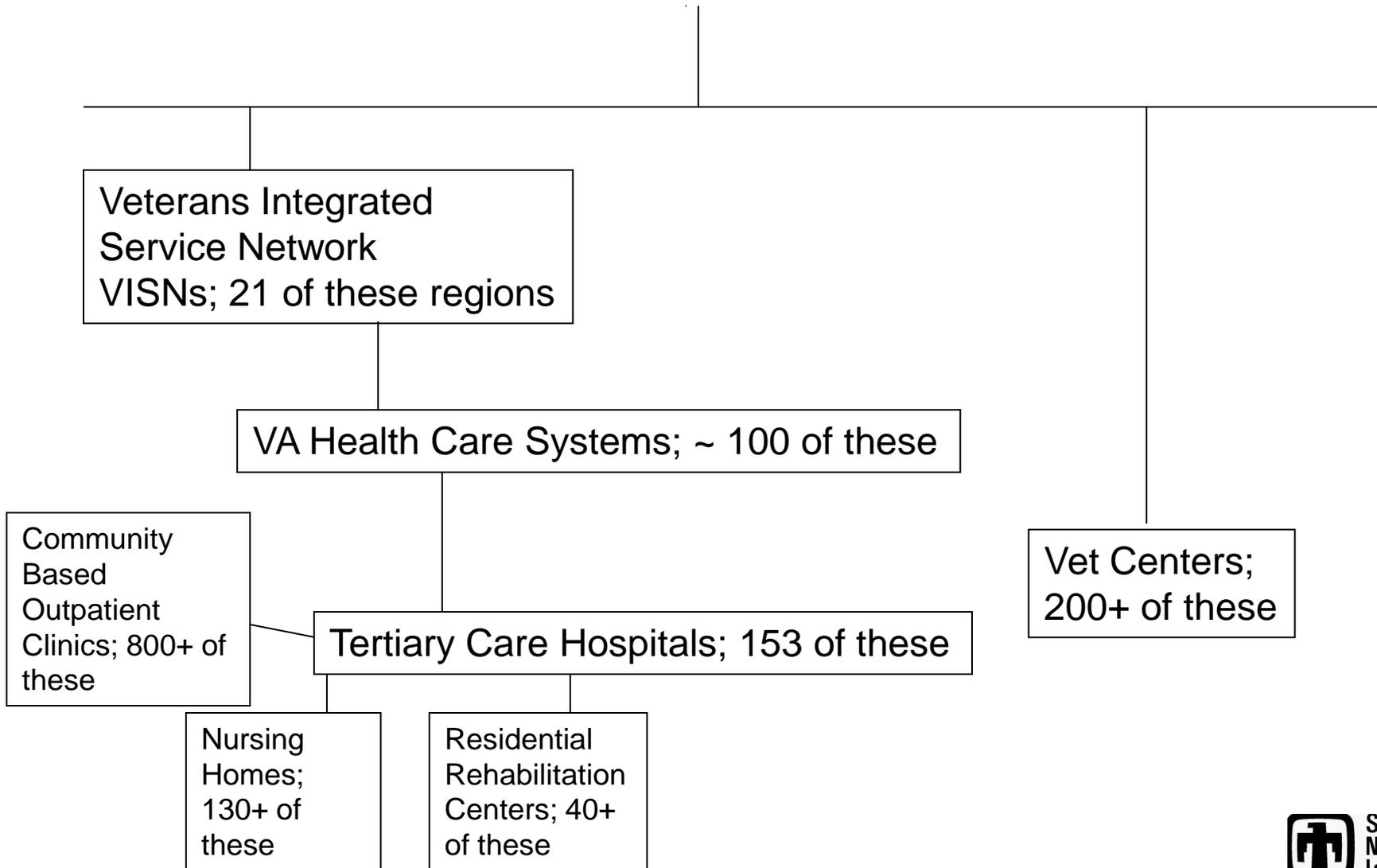
## Conclusions:

- Threats perceived as Local
- Thus our concern is raised to the system level or **Systemic Risk**
  - Response to national disasters
  - Normal operations weighted down by mandates

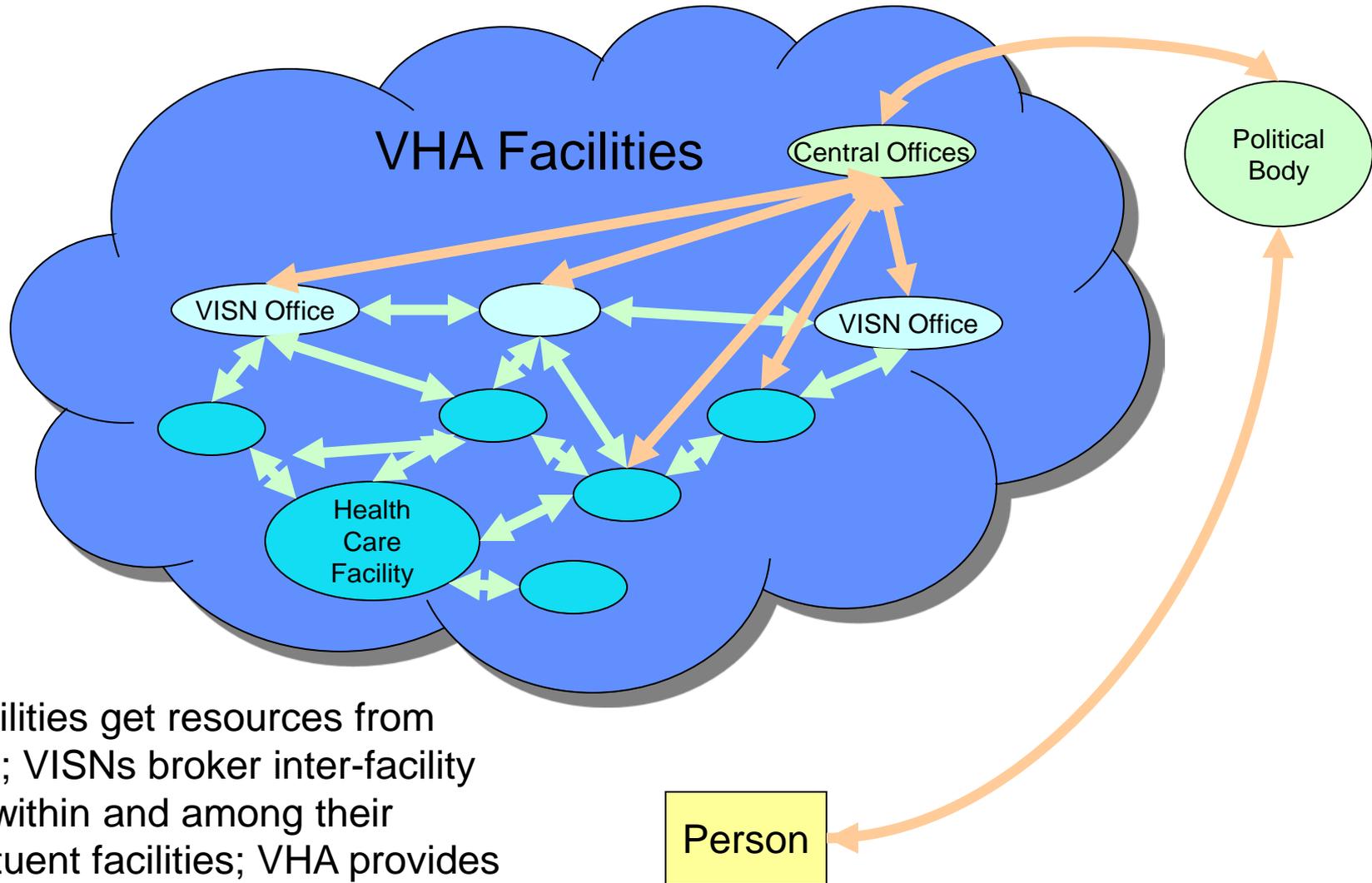
... Moving to Conceptual Modeling



# Veterans Health Administration

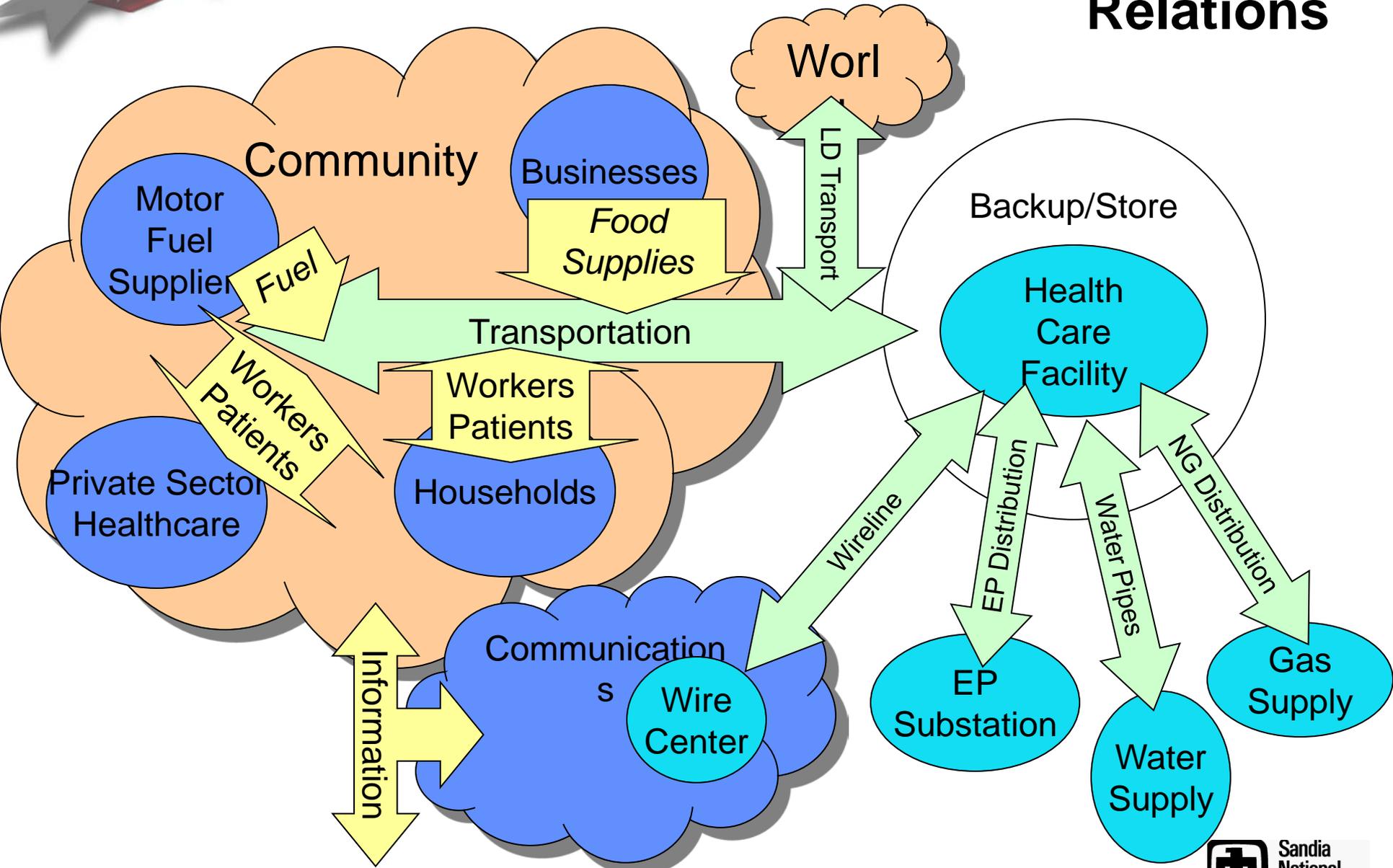


# Political/Funding pathways

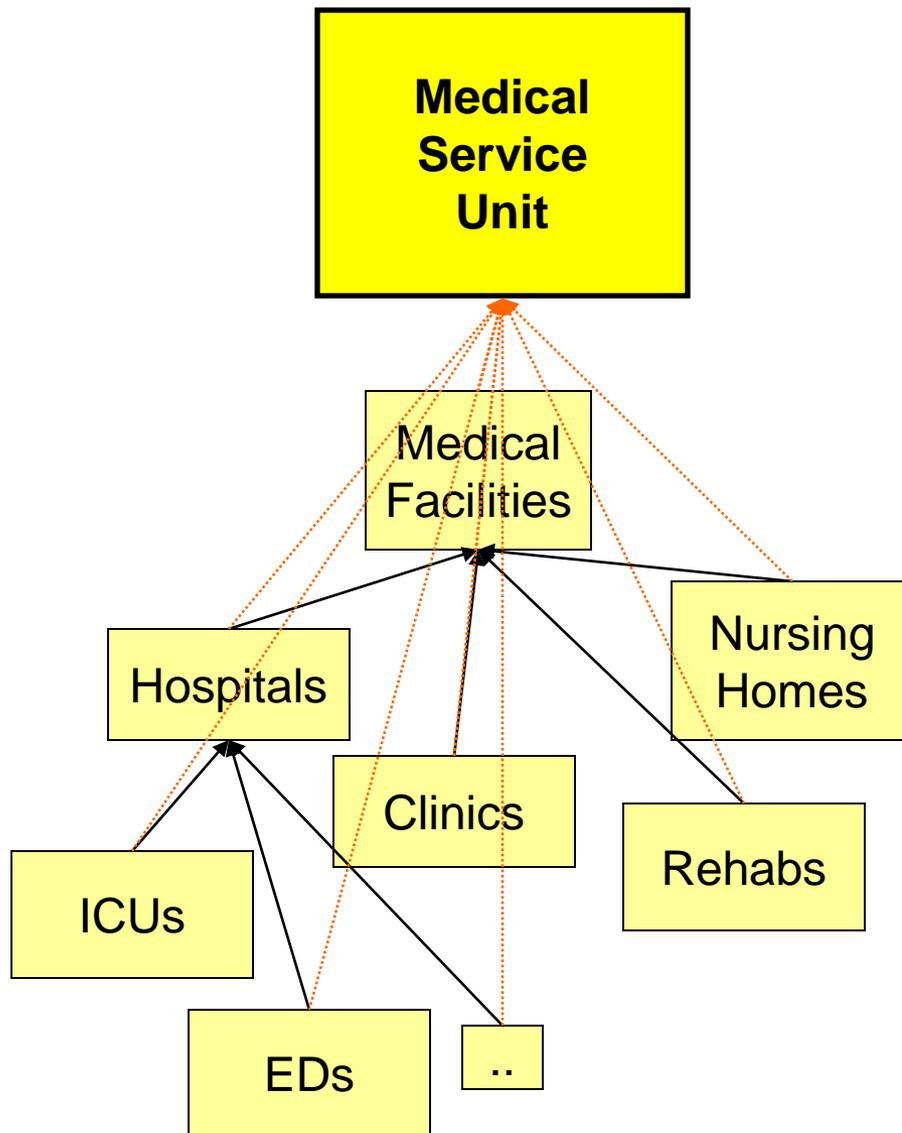


VA facilities get resources from VISNs; VISNs broker inter-facility flows within and among their constituent facilities; VHA provides funding, resources, information, and obtains status information

# Major Entity Types, Aggregations, and Relations



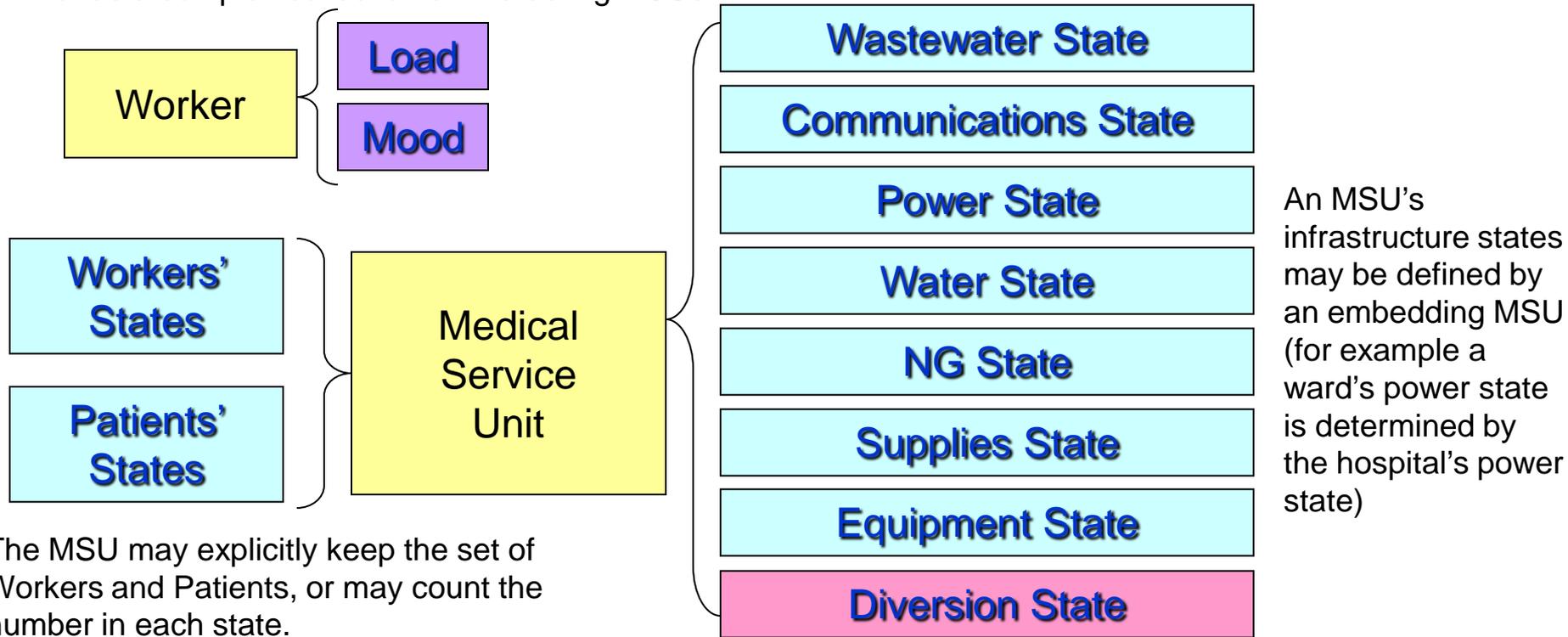
# Fundamental building block for Health Care Facilities



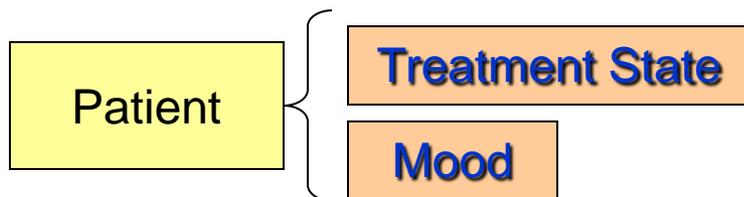
We've defined a **Medical Service Unit (MSU)** as a generic model for any location where some kind of medical service is provided. It can be applied at a large scale (to represent an entire hospital for example) or at a small scale (to represent an individual ICU station), and *may be nested*

# Basic Medical Service Unit - States

A Medical Service Unit (MSU) is a location at which workers (of one or more types) service patients (having one or more kinds of conditions). MSU's capture the basic processes common to many facilities at many scales. Complex facilities (hospitals) can be represented as an MSU or as a complex collection of interacting MSUs.



The MSU may explicitly keep the set of Workers and Patients, or may count the number in each state.



The diversion state, which may be a simple function of other states, indicates whether the MSU is accepting new patients and/or is attempting to relocate existing patients

# Modeling a Generic Entity



Health decays with some time constant unless it's sustained by new consumption: first-order decay

Consumption makes you healthy and happy

Having more input leads to more consumption, up to a point

Production fills the tank: Integration

Consumption drains the tank: Integration

Production slows when output piles up

Some consumption may be directly driven by production

Having "enough" input deters purchasing

Sales drains the tank: Integration

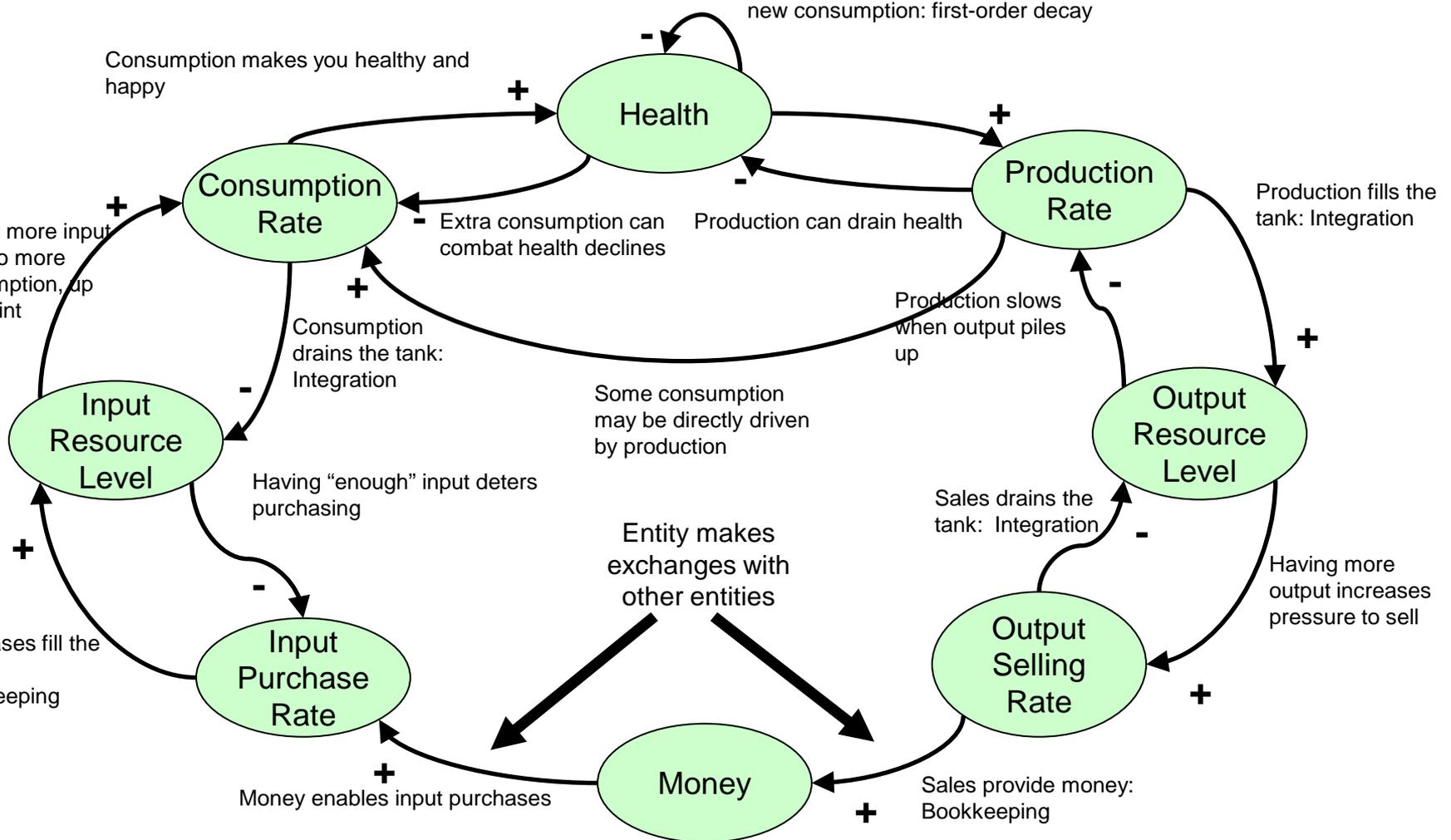
Having more output increases pressure to sell

Entity makes exchanges with other entities

Purchases fill the tank: Bookkeeping

Money enables input purchases

Sales provide money: Bookkeeping





## NEXT STEPS

- In process of creating generic computational entity (mathematics and computational solution)
- Specialize general entity for: MSU, patients and medical staff
- Link MSUs into a network to represent several scales within the VA: a hospital, a VISN, the national system
- Operate stylized systems under normal conditions and allow individual entities to adjust, compare to expectations from the real world
- Consider robustness of system to perturbations of a variety of types and a range of sizes, find those that are problematic at the scale of interest (focus is on entire system)
- Consider tradeoffs between a set of strategies that could be implemented to mitigate the severity of perturbations
- AND... re-define, re-simulate, use to define critical research, apply in exercises, test and evaluate, prepare, use



# Q&A



# Slides in Reserve

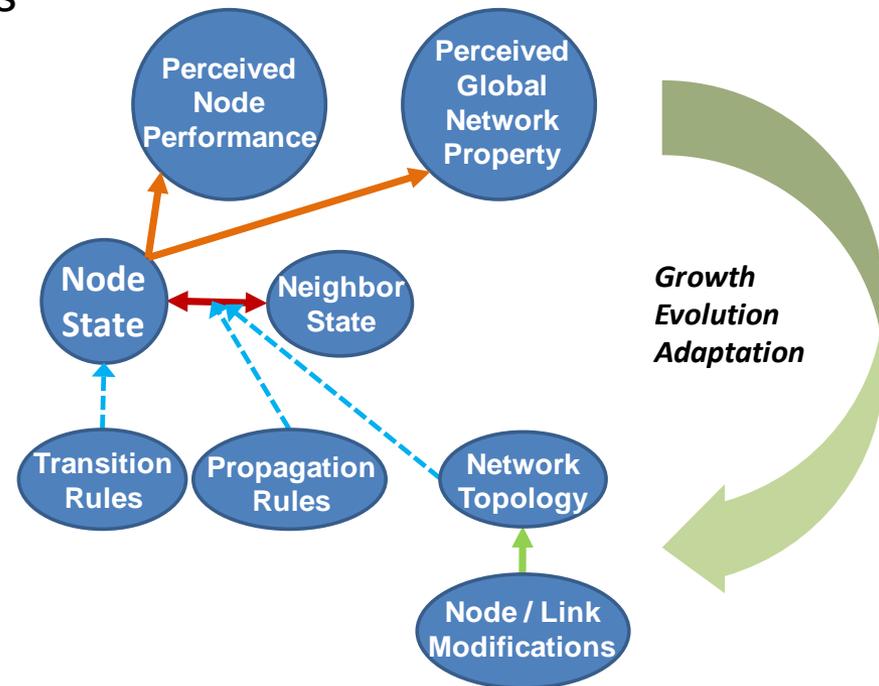
# Generalized Conceptual Modeling Approach for CASoS Engineering

**Take any system and Abstract as:**

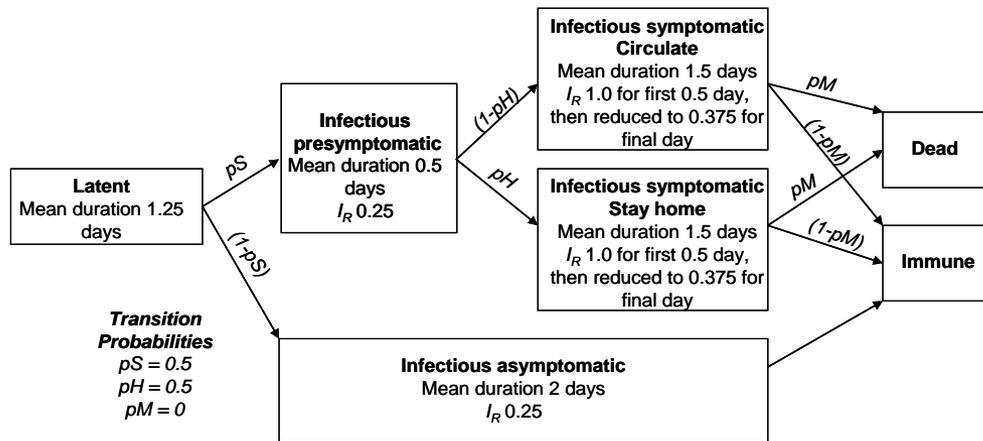
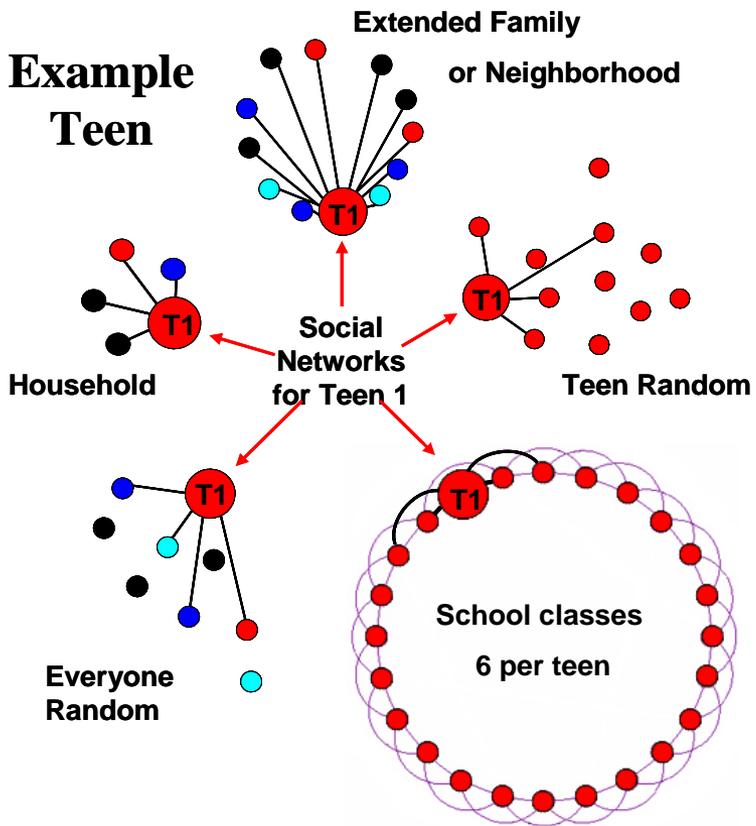
- Nodes (with a variety of “types”)
- Links or “connections” to other nodes (with a variety of “modes”)
- Local rules for Nodal and Link behavior
- Local Adaptation of Behavioral Rules
- “Global” forcing

**Connect nodes appropriately to form a system (network)**

**Connect systems appropriately to form a System of Systems**



# Application: Community Containment for Pandemic Influenza



## Disease Manifestation

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.

**Design of Community Containment for Pandemic Influenza with Loka-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.

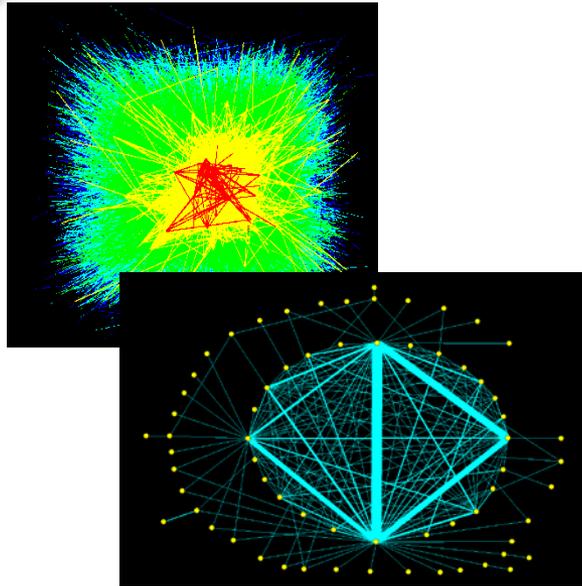
**Health Outcomes and Costs of Community Mitigation Strategies for an**

**Influenza Pandemic in the U.S.**, Perroth, Daniella J., Robert J. Glass, Victoria J. Davey, Alan M. Garber, Douglas K. Owens, *Clinical Infectious Diseases*, January, 2010.

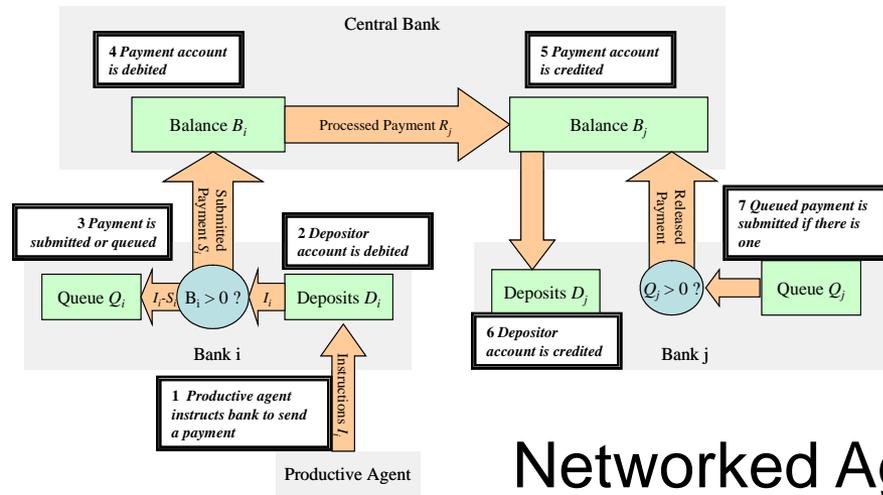


Social Contact Network

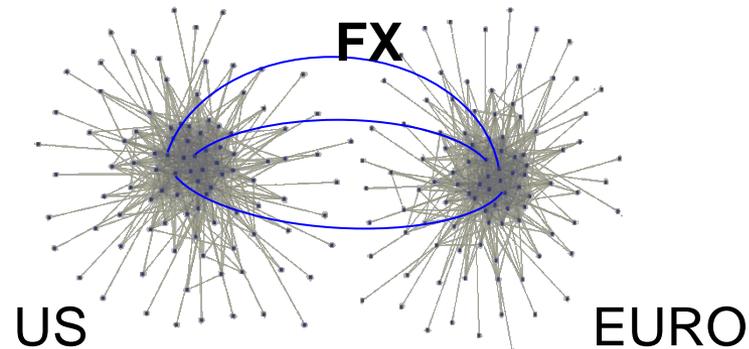
# Application: Congestion and Cascades in Payment Systems



Payment system network



Networked Agent Based Model



Global interdependencies

For Details see:

**The Topology of Interbank Payment Flows**,  
Soramäki, et al, *PhysicaA*, 1 June 2007; vol.379,  
no.1, p.317-33.

**Congestion and Cascades in Payment Systems**,  
Beyeler, et al, *PhysicaA*, 15 Oct. 2007;  
v.384, no.2, p.693-718.

**Congestion and Cascades in Coupled Payment Systems**,  
Renault, et al, Joint Bank of England/ECB Conference on Payments and  
monetary and financial stability, Nov, 12-13 2007.