Engineering Change in Socio-Technical Systems

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Slides pulled from presentations posted at: http://www.sandia.gov/casos/
Infrastructures are Complex Adaptive Systems of Systems or “CASoS”

People design, use, construct, maintain, evolve...

LOAD & DRIVE

Multiple Interdependent Infrastructures coupled to socio-economic activity that generates both a Load and a Drive

Western Power Grid (WECC), 69 kev lines and above
"Big" events are not rare in many such systems.

- Earthquakes: Gutenberg-Richter
- Wars, Extinctions, Forest fires
- Power Blackouts?
- Telecom outages?
- Traffic jams?
- Market crashes?
- … ???

"heavy tail" region
Illustrations of natural and constructed network systems from Strogatz [2001].
ADAPTIVE: Grow and Adapt

Grow and adapt in response to local-to-global policy
Conceptual Lens for Modeling/Design

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

Connect nodes appropriately to form a system (network)
Connect systems appropriately to form a System of Systems
Application: Congestion and Cascades in Payment Systems

Payment system network

Networked Agent Based Model

Global interdependencies

For Details see:


CASoS Engineering

- Harnessing the tools and understanding of Complex Systems, Complex Adaptive Systems, and Systems of Systems to Engineer solutions for some of the world's biggest, toughest problems:

**The CASoS Engineering Initiative**


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

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

• Are **Complex**: composed of many parts whose interaction via local rules yields *emergent structure (networks) and behavior (cascades)* at larger scales

• **Grow and adapt** in response to local-to-global *policy*

• **Contain people**

• Are interdependent “**systems of systems**”

Critical infrastructures are -

**Complex Adaptive Systems of Systems:**

CASoS
Engineering Change within CASoS:

- 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
- ... Combining understanding across all CASoS application domains
National Infrastructure Simulation and Analysis Center (NISAC)

Multiple Interdependent infrastructures

Consequences of Perturbations
Economic
Social

Systemic Risk

Source: Energy Information Administration, Office of Oil & Gas

Active Refinery Locations,
Crude and Product Pipelines
Socio-Technical Systems are:

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

Socio-Technical Systems are Complex Adaptive Systems of Systems or “CASoS”
Application: Community Containment for Pandemic Influenza

For Details see:


Targeted Social Distancing Design for Pandemic Influenza, RJ Glass, LM Glass, WE Beyeler, and HJ Min, Emerging Infectious Diseases November, 2006.


Rescinding Community Mitigation Strategies in an Influenza Pandemic, VJ Davey and RJ Glass, Emerging Infectious Diseases, March, 2008.


Application: Industrial Disruptions

Disrupted Facilities

Reduced Production Capacity

Diminished Product Availability
Application: Petrochemical & Natural Gas

Disrupted Refineries

Disrupted Petrochemical Plants

Disrupted NG Compressors/Stations

Service Territories

Indirectly Disrupted Petrochemical Plants

Petrochemical Network Model

Gas Network Model

Indirectly Disrupted Petrochemical Plants

Petrochemical Shortfalls
Application: Congestion and Cascades in Payment Systems

- **Network defined by Fedwire transaction data:**
  - Payments among more than 6500 large commercial banks
  - Typical daily traffic: more than 350,000 payments totaling more than $1 trillion
  - Node degree and numbers of payments follow power-law distributions

- **Bank behavior controlled by system liquidity:**
  - Payments activity is funded by initial account balances, incoming payments, and market transactions
  - Payments are queued pending funding
  - Queued payments are submitted promptly when funding becomes available

For Details see:

Application: Coupled Payment Systems