CRIM 3460 Introduction to Critical Infrastructure Protection
Spring 2016

Chapter 4 – Complex Critical Infrastructure Key Resources (CIKR) Systems

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Chapter Discussion Topics

- California on Fire
- Financial Meltdown of 2008
- Enrichment: Too Much of a Good Thing Can Ruin It
- Tragedy of the Commons: Bad Behavior in a Non-linear World
California On Fire

- California wildfires
- Are California wildfires normal accidents?
- Forest Fires as Complex Systems (SOC)
- Percolation and SOC
- Bak’s punctuated equilibrium
- Policy Implications
California On Fire

- October - November 2007
  - Santa Ana Winds (20-40 mph)
  - 17 deaths
  - 140 injured
  - 3,069 homes destroyed
  - 900,000+ displaced
  - 500,000+ acres burned
  - Interdependencies:
    - Power Grid
    - Telecommunications
    - Water resources
California On Fire

- Resources committed and consequences
- From 10/21 thru 10/31:
  - An average of 1070 engines per day deployed
  - An average of 9952 personnel per day deployed
  - Total acres burned was 517,937
Risk of Wildfires in California

- Exceedence Probability (Probability Consequence > x)
- Risk = PML = EP * Consequence

2007 California Wildfires vs Size

- Risk, q = 0.6 (High Risk)
- Exceedence (Exponent, q)
Definitions

- Percolation increases risk by increasing the juxtaposition and structure (spectral radius) of a CIKR system represented as a network.
- **Density** – A measure of how compact or concentrated something is
- **Consequence** – An effect of an event, incident or occurrence.
- **Resilience** – Ability to resist, absorb, recover from or successfully adapt to adversity or a change in conditions.
- **Self-Organized Criticality** – Measured in terms of spectral radius, which is a measure of network structure and equates to fragility and non-resilience.
Forest Fire Simulation

Simulation: Lightning Strike Interval = **Once every 25 Time Intervals**

- Forest = 4096 squares
- Green = Trees
- Red = Lightning bolts
- White = Empty ground

- **Percolation:**
  Contiguous clusters

- **Density:**
  Fraction of green squares

- **Consequence:**
  Fraction of burned trees
Forest Fire Simulation

- Simulation: Lightning strike interval = **Once every 100 Time Steps**
  - Strikes occur less often
  - Consequences are higher
  - Risk is higher
  - Clusters are larger
  - Resilience is lower

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![2007 California Wildfires vs Size](chart.png)
Resilience exponent decreases with strike interval
- Infrequent fires are bigger
- Increased frequency reduces size
Forest Self-Organized Criticality (Cont.)

- Size of fire increases with infrequent thinning
  - Consequence vs lightning strike interval
Generalization: Self-Organized Criticality

- Percolation increases SOC
- SOC explains why resilience differs for different systems:
  - “100-Year” Power Outages Every 10 Years
  - High Occurrence of Fires In Southern California
  - Criticality of USA Telecom Sector
  - Spread of contagious diseases
  - ....others TBD
- Political SOC:

Complexity Theory Hypothesis

- Risk increases with self-organized criticality
  - Bak’s Sand Pile (critical points)
  - Perrow’s Normal Accidents (linked systems)
  - Taleb’s Black Swans (power laws)
  - Malamud’s Forest Fires (percolation)

- Self-organization increases with efficiency
  - Remove surge capacity
  - Reduce redundancy
  - Optimize for profit
Policy Implications

- Terrorist attacks and natural disasters randomly occur
  - Unpredictable collapses and magnitude obey a power law
  - SOC is a force multiplier increased by reduced resilience
  - Risk increases because of percolation

- Policy options: Backing away from SOC
  - Sub-optimal operation with lower efficiency
  - Addition of “surge capacity” at a higher cost
  - Decrease “connectivity” via the regulatory process
  - Harden clusters, concentrations, hubs and infrastructure
Financial Meltdown of 2008

What happened?
- A sudden drop in the stock market precipitated by the collapse of major investment firms and banks, “cascaded” throughout the financial sector resulting in stalling industrial production; a 22% decline

Key Words:
- Sudden drop
- Cascaded
- Stalling
Was it the housing crash?
- Subprime mortgages in 1993
  - Interest only
  - Adjustable rates
  - Reverse-equity loans
- MBS = Mortgage-Backed Securities
  - Resold packaged home mortgages
- CDO = Collateralized Debt Obligations
  - Resold packaged MBS’s
- CDS = Credit Default Swap
  - Insurance against default of CDO
Financial Meltdown of 2008 (Cont.)

Was policy?

- **ERISA = Employer Retirement Income Security Act, 1974**: Basis of mortgage-backed securities trading
- **CRA = Community Reinvestment Act, 1977**: Motivated banks to make loans to entire community
- **DDMCA = Depository Deregulatory and Monetary Control Act, 1980**: Eliminated rate caps for mortgages
- **Subprime lending, 1993**: from 5% to 20% of all loans by 2006: Repeal of Glass-Steagall Act, 1999
- **Commodity Futures Modernization Act, 2000**: deregulates sale of CDS’s
- **Wall Street Replaces Fannie Mae/Freddie Mac as primary buyer mortgages, 2005.**
- **Lender Failure in Irvine, CA. August 2007.**
Financial Meltdown of 2008 (Cont.)

- Two theories
  - Normal accidents happen (irregularly)
  - Economic collapses are “predictable” black swans....
Financial Meltdown of 2008 (Cont.)

- Two theories (cont.)
  - Paradox of Enrichment (too much of a good thing)
  - Economic collapses are “predictable” Minsky Moments
Financial Meltdown of 2008 (Cont.)

- Normal Accident Theory

Russia  China  Iceland  Europe  France  Norway

Lehman  BearStearns  Barclays  UBS  CitiGroup  Wachovia  AIG  WaMu

FannieMae  FreddieMac  MorganStanley  GoldmanSacks

WellsFargo  CountryWide  Conesco  BofA  QuickLoan  GreenTree  AmeriQuest  NewCentury

Normal Accident
Financial Meltdown of 2008 (Cont.)

- Network Meltdown

Diagram showing connections between various financial entities and regions.
Financial Meltdown of 2008 (Cont.)

- Sand Pile

Russia China

Europe France Norway

Lehman BearStearns Barclays UBS

Wachovia AIG WaMu

FannieMae FreddieMac

GoldmanSacks

WellsFargo CountryWide Conesco BofA

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Consequence
Financial Meltdown of 2008 (Cont.)

- Paradox Enrichment Theory
  - Minsky moments:
    - Speculative euphoria leads to an inevitable crash
    - Bubbles are inevitable
  - Paradox of Enrichment:
    - “When exceeding the carrying capacity of an ecological system, you risk its collapse.”
    - In this case, the carrying capacity is GDP
Financial Meltdown of 2008 (Cont.)

- Predator/Prey Model
Financial Meltdown of 2008 (Cont.)

- GDP as “carrying capacity”

Is 65% the current carrying capacity of the US economy?
Other Examples

- Adding extra capacity to a network could reduce overall performance
- Applying pesticides could increase the pest population
- Adding security personnel could increase breaches
- Increasing automobile MPG could decrease mobility; gasoline taxes support highways
Financial Meltdown of 2008 (Cont.)

- What caused the 2008 Financial Crisis?
  - Self-organized Criticality
  - Enrichment
- Will it happen again?
  - Yes
- Can Financial Crashes be avoided?
  - Yes
- What policies should we consider to protect the system?
  - Avoid Self-organized Criticality
Paradox of Enrichment

- **Enrichment**: Too much of a good thing can ruin it
- **Dunbar’s Number**: Used to explain why the right size for a group; corporation, government agency, school, etc. is less than 150-200 individuals. Why is this?

- **Possible Explanations**:
  - Management overhead exceeds benefits
    - Overhead: it takes effort to maintain a relationship
    - Benefit: more people = more productivity
  - Failure to communicate

Source: Robin Ian MacDonald Dunbar Director of the Institute of Cognitive and Evolutionary Anthropology, University of Oxford
Paradox of Enrichment (Cont.)

- Failure to communicate
  - Network diameter: longest path from any individual to any other individual.
  - Productivity: group performance is inversely proportional to the group’s social network diameter.
In increasing the carrying capacity (number of people doing work) can decrease effectiveness

Where: carrying capacity (in biology) is the maximum, equilibrium number of organisms of a particular species that can be supported indefinitely in a given environment

Some concepts:
- The more programmers you have, the less productive they are
- Adding extra capacity could reduce overall performance.
- Adding lanes to a freeway increases congestion
- Applying pesticide may increase the pest population.

Paradox of enrichment was postulated by Michael Rosenzweig in 1971.
More Paradox of Enrichment

Does more carrying capacity help?
- Not always
- Rosenzweig observed this paradox in nature in 1971:
  - Increasing the carrying capacity of the ecological system beyond a certain value leads to dynamic instability, and extinction of the predator species

What happens if pasture capacity is increased?
- Increasing the carrying capacity
- Capacity = 1.0, 1.25, 1.5, 1.75, 1.95, 2.0, >2.0
- Critical point = “tipping point” = 2.0
Hypothesized Enrichments

- **“.com” Bubble 1990-2000**
  - Excess venture capital (enrichment) -> too many “.coms” -> collapse

- **2002-2009 Housing Bubble**
  - Homeownership politics (enrichment) -> low rates -> housing collapse

- **Recent Corn-Ethanol Incentives**
  - Ethanol subsidies (enrichment) -> corn price instability

- **Interstate Highway System**
  - Highway Trust Fund (enrichment) -> more highway -> ??
“.com” Bubble 1990-2000

- Hypothesis: Venture capital “enrichment” caused the market to crash
Observation: Cisco stock price tracks venture capital enrichment and leads to unstable price
Political motivation for home ownership
66% home ownership seems to be the ‘carrying capacity’ of the US housing economy
- Did we exceed carrying capacity?
- Is the housing market stable again?
- Does ownership have a critical point?
Corn Enrichment

- U.S. is the largest producer of field corn; 13B bushels a year.
- Since 2005, field corn crop has been increasingly used to create ethanol. Fuel blenders are obliged under the 2007 Energy Independence and Security Act (EISA) to mix eligible biofuels into the gasoline. Blenders receive a tax credit per gallon of ethanol.
- For corn-based biofuels, such as ethanol, current mandate under EISA is 12.6B gallons (increases to 15B in 2015). Source: Tom Capehart, USDA biofuels expert.
- At current levels, 39% of U.S. field corn is used to produce the gasoline substitute.
- Does EISA produce the Paradox of Enrichment?
Security Enrichment

- Increasing ....
  - Number of security personnel in airports may increase risk of insider misconduct (more people to access secure areas).
  - Increasing carrying capacity of roads, may increase number of traffic accidents (due to more cars).
  - Applying more pesticides may increase number of pests (due to increased resistance).
  - Adding Internet capacity may reduce its performance (Braess's paradox).
  - Increasing capacity of an electric power line may increase the size and severity of blackouts (due to SOC).
Policy Implications

- **Enrichment and CIKR**
  - CIKR sectors cannot be understood as simple systems
  - Complex systems approach to guide policy and strategy
  - Does Enrichment Threaten or Help Sustainment of CIKR?

- **Questions**
  - Should enrichment paradox (EP) be considered in CIKR security?
  - Does EP increase and/or decrease risk?
  - How do we identify “unintended consequences” of enrichment?
  - What should be done about EP, if anything?
Tragedy of the Commons:
Bad Behavior in a Non-linear World

- Fukushima Disaster 2011
  - Earthquake-tsunami-nuclear power plant meltdown
  - Buildings and infrastructure worth about $210B
  - Nearly 15,000 dead and missing; 9,000 missing
  - Excludes costs of radiation leaks, direct damage to reactors
  - Considered most-costly damage, ever.
  - Comparable to USA Financial Meltdown of 2008
Nuclear Disasters are Long Tailed

- Levy Flight of incidents
  - Idaho Falls - 1961 - 3 deaths
  - Czechoslovakia - 1976 - 2 deaths
  - Three-Mile Island - 1979 - 0 deaths
  - Chernobyl - 1986 - 58 deaths
  - Japan
    - 1999 - 2 deaths
    - 2004 - 5 deaths
    - 2011 - 3 deaths (nuke only)
Nuclear Power Industry “Shared Risk”

- 104 U.S. power reactors; each subject to $111.9M risk
- Price-Anderson Nuclear Industries Indemnity Act, 1957. Renewed in 2005 for 20 years
- Licensees required to insure first $375 million per reactor
- Reactor companies obliged to pay up to $111.9M per reactor for claims that exceed the $375M
- As of 2011, maximum amount of the fund is approximately $12.22B ($111.9M X 104 reactors). Fund is not paid into unless an accident occurs. Payments are capped at $17.5M per year, until $111.9M or liability is reached.
- Construction cost: $10B; risk of $111.9M approx. 1% of cost
The Commons is a Complex System

- **Negative Examples**
  - Water/air pollution damage crops, buildings, public health
  - “Too big to fail” banking that shifts losses to taxpayers
  - Over fishing of oceanic fisheries
  - Risk transfers in health care, maintenance of roads, etc.

- **Positive Examples**
  - Network effects: individual buying a cell phone benefits all
  - Quarantining infectious diseases benefits everyone
  - Keeping up the neighborhood increases all home values

- **Unintended Consequences**
  - Positive effects may turn into negative effects
The Commons is a Complex System

- Critical Points
  - Tipping point or threshold effect
  - Small change near critical point leads to major change
  - System becomes unstable near its critical point

- Commons is sustainable
  - Populations vs. Time
  - Grass grows as fast as eaten
  - Cows sold as fast as reproduced

- Limit cycle
  - Does not reach 0
  - Repeats forever; sustainable
The Commons is a Complex System

- Commons dies out
  - Population vs. Time
    - Overstocking with cows
    - Grass grows too slowly
    - Commons eventually dies
    - Death to prey => death to predator
  - Limit Cycle
    - Eventually reaches zero
    - At 0: One or both die out
TOC Threats to Infrastructure

- **Moral Hazards**
  - Private sector accepts upside risk and keeps the profits
  - Public sector accepts downside risk and pays for any losses
  - Examples: Bailouts of 2008-2009; environmental damage; social security and Medicare

- **Regulations**
  - 1992 EPACT Regulation: Transmission lines in the power grid
  - 1996 Telecom Regulation: Wired landlines in communications

- **Others**
  - # hospital beds, # maintenance of highways, fishing in international waters and the rise of resistant diseases due to careless use of antibiotics.
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