



## Project 'System Shock'

Application of System Shock: Supply Network Disruptions

# Cambridge Risk Taxonomy of Macro-Threats

Research Overview & Status

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# Catastrophe Modelling Meets Complex Systems

- The System Shock project arises from shared interests by the participants in exploring areas of intersection between
  - Catastrophe modelling and extreme risk analytics
  - Complex systems and networks failures
- Advance the scientific understanding of how systems can be made more resilient to the threat of catastrophic failures

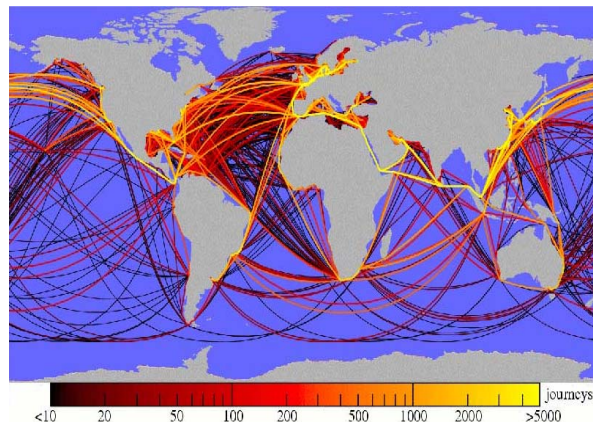
To answer questions such as:

‘What would be the impact of a [War in Taiwan] on the [Cargo Shipping Network] and how would this impact the [Oil Price]?’

Regional Conflict



Cargo Shipping Network



Global Economy





# Terminology

## Threats

Scenario



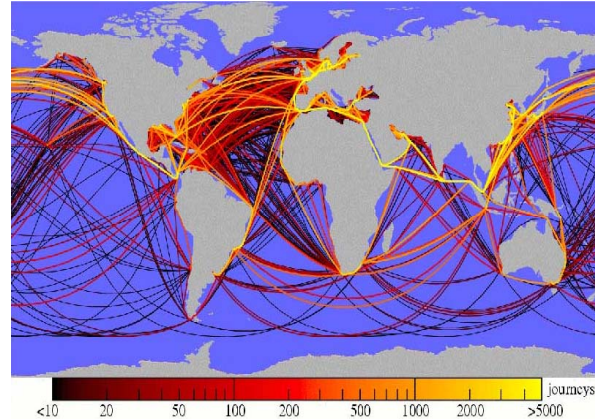
e.g.: Regional Conflict

Other examples:

- Natural Catastrophes
- Climatic Catastrophes
- Environmental Catastrophes
- Technological Catastrophes
- Financial Shocks
- Trade Disputes
- Geopolitical Conflicts
- Political Violence
- Disease Outbreaks

## Networks

Network Response



Cargo Shipping Network

### Business supply chains

- Shipping network
- Business travel network
- Communications network
- Energy supply network
- Trading networks
- Banking network

## Systems

Business Metrics



Oil Price

### Business Continuity Metrics

Macro-economic systems

- GDP
- Employment etc.

Investment assets

- Equity Market
- Fixed Income Market
- Exchange R

Business operational systems

- Profitability
- Continuity metrics

# Business Systems – Current Focus on Supply Chains

- Anecdotal: One anonymous firm surveyed by Rice and Caniato (2003) estimated the **daily cost** impact of a disruption in its supply network at **\$50-\$100 million**
- Studies of 'long-run' equity values of companies following disruption to supply chain show:
  - Average abnormal stock returns of -40% for firms suffering disruptions
  - Shareholders lose average of 10% of their stock value at announcement
  - 14% increase in equity risk in the year following a disruption announcement
  - Firms do not quickly recover from the negative effects of disruptions
  - Source: Hendricks & Singhal, 2005 (sample of 827 disruption announcements made during 1989–2000)
- 2004 Survey of top executives at Global 1000 firms showed supply chain disruptions and associated operational and financial risks to be single greatest concern
  - (Green, 2004)
- What is the implications of current trends in global supply chain best practice for disruption severity:
  - Cost management and efficiency improvements
  - Supply base reduction
  - Global sourcing
  - Sourcing from supply clusters
  - Source: Craighead et al., 2007, The Severity of Supply Chain Disruptions: Design Characteristics and Mitigation Capabilities

# Taxonomy of Macro-Threats

A framework for categorising socio-economic threats and collecting structured data

Version 2.0 Released February 2012



## 1 Financial Shock

- 1.1 Asset Bubble
- 1.2 Financial Irregularity
- 1.3 Bank Run / Credit Default
- 1.4 Sovereign Structural Failure
- 1.5 Market Volatility



## 5 Natural Catastrophe

- 5.1 Earthquake
- 5.2 Windstorm
- 5.3 Tsunami
- 5.4 Flooding
- 5.5 Volcanic Eruption



## 9 Disease Outbreaks

- 9.1 Human Epidemics
- 9.2 Animal Epidemics
- 9.3 Plant Epidemics



## 2 Trade Dispute

- 2.1 Labour dispute
- 2.2 Trade Sanctions
- 2.3 Tariff Wars
- 2.4 Nationalization
- 2.5 Cartel Pressure



## 6 Climatic Catastrophe

- 6.1 Drought
- 6.2 Freeze Event
- 6.3 Heat Wave



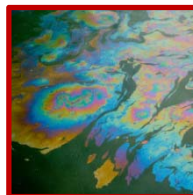
## 10 Humanitarian Crisis

- 10.1 Famine
- 10.2 Water Supply Failure
- 10.3 Population Migration
- 10.4 Welfare System Failure



## 3 Geopolitical Conflict

- 3.1 Conventional War
- 3.2 Asymmetrical War
- 3.3 Nuclear War
- 3.4 Civil War
- 3.5 External Force



## 7 Environmental Catastrophe

- 7.1 Sea Level Rise
- 7.2 Oceanic Circulatory System Change
- 7.3 Atmospheric System Change
- 7.4 Pollution Event
- 7.5 Wildfire



## 11 Externalities

- 11.1 Meteorite
- 11.2 Space Weather



## 4 Political Violence

- 4.1 Terrorism
- 4.2 Separatism
- 4.3 Civil Disorder
- 4.4 Assassination
- 4.5 Organized Crime



## 8 Technological Catastrophe

- 8.1 Nuclear Power Plant Accident
- 8.2 Industrial Accident
- 8.3 Infrastructure Breakdown
- 8.4 Technological Accident
- 8.5 Cyber-Catastrophe



## 12 Other Shock

Community peer review being conducted at <http://systemshock.org.uk>

# Representative Shock Test Scenarios

## Once-a-Century Level of Severity

- Financial Shock wipes 10% off global GDP
- Tariff war that closes business between China and West for 6 months
- War envelops most of the Middle East, drawing in all super-powers
- Terrorist attack with a WMD on a western nation, kills 100,000 people
- 20 Cat 5 Typhoons in the Pacific Ocean in a single season (> one a week)
- A VEI 5 'Cataclysmic' Volcanic eruption produces 10 km<sup>3</sup> of ash, stopping air traffic over a third of the world and cools the globe by 3 degrees
- Deep freeze grips Europe and NE America for 7 weeks
- Massive oil spill in Arabian Gulf closes shipping lanes for 3 months
- Cyber attack by hackers releases worm that corrupts corporate databases
- Pandemic causes 40% of the labour force to be off sick for 5 days
- Famine in Indian subcontinent causes major political and social upheaval
- X-class solar flare causes power system burn out and disrupts communications

# Why Is This Analysis Useful?

- Demonstrates the correlation of potential failures in business systems such as supply chains
  - i.e. multiple elements of the supply chain are impacted by the same event
- Helps us understand potential patterns of failure from shock events
  - We expect to be able to characterize and classify failure types
- Identifies strategies to reduce the consequences of shocks
  - Improves resilience to catastrophic failure
- Indicates the frequency and severity of shock events
  - Anchors the cost-benefit analysis of resilience investment

# Disruption Management Strategies

- Potential disruption-management strategies:
  - Mitigation by carrying inventory
  - Mitigation by single-sourcing from the most reliable supplier
  - Mitigation from multiple sourcing
  - Passive acceptance
- Nature of the disruptions are key determinants of the optimal strategy
  - Supplier's Percentage Uptime
  - Frequent but short versus rare but long

Source: Brian Tomlin 2006,

'On the Value of Mitigation and Contingency Strategies for Managing Supply Chain Disruption Risks' Management Science, Vol. 52, No. 5, May 2006, pp. 639–657



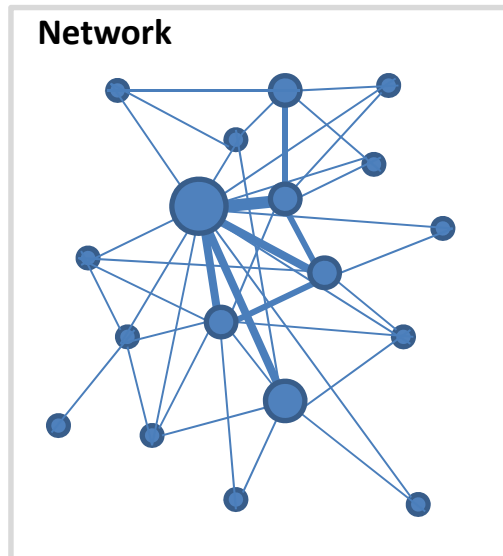
# Disruption Management Strategies

Strategy	Tactic	Examples
<b>Financial Mitigation</b>	Business Interruption Insurance	2003 Q4, Palm Inc. received a \$6.4 million insurance settlement arising from an earlier fire at a supplier's factory.
<b>Operational Mitigation</b>	Inventory	Playmates Toys mitigated the impact of the 2002 west-coast dock disruption by investing in inventory earlier in the year.
		U.S. Strategic Petroleum Reserve protects the U.S. against interruptions in crude-oil supplies
	Sourcing	Nokia's multiple-supplier sourcing strategy mitigated the impact of the Philips Semiconductor disruption in 2000
		Chiquita's multiple-location sourcing strategy mitigated the impact of the 1998 Hurricane Mitch disruption
<b>Operational Contingency</b>	Rerouting	Nokia responded to the Philips Semiconductor disruption by temporarily increasing production at alternative suppliers
		Chiquita responded to the Hurricane Mitch disruption by temporarily increasing production at alternative locations.
		New Balance responded to the west-coast dock disruption by rerouting ships to the east coast and by air freighting supplies
		Chrysler responded to the air-traffic disruption in the immediate aftermath of September 11th by temporarily switching to ground transportation to move components from a U.S. supplier to the Dodge Ram assembly plant in Mexico
	Demand Management	Dell responded to the disruption in memory supply after 1999 Taiwanese earthquake by shifting customer demand to lower-memory personal computers

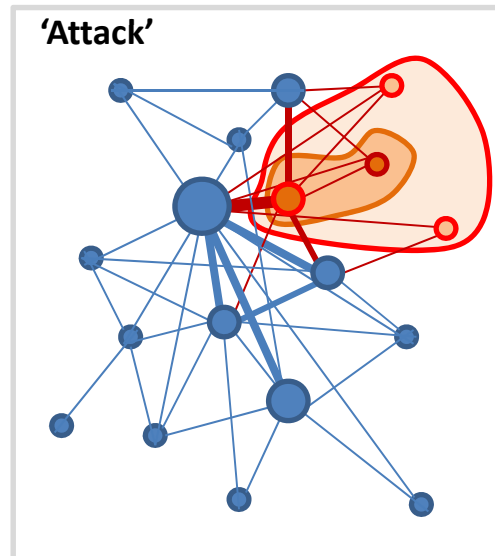
Source: Brian Tomlin 2006, 'On the Value of Mitigation and Contingency Strategies for Managing Supply Chain Disruption Risks' Management Science, Vol. 52, No. 5, May 2006, pp. 639–657

# Networks, Attacks, and Residual Modeling

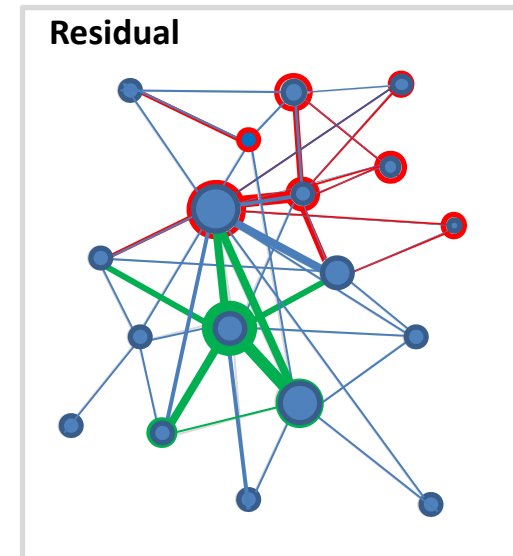
- A framework for assessing the consequences of an event on a system network



- Describe the topology of the network as nodes and links
- Baseline efficiency of the network quantified through standard metrics of **Value Function**:
  - Connectivity
  - Reference path length
  - Diameter
  - Social Welfare



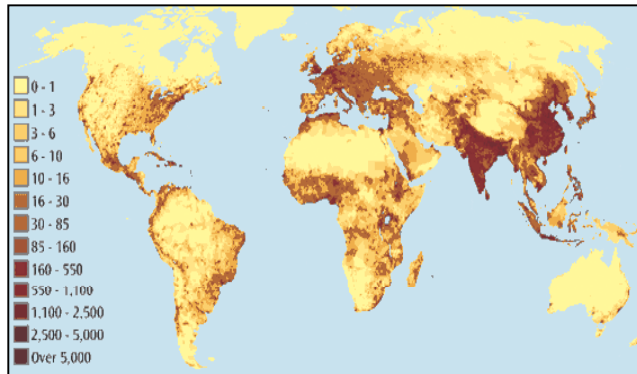
- Degradation of the network through localized impairment or removal of nodes and links
- Attack measured by 'k-cut' metrics



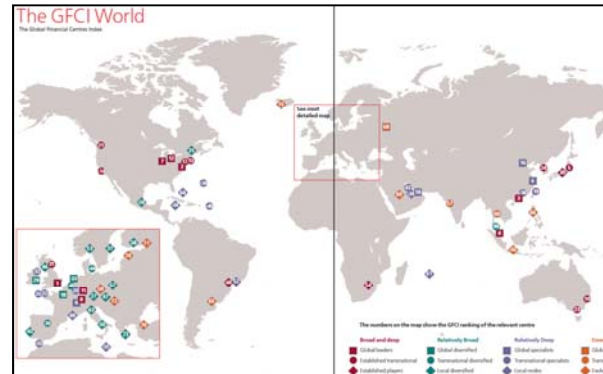
- Post-attack network either static or adaptive
  - Network may be fragmented after an attack
- Adaptive response of a network adjusts traffic and relationships
- May introduce congestion
- Changes in **Value Function** are measured as a result of the attack

# Understanding the Networks at Risk

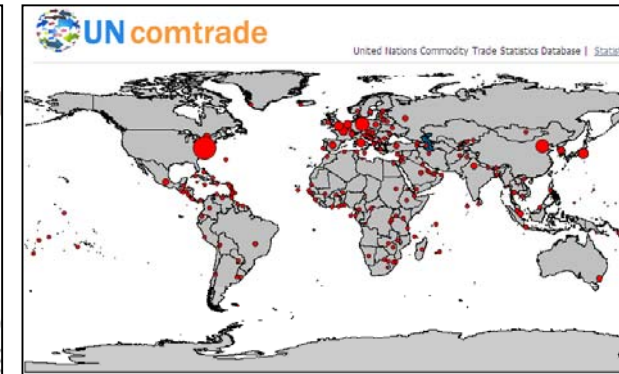
Population Centres



Global Financial Centres



Trading Networks

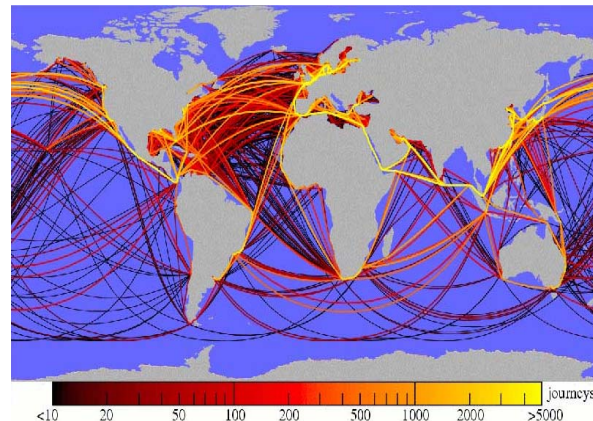


## Geography vs Topology

Air Travel Network



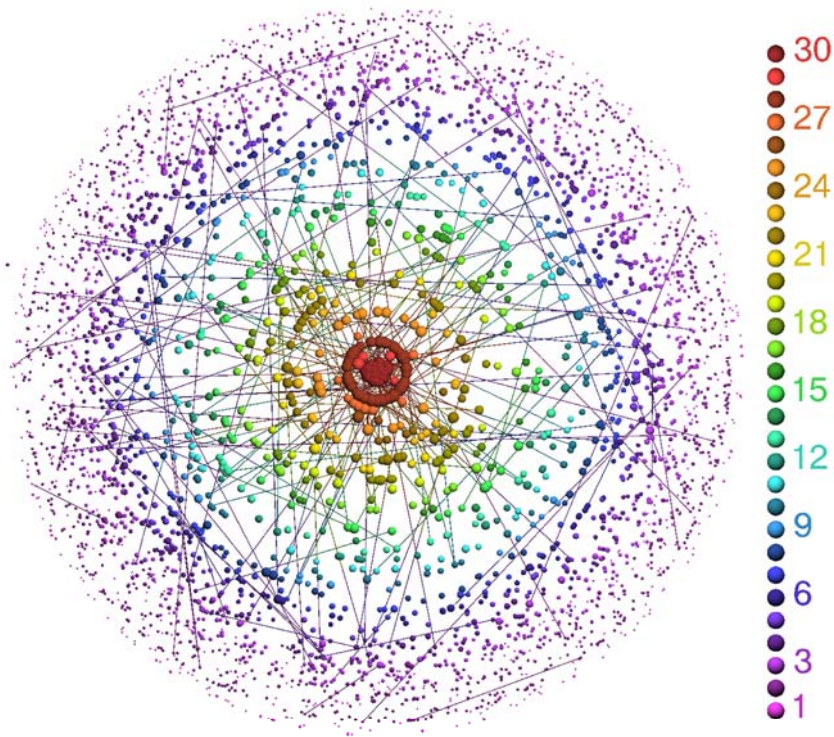
Cargo Shipping Networks



Communications Networks

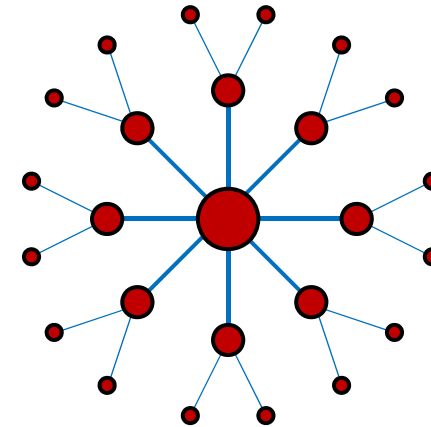


# Airport Network Topology



Routes mapped by volume

High-Order Star

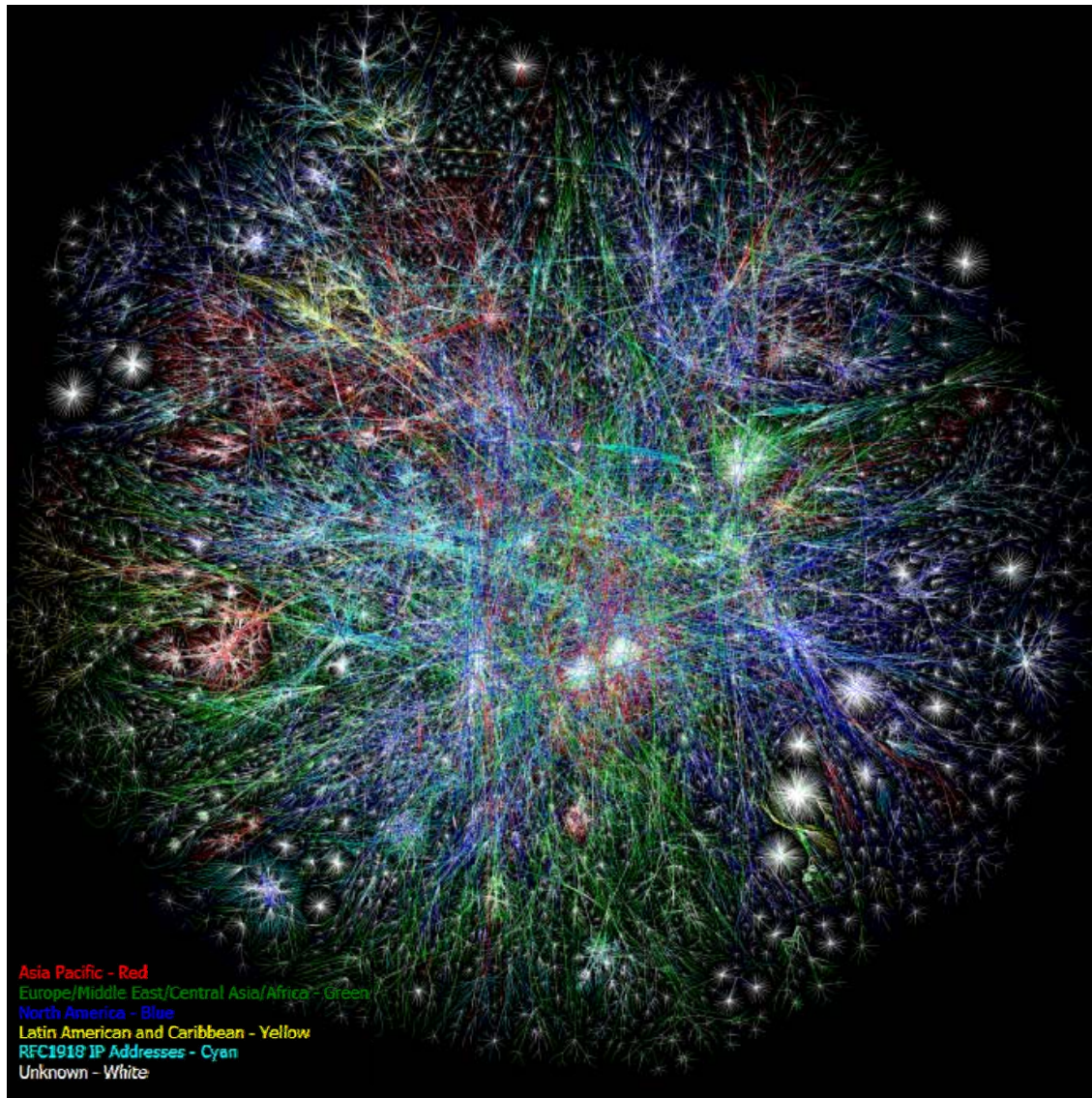


		Location	IATA Code	Passengers 2011
1	Hartsfield–Jackson Atlanta	Georgia, USA	ATL/KATL	53,892,885.00
2	Beijing Capital	Beijing, China	PEK/ZBAA	44,097,339.00
3	London Heathrow	United Kingdom	LHR/EGLL	39,762,295.00
4	O'Hare	Chicago, Illinois, USA	ORD/KORD	38,248,474.00
5	Los Angeles	California, USA	LAX/KLAX	35,933,812.00
6	Paris Charles de Gaulle	Paris, France	CDG/LFPG	34,969,496.00
7	Tokyo	Japan	HND/RJTT	33,524,239.00
8	Dallas Fort Worth	Texas, USA	DFW/KDFW	33,498,596.00
9	Frankfurt	Germany	FRA/EDDF	32,090,166.00
10	Denver	Colorado, USA	DEN/KDEN	30,570,965.00
11	Hong Kong Chek Lap Kok	China	HKG/VHHH	30,481,000.00
12	Dubai	United Arab Emirates	DXB/OMDB	29,291,927.00
13	Madrid Barajas	Spain	MAD/LEMD	28,792,188.00
14	Amsterdam Schiphol	Netherlands	AMS/EHAM	28,266,665.00
15	Bangkok, Suvarnabhumi	Thailand	BKK/VTBS	28,162,022.00

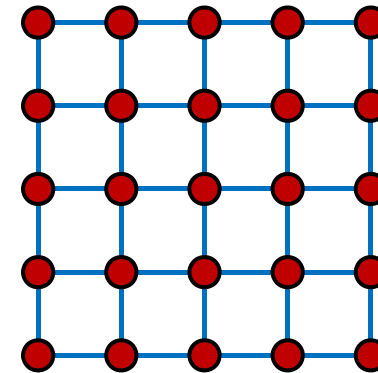
Top 15 Airports by Traffic Volume



# Internet Topology



Low-Order, 'Regular' Network

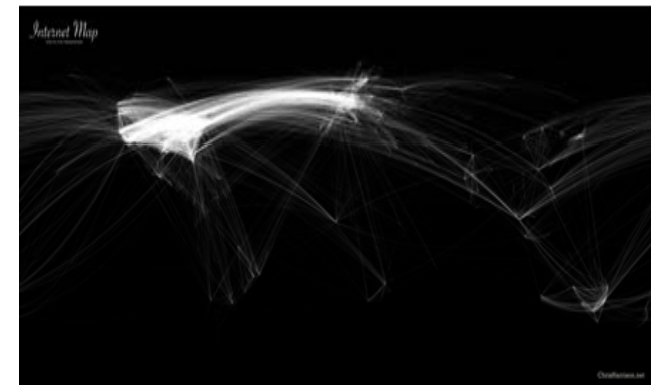


Source:

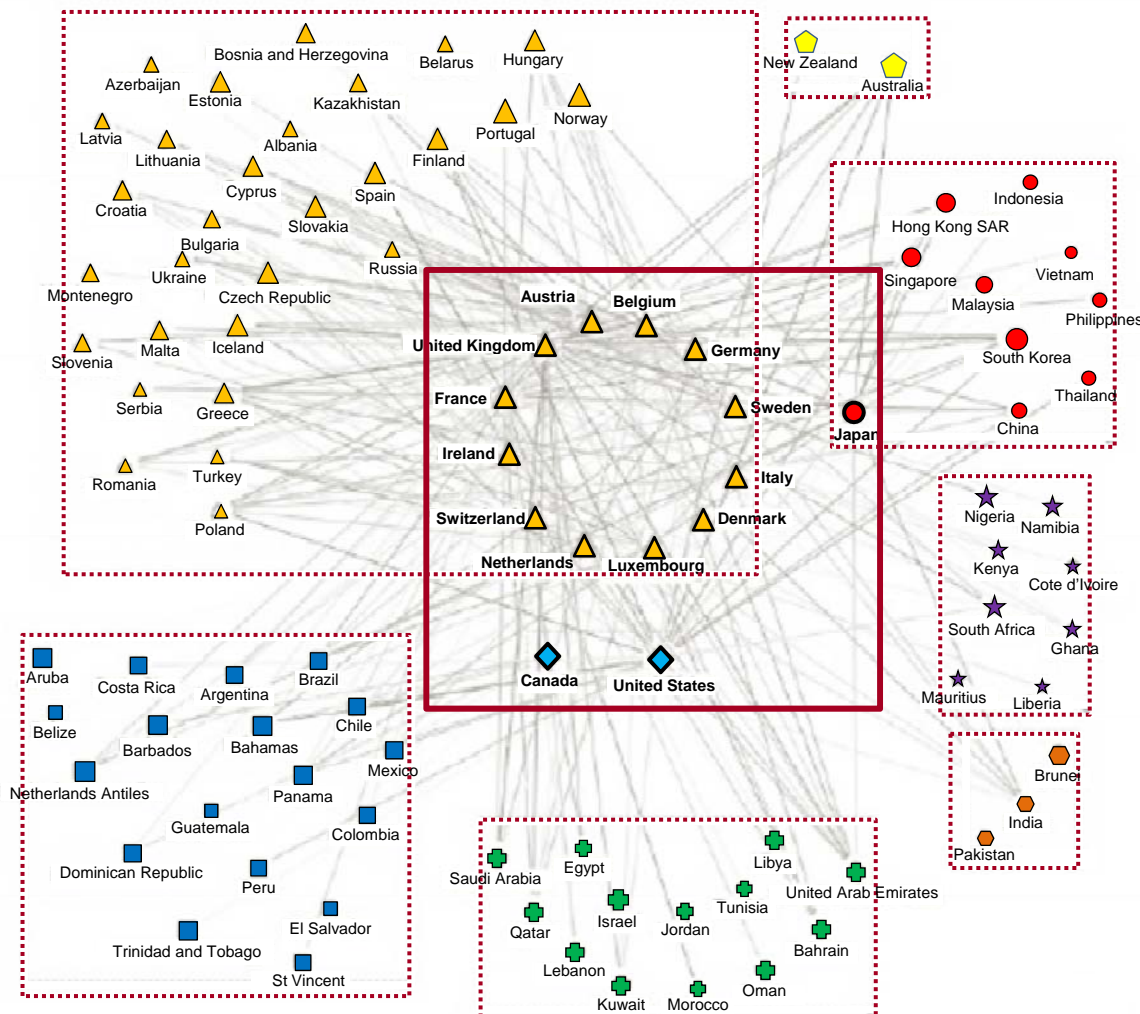
AT&T Labs Research, The OPTE Project, Large Graph Layout (LGL) by Alex Adai and Graphviz by Peter North

[Image derived from 50 million hop count & over 5 million edges]

<http://www.opte.org/maps/>



# Network Analysis of Global Banking Network

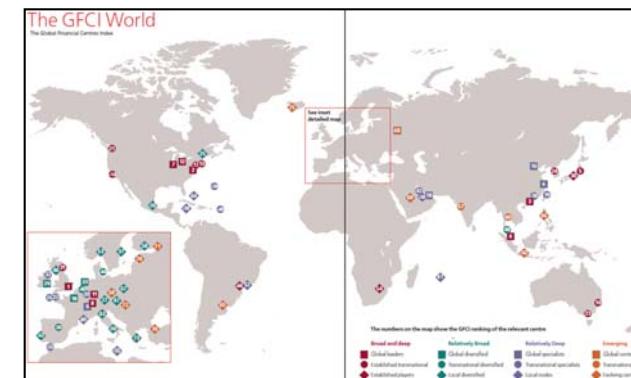
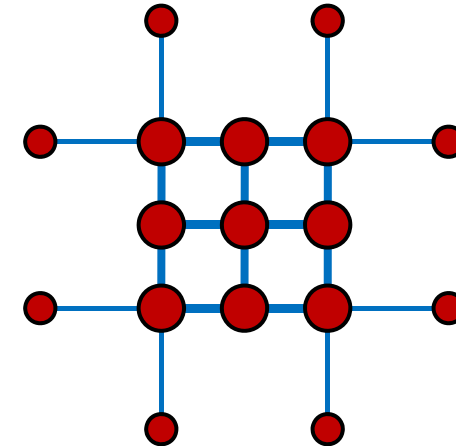


Source:

A network analysis of global banking: 1978-2009; Minoiu, Camelia ; Reyes, Javier A., IMF Working Paper

<http://www.imf.org/external/pubs/ft/wp/2011/wp1174.pdf>

## Core Periphery Network



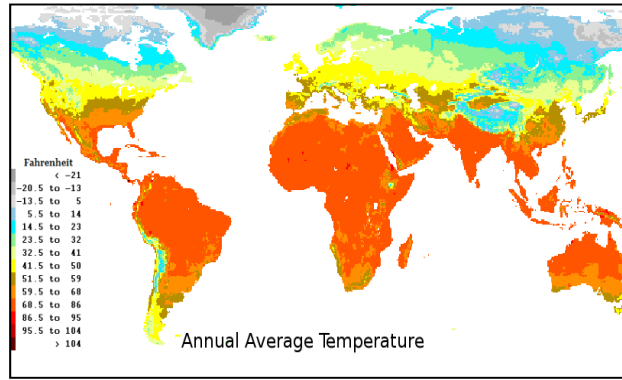


# Threats and Their Characteristics

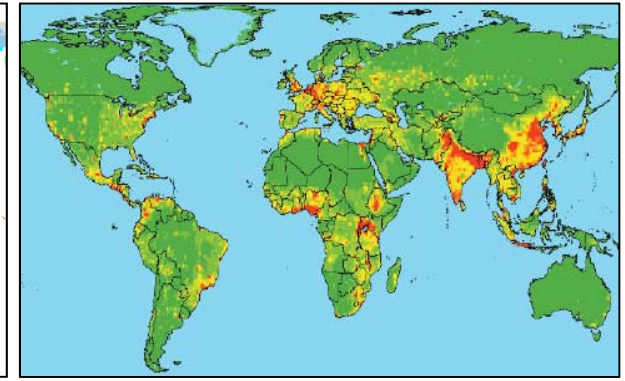
Political Risk



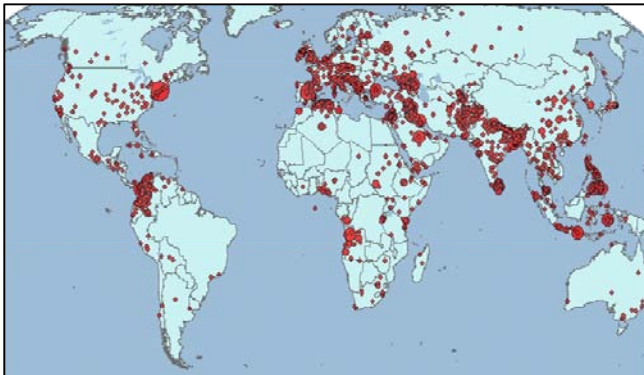
Climatic Hazards



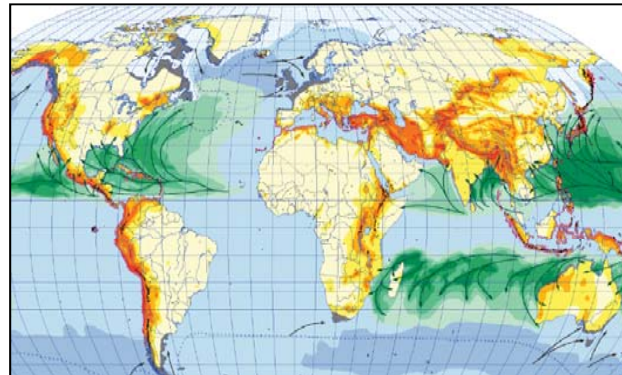
Disease Risk



Terrorism



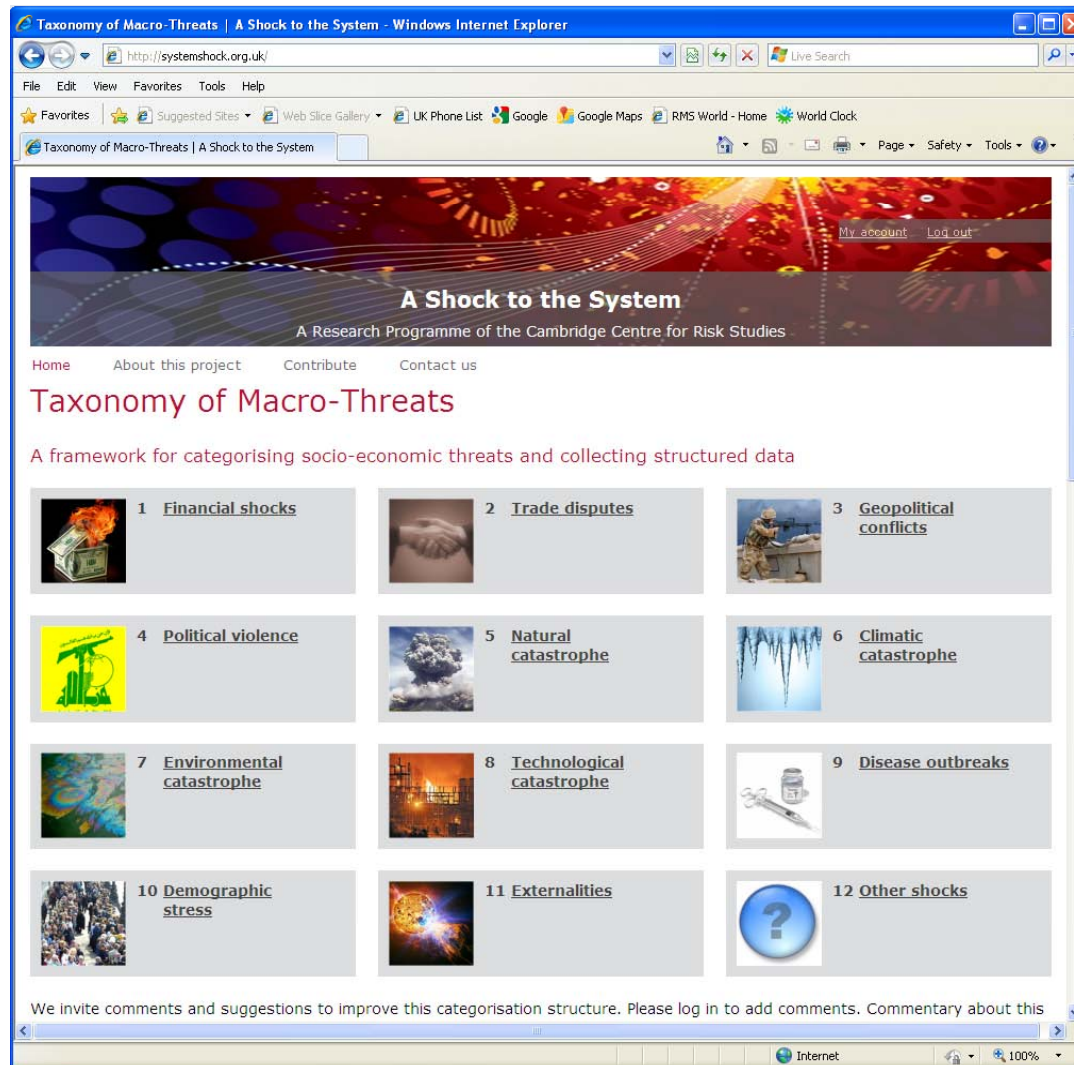
Natural Hazards



Technological Accidents



# Web-Based Knowledge Repository on Threats



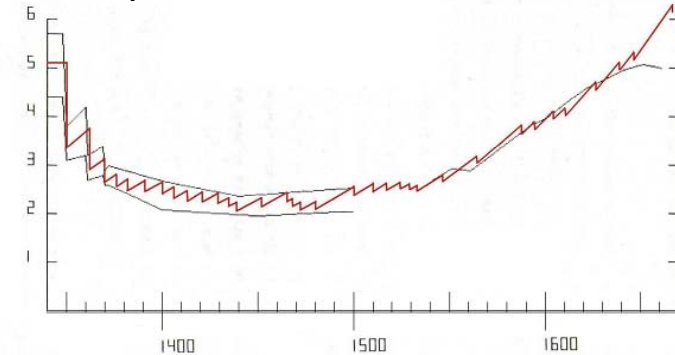
Community peer review being conducted at <http://systemshock.org.uk>



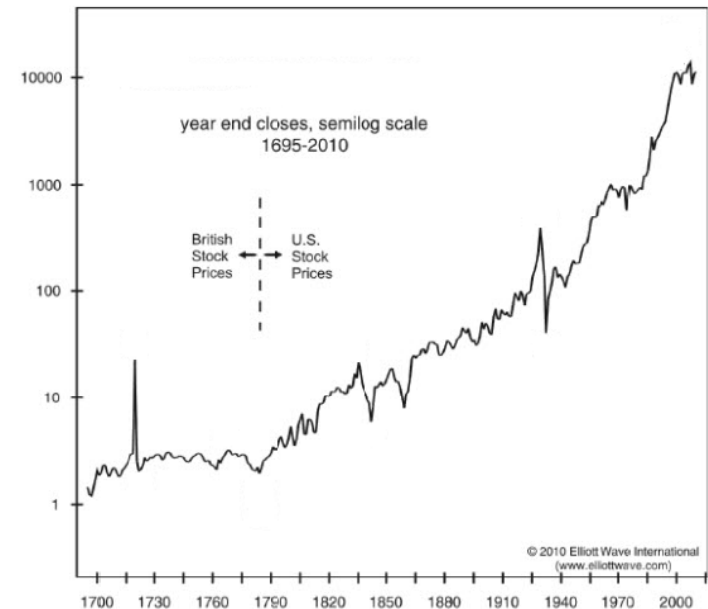
# Approach to Evidence-Based Completeness

- We are reviewing a thousand years of data for historical events causing disruption to social life and economic well-being
- Categorization of causes
  - Primary effort is to ensure that all categories are captured
  - Identify drivers of risk
- Counter-Factual History
  - Near-miss events that could have caused catastrophe with plausible minor deviations from actual events
- Scientific publications proposing mechanisms for major disruptions that do not appear in the historical records
  - Climate change; new technology hazards; changes in frequency and severity of threats

UK Population 1300-1700



300 years of Stock Market records



Source: Jay (2010)

























<http://fintrend.com/tag/bear-market/>

# Cascading Catastrophes

- Some of the worst manifestations of events involve the triggering of one event category by another
  - A cascade catastrophe
  - For example, an earthquake could cause damage that will cause a nuclear power plant meltdown, and this could trigger a financial shock in the markets
- This is considered in a qualitative structuring of the causal and consequential correlation matrix for the threat taxonomy

# Causal and Consequential Correlation of Threats

Primary Trigger

			Consequential Threat											
			1	2	3	4	5	6	7	8	9	10	11	12
			Financial Shock	Trade Dispute	Geopolitical Conflict	Political Violence	Natrual Catastrophe	Climatic Catastrophe	Environmental Cat	Technological Cat	Disease Outbreak	Humanitarian Crisis	Externality	Other
														
1	Financial Shock		4	3	2	2	1	1	1	1	1	2	1	1
2	Trade Dispute		3	4	2	3	1	1	1	1	1	1	1	1
3	Geopolitical Conflict		3	2	4	3	1	1	1	1	1	2	1	1
4	Political Violence		2	2	3	4	0	0	0	3	3	2	1	1
5	Natural Catastrophe		2	2	2	1	4	2	3	3	2	2	1	1
6	Climatic Catastrophe		3	2	3	2	3	4	3	2	2	3	1	1
7	Environmental Catastrophe		3	2	2	2	3	3	4	2	2	2	1	1
8	Technological Catastrophe		2	2	2	2	2	2	0	4	1	1	1	1
9	Disease Outbreak		3	2	1	1	1	1	1	2	4	2	1	1
10	Humanitarian Crisis		2	2	3	3	1	1	1	1	2	4	1	1
11	Externality		3	2	2	1	3	3	3	3	2	2	1	1
12	Other													

0

No causal linkage  
No ability to exacerbate

1

No causal linkage, but would exacerbate consequences if they occur

2

Weak potential to trigger threat occurrence

3

Strong potential to trigger threat occurrence

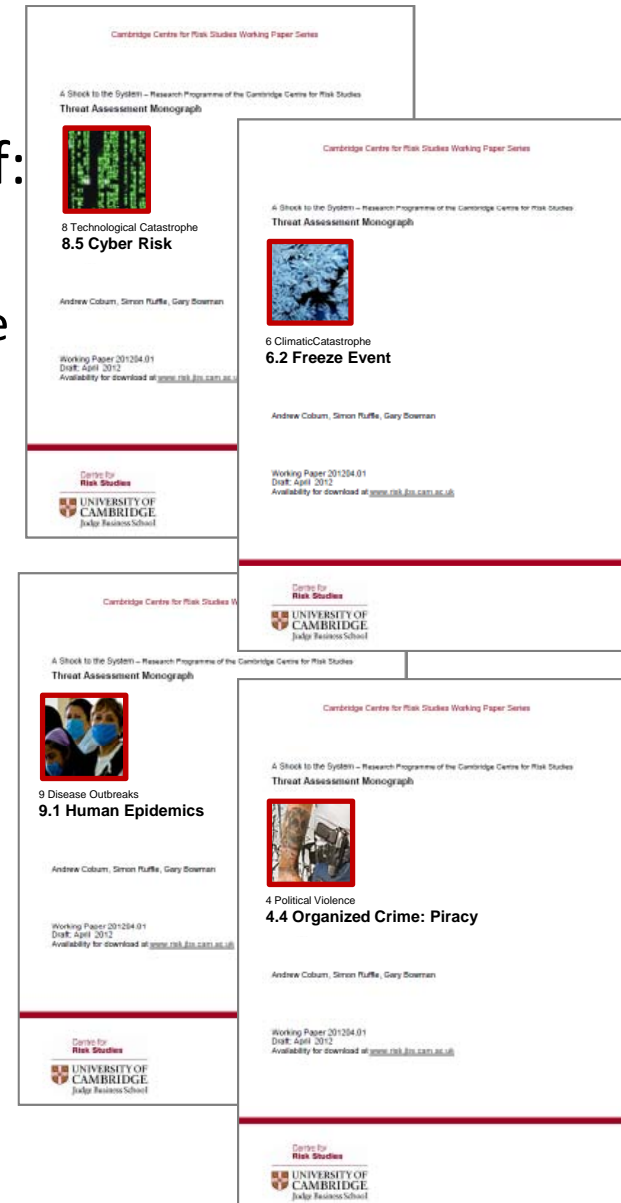
4

Ability to trigger  
Other threats within same type class

# Profile of each Macro-Threat Class

We intend to compile and publish a monograph on each of the 47 threat categories, consisting of:

- State-of-knowledge summary of the science
- Identify the leading authorities and publications on the subject
- Catalogue of historical events
- Map the geography of threat
- Define an index of severity ('magnitude scale')
- Assess a first-order magnitude-recurrence frequency (worldwide)
- **Provide illustrative 'Stress Test' scenarios of large magnitude events**
  - For e.g. 1-in-100 (or 1-in-1,000) annual probability
- System impact (vulnerability) knowledge
- Assessment of uncertainties





# How Far Have We Got?

## ■ We have the following threat profiles and scenarios in progress:

- 6.2 Freeze Event
- 4.5 Organized Crime: Piracy
- 9.1 Human Epidemics
- 1.2 Financial Irregularity: Rogue Trader

## ■ Examples being discussed/Proposals being developed for:

- 8.5 Cyber Catastrophe
- 5.5 Volcanic Eruption
- 7.1 Sea Level Rise
- 4.3 Civil Disorder (Arab Spring)
- 1.4 Sovereign Structural Failure (Eurozone breakup)
- 3.1 Conventional War (Military conflict in South China Sea)
- 5.2 Windstorm (Severe typhoon season in Pacific)
- 5.3 Tsunami (West Coast US)

# Resilient International Supply Chains: Project Status

## 1. Overall Project Framing and Prioritization

Status May 31, 2012

- Nov 2011 to March 2012
- Identification of 'supply chain shock' concepts
- Shock taxonomy development
- Research partnership consultation

☒ Completed  
☒ Completed  
☒ Completed

## 2. Data Structure Development

- March to mid June
- Development of a detailed framework for description and evaluation of supply chain for one of the industrial sectors
- Project meeting 18 June

☒ Completed  
☒ In progress!

## 3. Industry Profiling and Analysis

- mid-June to mid-Sept
- Collection of information on typical supply chain structures of three sample industry sectors: Auto; Consumer Electronics; Life Science;
- Sample shock analyses

☒ In progress  
☐ Not yet started

## 4. Framework Development, Conclusions, and Report Production

- Mid-Sept-end Nov
- Comparisons of different industry supply chain characteristics and resilience to different types of shocks
- Development of conclusions
- Drafting of report

☐ Not yet started  
☐ Not yet started  
☐ Not yet started