Planning for Efficiency, Risk and Resilience in Supply Chains

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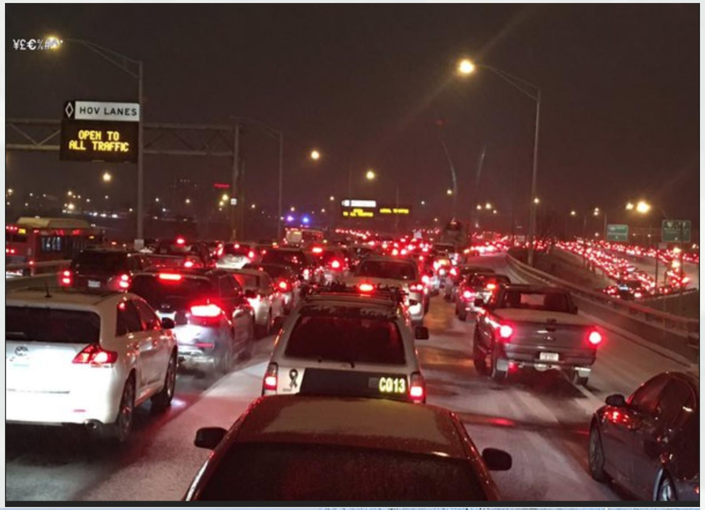
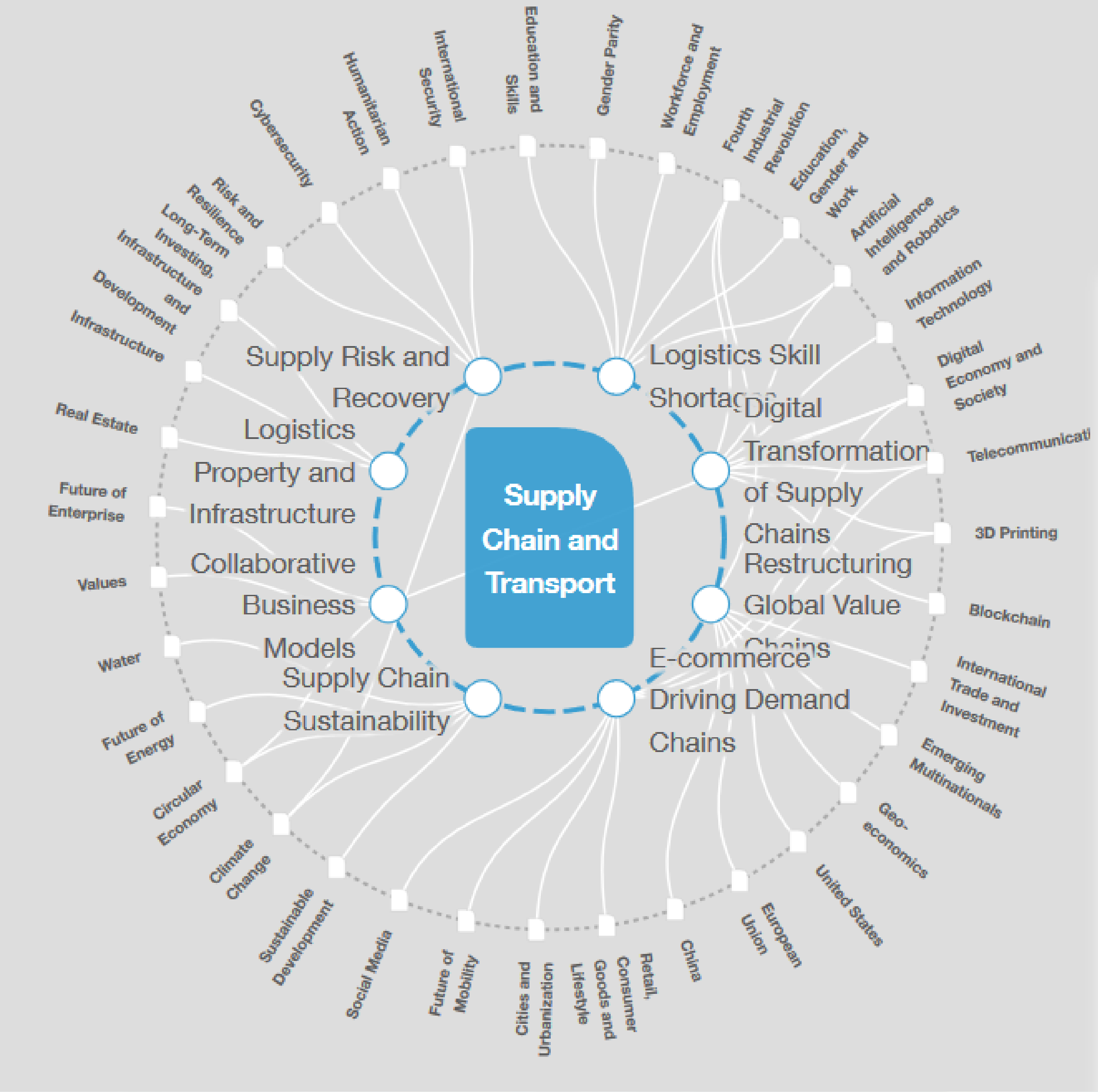
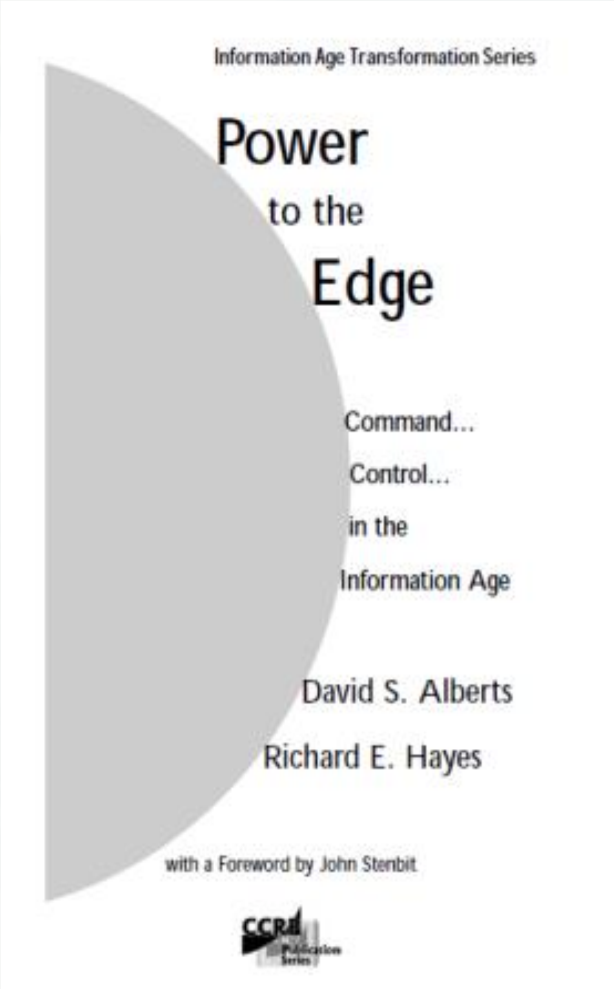


OECD
International Transportation Forum,
12 April 2018



From World Economic Forum

Military Systems Doctrine as a Foundation for Multimodal Supply Chain Resilience



Physical: system performance in space and time.

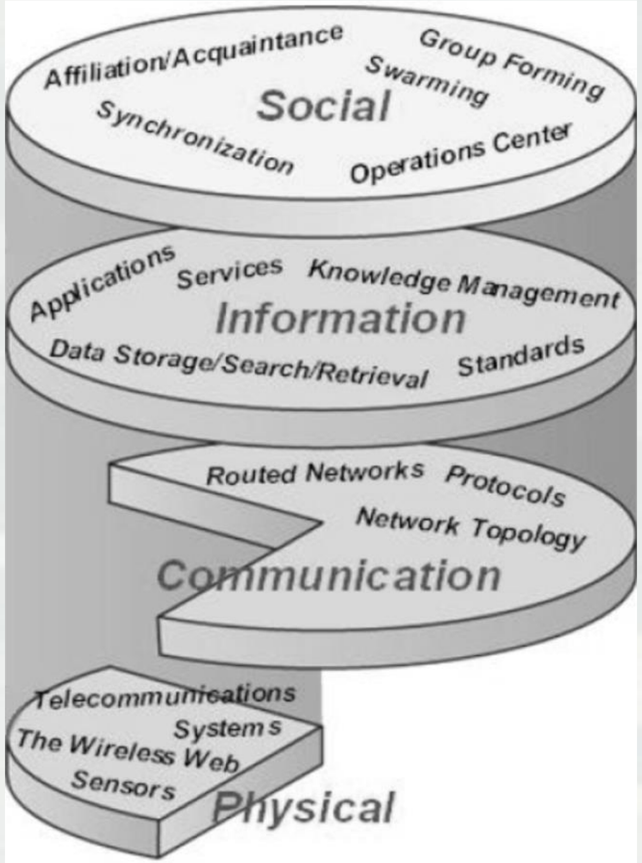
Information: creation, manipulation and sharing information.

Cognitive: translating, sharing, and acting upon information to enable system management.

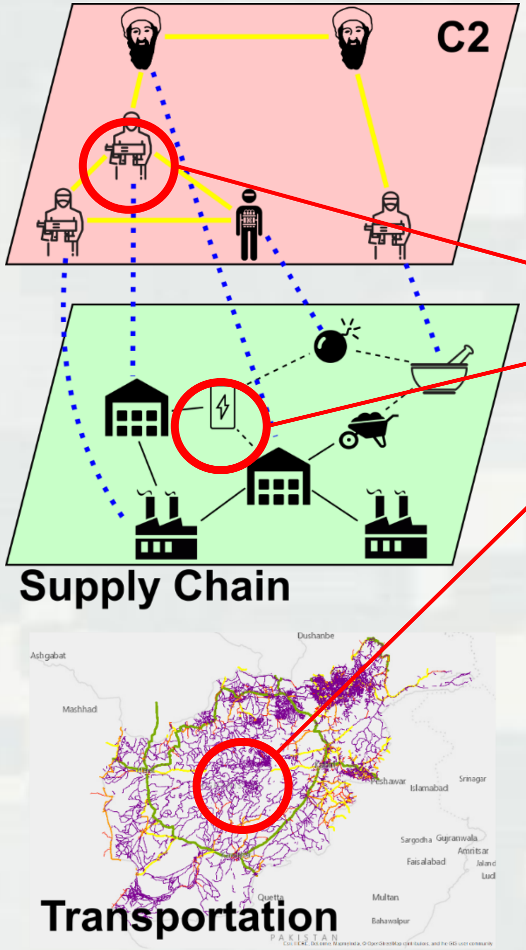
Social: interaction, collaboration and self-synchronization between individuals and entities.

Vision for Transportation Supply Chain Resilience

Real World



Model



Operations

Management Alternatives

Problem Statement

- The multi-modal transportation threat space is complex
- Supply chain is getting to be lean/smart and global, less sustainable, secure and resilient
- Regulators have attempted to make supply chain more resilient and secure, but tradeoff space is unexplored
- We hypothesize that resilience and efficiency of supply chain can be modeled as complex interconnected system

Agenda

- Risk vs. Resilience
  - Terminology
  - Supply chain impact
- Supply Chain Efficiency and Resilience
  - Concepts
  - Literature Review of Supply Chain Resilience
- Supply Chain Modeling for Transportation
  - Network Theory of Resilience
  - Application to Road Network (1 layer)
  - Adding Cyber and Social Layers (2-3 layers)
- New Technologies and Tools (blockchains, etc.)
- Questions

Efficiency—achieving maximum productivity with minimum wasted effort.

Risk—“a situation involving exposure to danger [threat].”

Security [Robustness]—“the state of being free from threat.”

Resilience—“the capacity to recover quickly from difficulties.”

Definitions by Oxford Dictionary

30 | NATURE | VOL 555 | 1 MARCH 2018

Don’t conflate risk and resilience

‘Risk’ and ‘resilience’ are fundamentally different concepts that are often conflated. Yet maintaining the distinction is a policy necessity. Applying a risk-based approach to a problem that requires a resilience-based solution, or vice versa, can lead to investment in systems that do not produce the changes that

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Calls for Increased Resilience

The White House

Office of the Press Secretary

For Immediate Release October 31, 2013

Presidential Proclamation -- Critical Infrastructure Security and Resilience Month, 2013

CRITICAL INFRASTRUCTURE SECURITY AND RESILIENCE MONTH, 2013

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BY THE PRESIDENT OF THE UNITED STATES OF AMERICA

A PROCLAMATION

Over the last few decades, our Nation has grown increasingly dependent on critical infra
our national and economic security. America's critical infrastructure is complex and diver
both cyberspace and the physical world -- from power plants, bridges, and interstates to
massive electrical grids that power our Nation. During Critical Infrastructure Security and
resolve to remain vigilant against foreign and domestic threats, and work together to furt
systems, and networks.

"Resilience" means the ability to anticipate, prepare for, and ***adapt*** to changing conditions and ***withstand, respond to***, and ***recover*** rapidly from disruptions.

(vi) Effective immediately, it is the policy of the executive branch to build and maintain a modern, secure, and more **resilient executive branch IT architecture**.

The White House

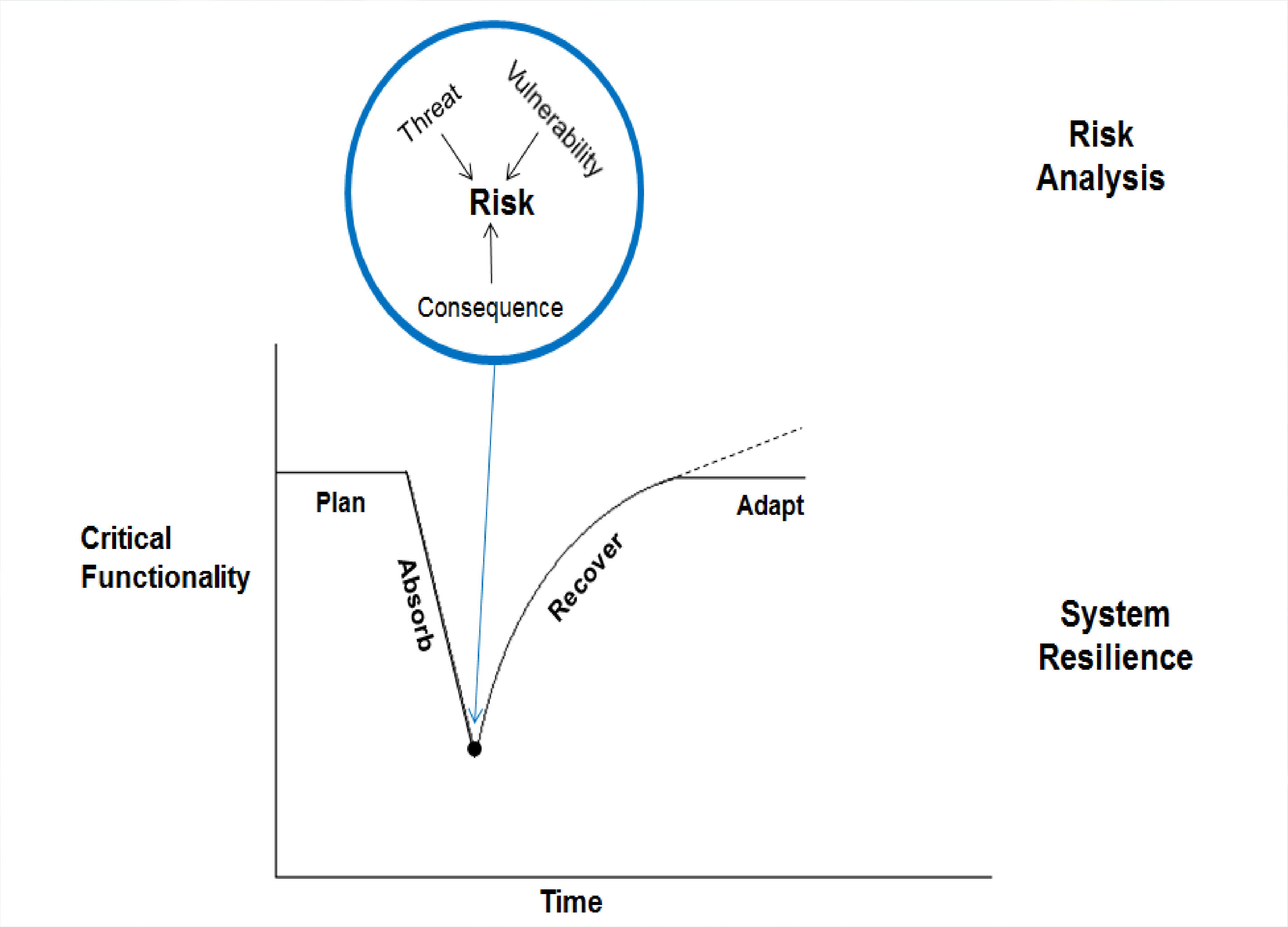
Office of the Press Secretary

For Immediate Release May 11, 2017

Presidential Executive Order on Strengthening the Cybersecurity of Federal Networks and Critical Infrastructure

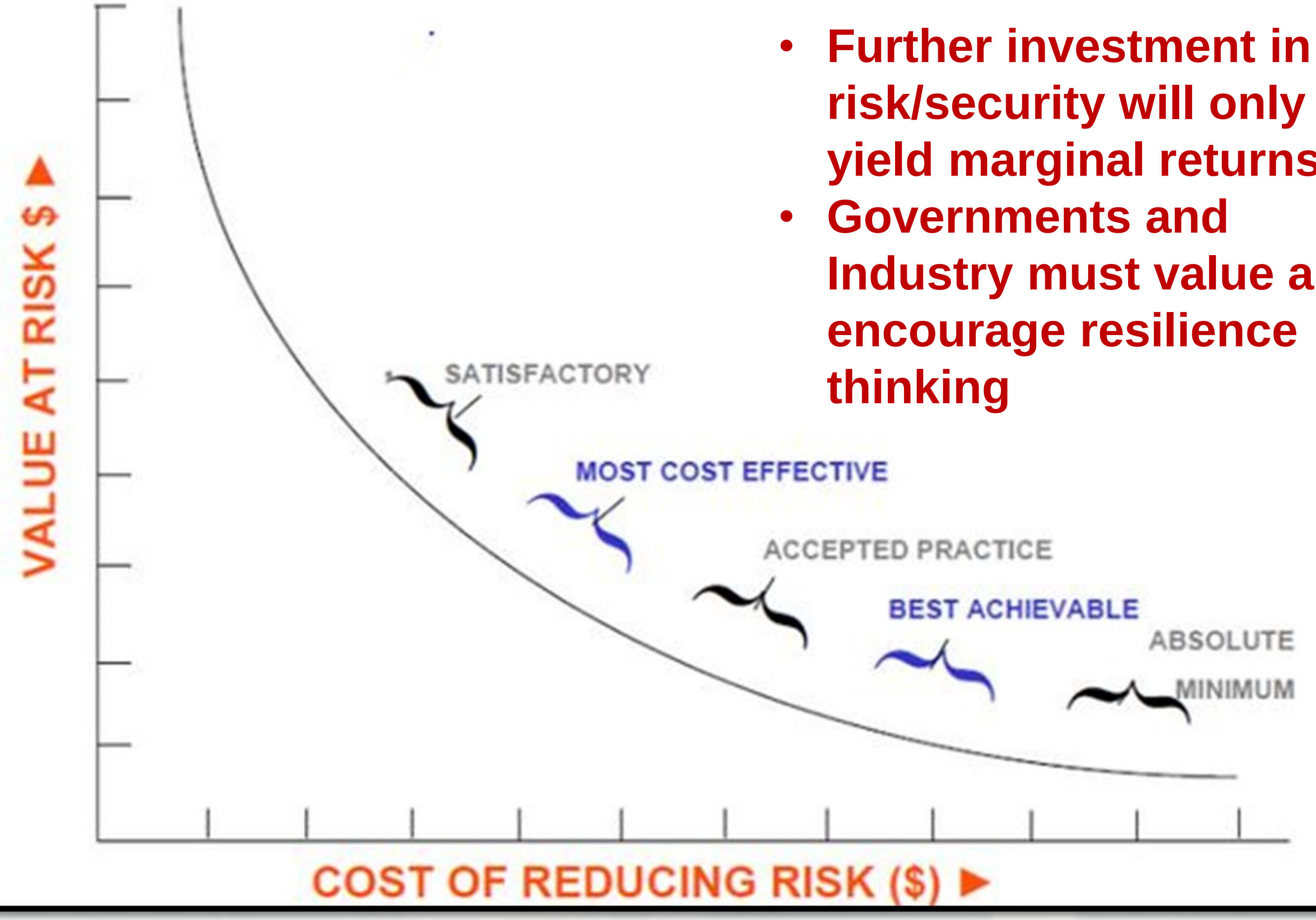
EXECUTIVE ORDER

The Whole Picture: System Risk and Resilience



After Linkov et al, Nature Climate Change 2014

Buying Down Risk vs Managing Resilience?

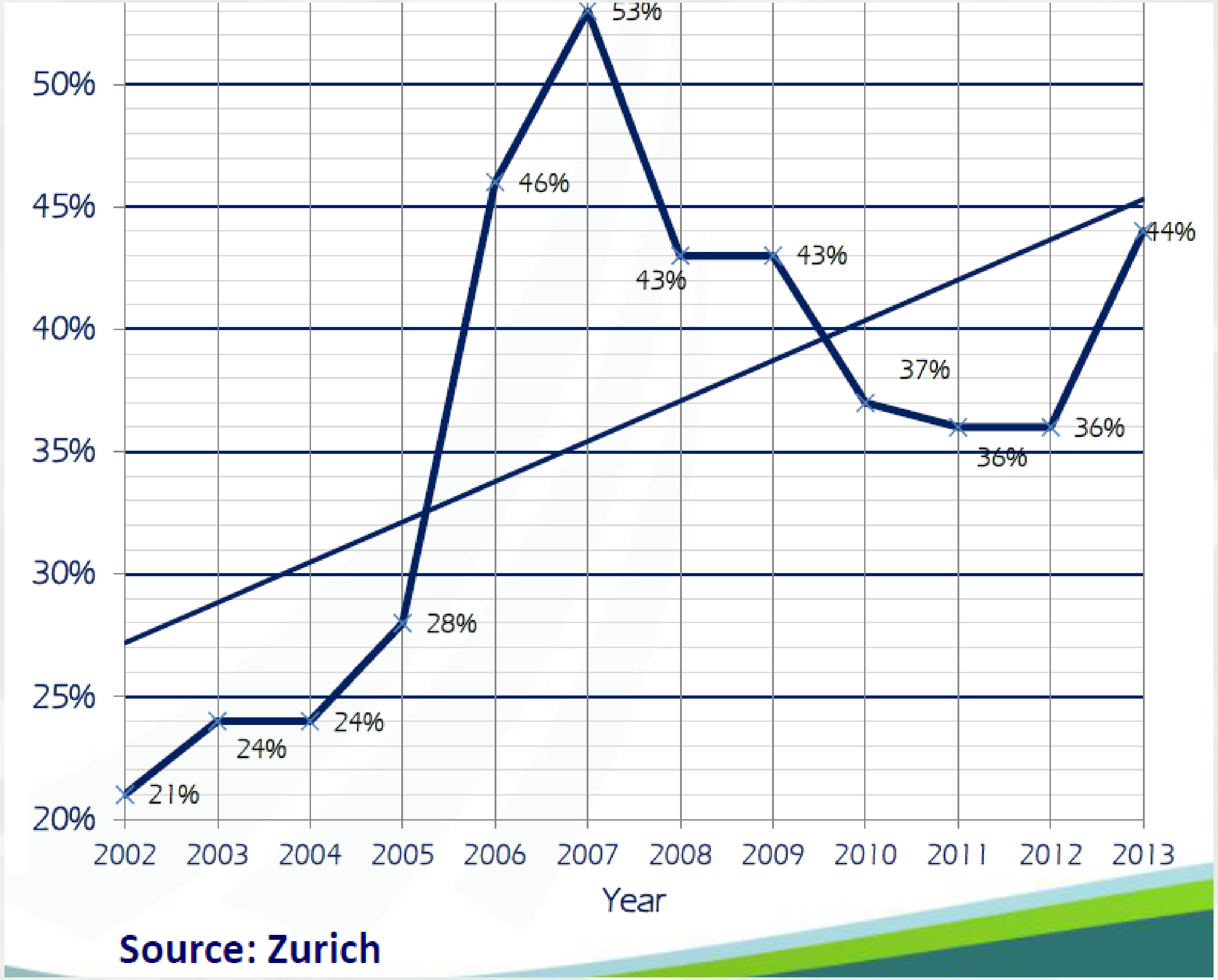


- **Further investment in risk/security will only yield marginal returns**
- **Governments and Industry must value and encourage resilience thinking**

After Bostick et al 2018

Business Interruption and Supply Chain

Share of Business Interruption in Total Property Claims



What is a Supply Chain?

An integrated process wherein various businesses work together in an effort to:

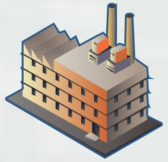
- Acquire raw materials,
- Convert these raw materials into specified final products, and
- Deliver these final products to retailers

This can be represented as a network, or set of interlaced networks

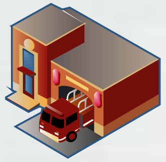
Beamon, B. M. Supply Chain Design and Analysis:: Models and Methods. *International Journal of Production Economics*, Vol. 55, No. 3, 1998, pp. 281–294. https://doi.org/10.1016/S0925-5273(98)00079-6.

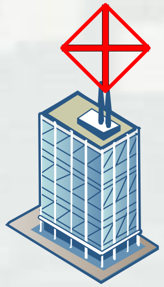
Supply Chain Critical Functionality is a Product of Multiple Factors, Dependent on Context

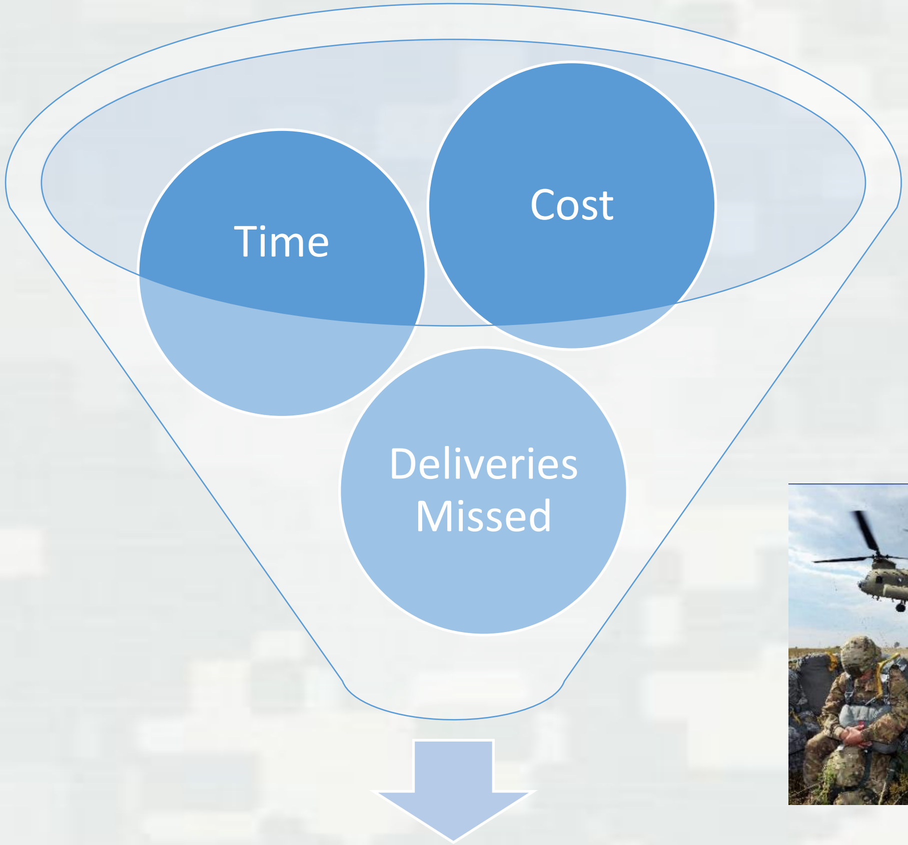
Commercial



Humanitarian



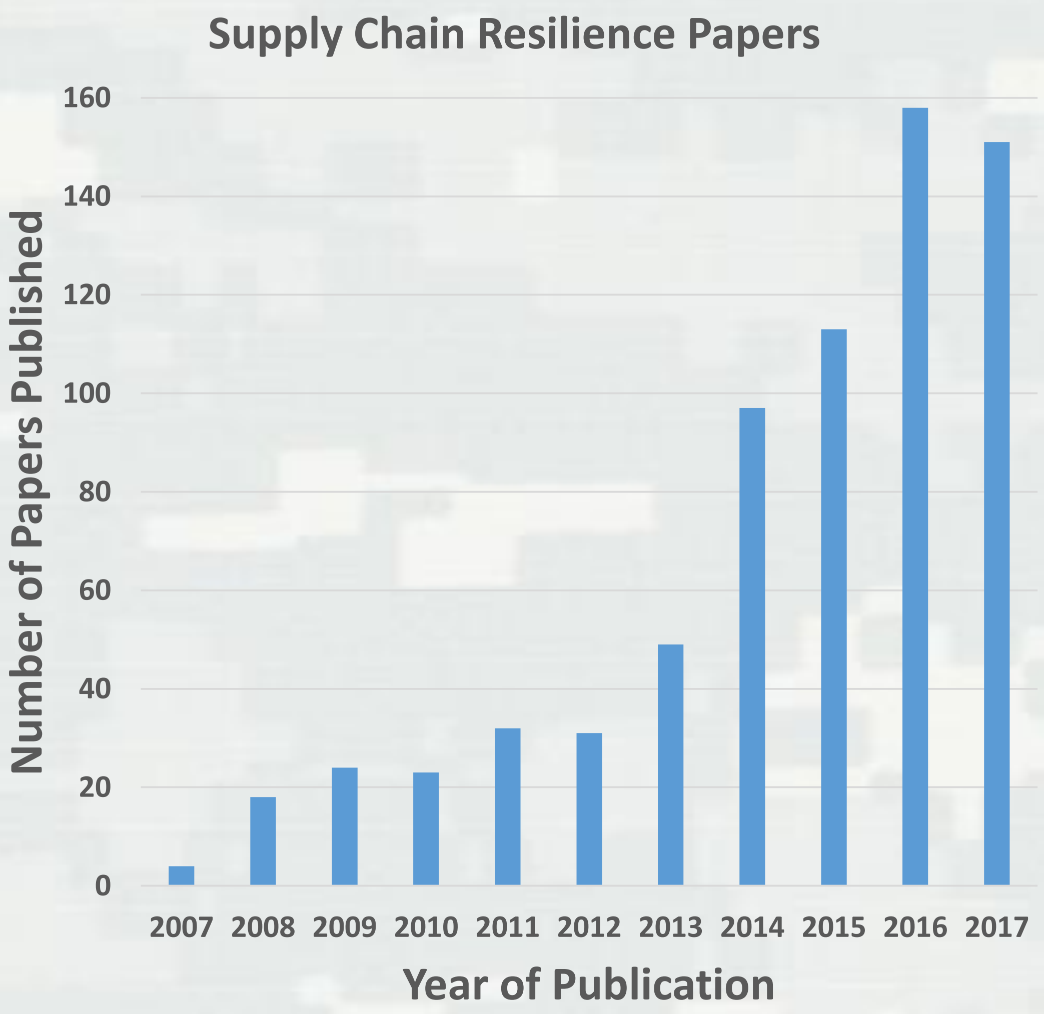


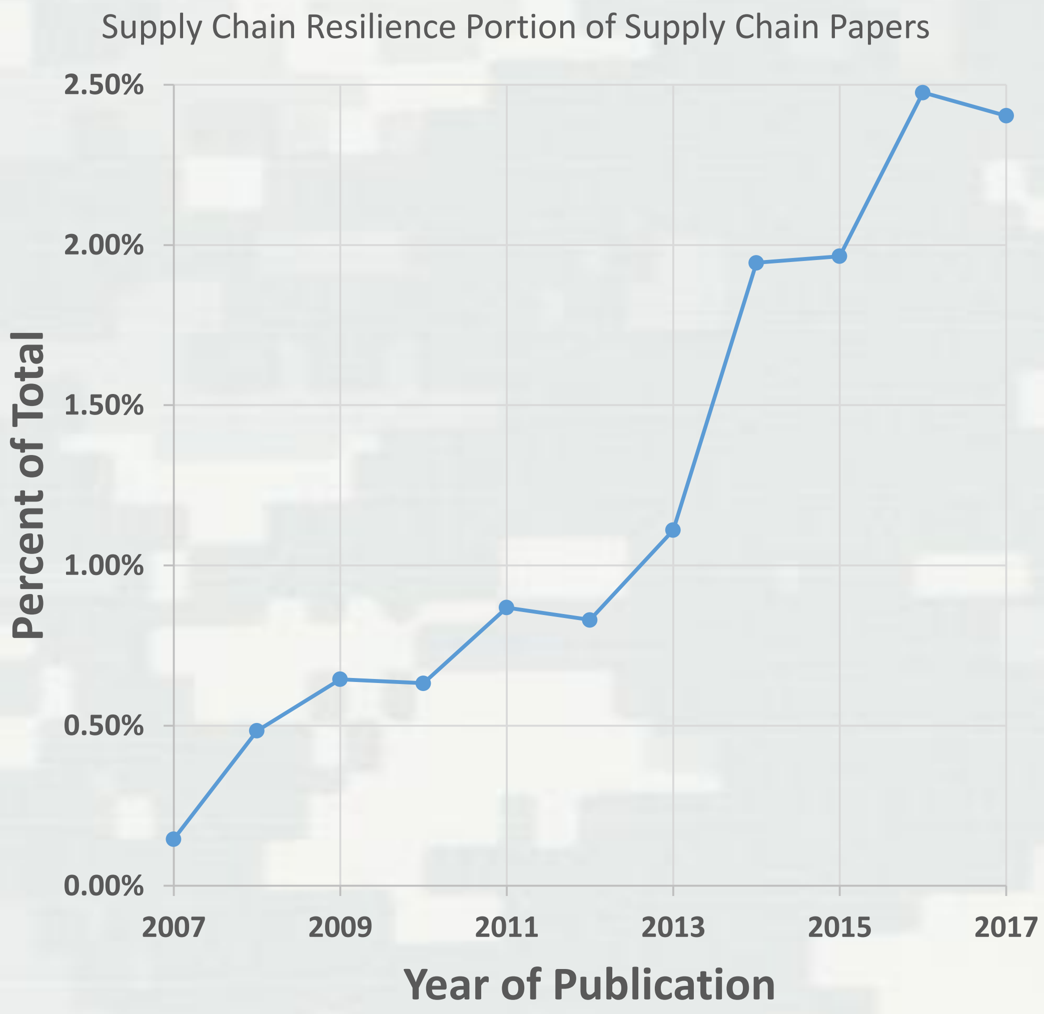


Supply Chain Critical Functionality

Military

Trends in Supply Chain Resilience Research: Web of Science



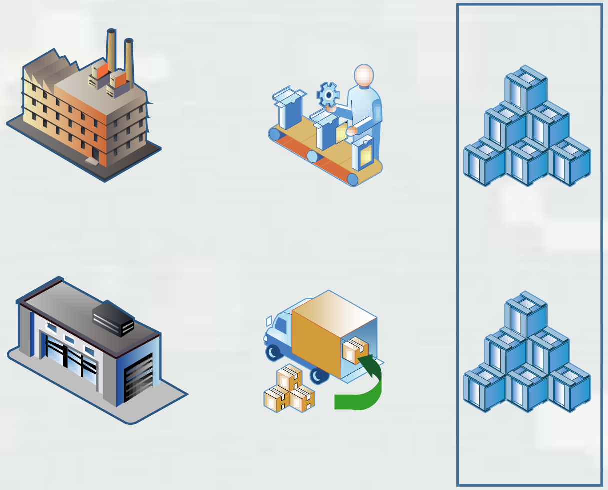


Supply Chain Management: Just in Case (JIC) and Just In Time (JIT)

JIC

Keep extra stock on hand in warehouses and facilitates to cover potential disruptions

Have multiple possible suppliers with excess capacity and spare internal production capacity



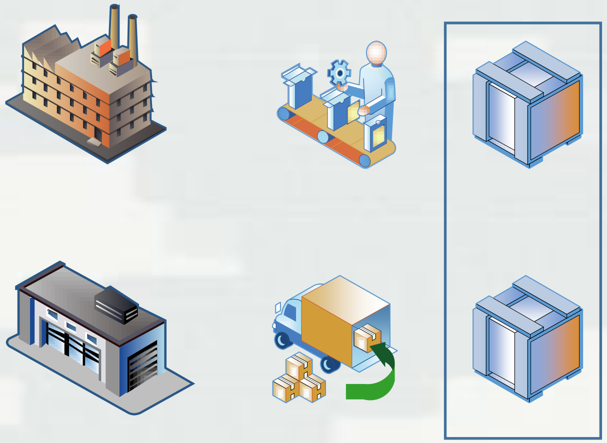
JIT

Better coordinatization deliveries and manufacturing to minimize stock on hand

Known to be used for early Model T production, but abandoned in favor of JIC

Developed in Japan in the 1960s

Migrated to America in the 1970s



Just in Case and Just in Time for Efficiency, Risk and Resilience

JIC

Protection: Resilience and Risk

Stock Buffers Against Shocks Universal Buffers for the Unexpected	More Capital Held in Stock

Efficiency

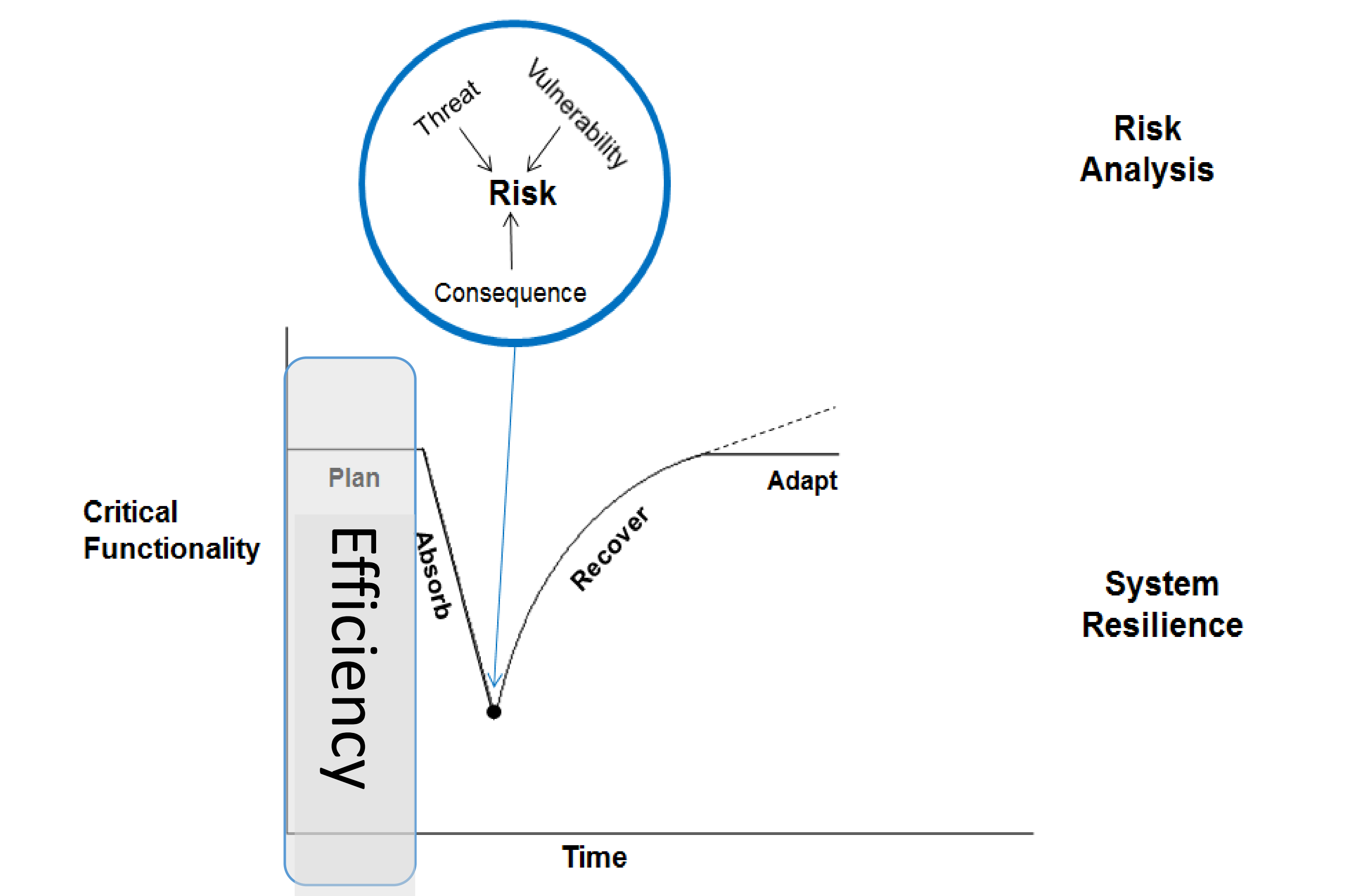
JIT

Efficiency

Less Capital Held in Stock More Capital for Investment	No Stock Buffer

Protection: Resilience and Risk

What are Efficiency, Risk and Resilience in the Supply Chain Context



“What is the **critical functionality** of a supply chain?”

After Linkov et al, Nature Climate Change 2014

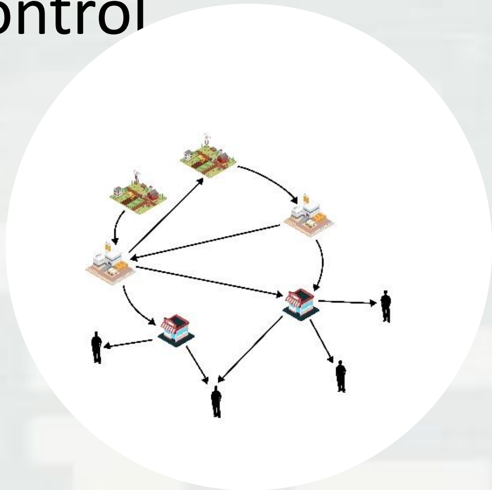
How does Current Literature Measure Supply Chain Resilience?

Paper	Plan	Absorb	Recover	Adapt	Data Source	Data Type	Resilience Metric	Supply Chain Model	Transportation Network Model	Decision Control	Scenario Analysis
Berle et al 2011	Yes	Yes	No	No	Interview	Qualitative	No	Multi-Step Linear Distribution	Same as Supply Chain	None	Event Tree
Blackhurst et al, 2011	Yes	Yes	Yes	No	Interview	Qualitative	No	None	None	None	Case Study
Brandon-Jones et al, 2014	Yes	Yes	Yes	No	Questionnaire	Qualitative	Yes	None	None	None	None
Büttner et al, 2015	Yes	Yes	No	No	Trade Data	Quantatative	Yes	Network Graph	None	None	Case Study
Carvalho et al, 2012	Yes	Yes	No	No	None	Quantatative	No	Network Graph	Same as Supply Chain	None	Case Study
Craighead et al, 2007	Yes	Yes	Yes	No	Interview	Qualitative	No	Network Graph	None	None	Case Study
Govindan et al, 2014	Yes	Yes	Yes	No	Interview	Qualitative	Yes	None	None	None	Case Study
Hasani and Khosrojerdi, 2016	Yes	Yes	Yes	No	Interview	Quantatative	Yes	Network Graph	Same as Supply Chain	Optimization: Memetic Algorithm	Case Study
Kim et al, 2015	Yes	Yes	No	No	None	Quantitative	Yes	Network Graph	Same as Supply Chain	None	Monte Carlo
Klibi et al 2012	Yes	Yes	Yes	No	None	Quantatative	No	Three Tier / Production - Warehouse-Distribution	Same as Supply Chain	Linear Optimization	Monte Carlo
Schmitt and Singh, 2012	Yes	Yes	Yes	No	Company Provided	Quantatative	Yes	2 Stage Production and 1 Stage Distriibution	Same as Supply Chain	None	Scenario List
Urciuoli et al, 2014	Yes	Yes	Yes	Yes	Interview	Qualitative	No	Production -Multi Stage Distibution	Alternative Modes and Political Routes	None	Case Study
Validi et al, 2014	Yes	Yes	No	No	Questionnaire	Qualitative	No	Two Tier / Production - Distribution	None	Optimization: Genetic Algorithm	Set List
Zhao et al , 2011	Yes	Yes	No	No	Computer Generated	Quantatative	Yes	Network Graph	None	None	Monte Carlo / Targeted

Simulation is Complicated: Supply Chains are Multi-Level Networks

Supply Chain

Command and Control



Material Flows

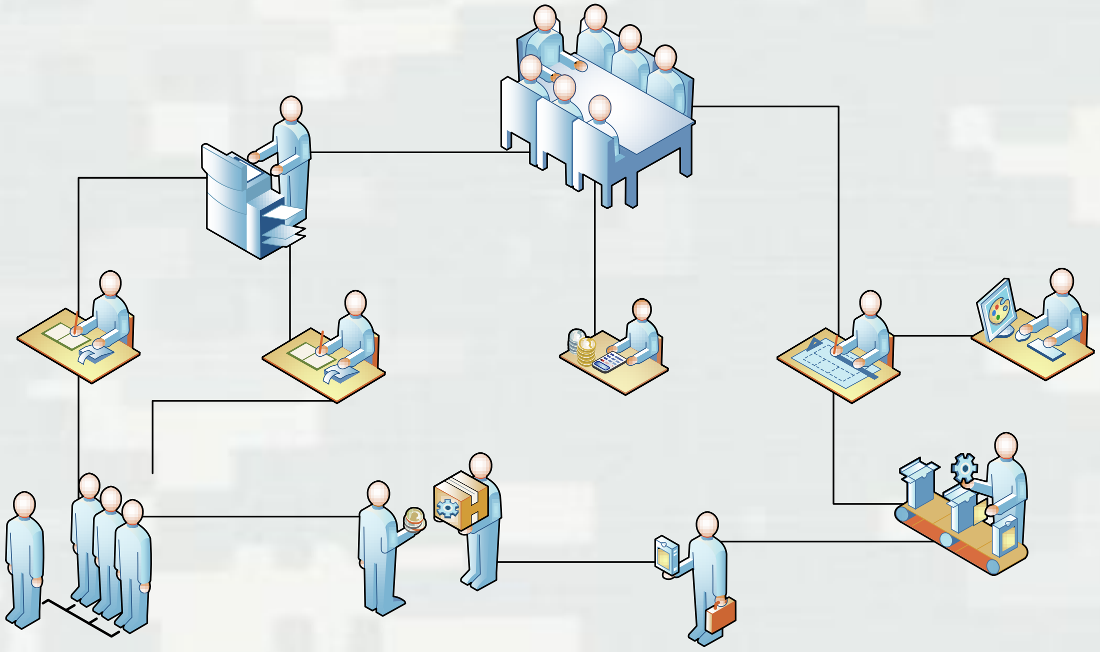
Civil Infrastructure

Command and Control: How Decisions get Made

An organization is made up of individual people

These people have pieces of the Supply Chain that they can control

- and pieces information that they must act on



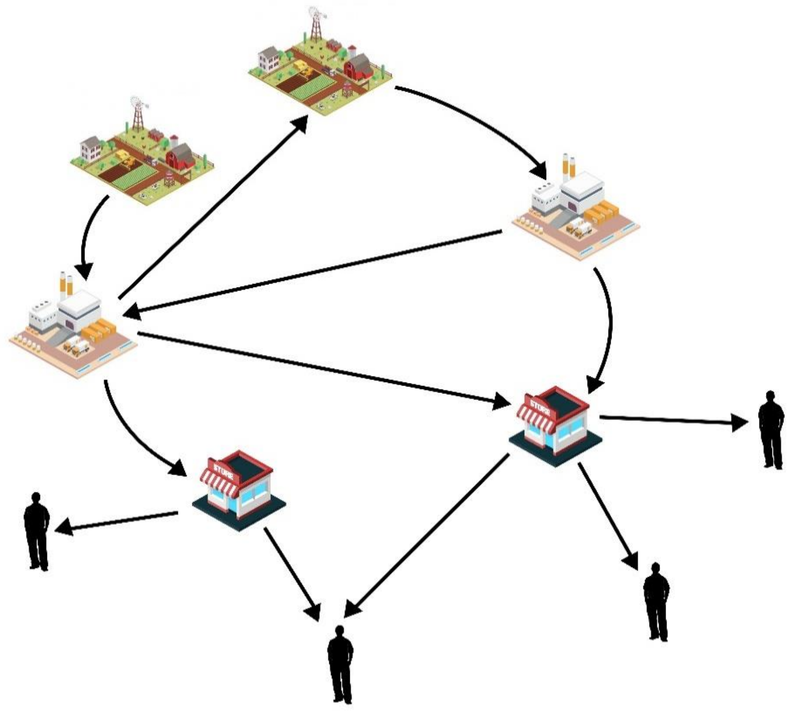
Material Flows: Where do things have to go?

What series of processes must take place?

What sequences are possible?

Where do these happen?

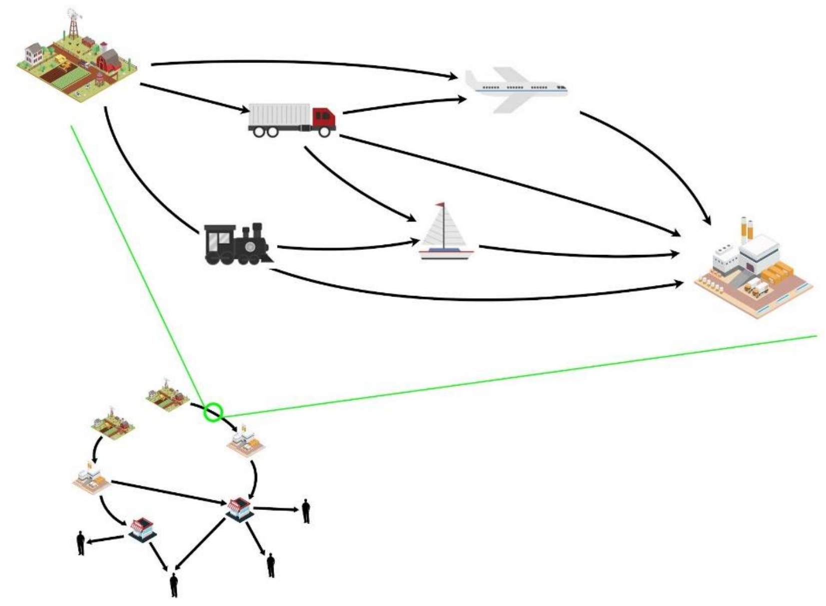
What options are possible?



Civil Infrastructure: How does the Material Move?

Material flows among different supply chain nodes must use built Civil Infrastructure networks

- These networks are likely to be shared by other players and are outside of the organization's control

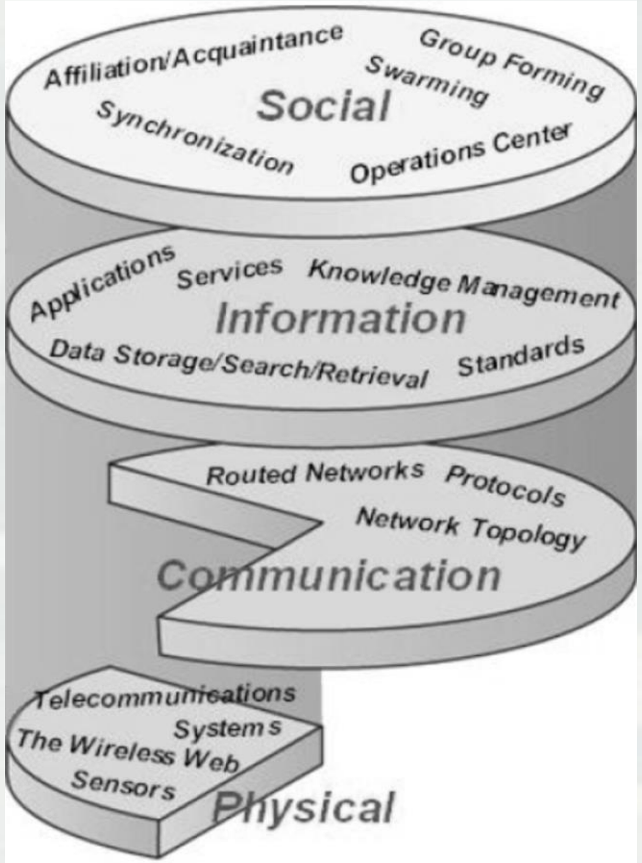


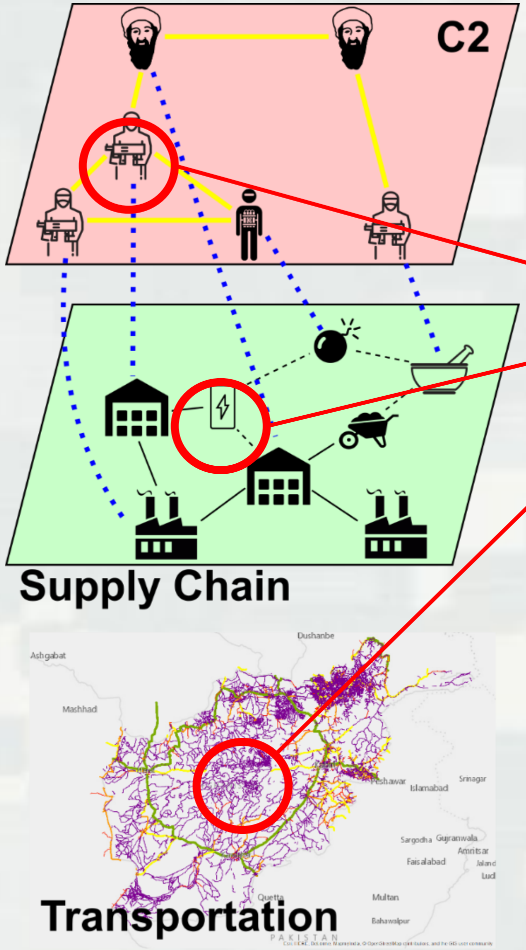
Vision for Transportation Supply Chain Resilience

Real World

Model

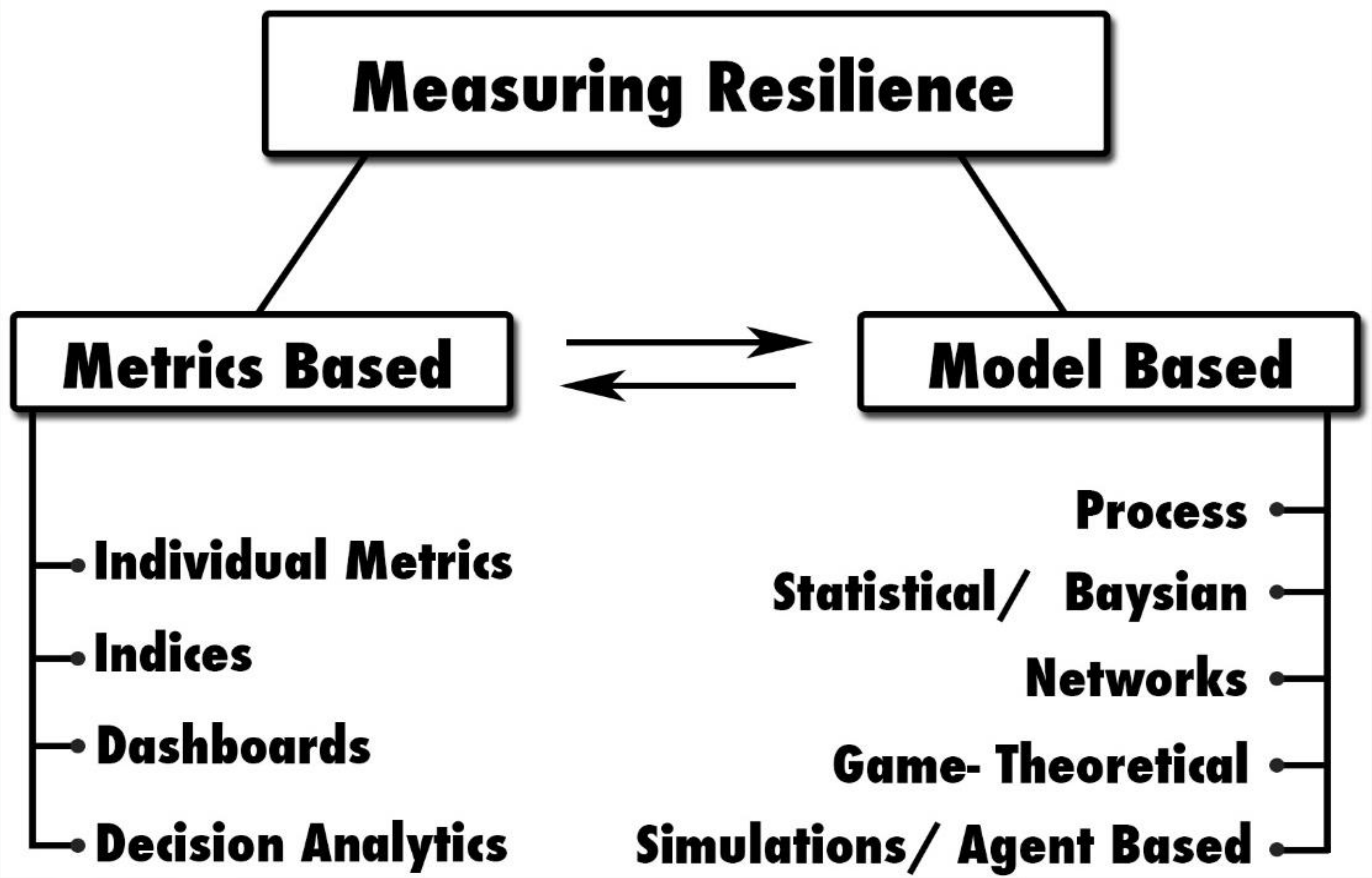
Operations





Management
Alternatives

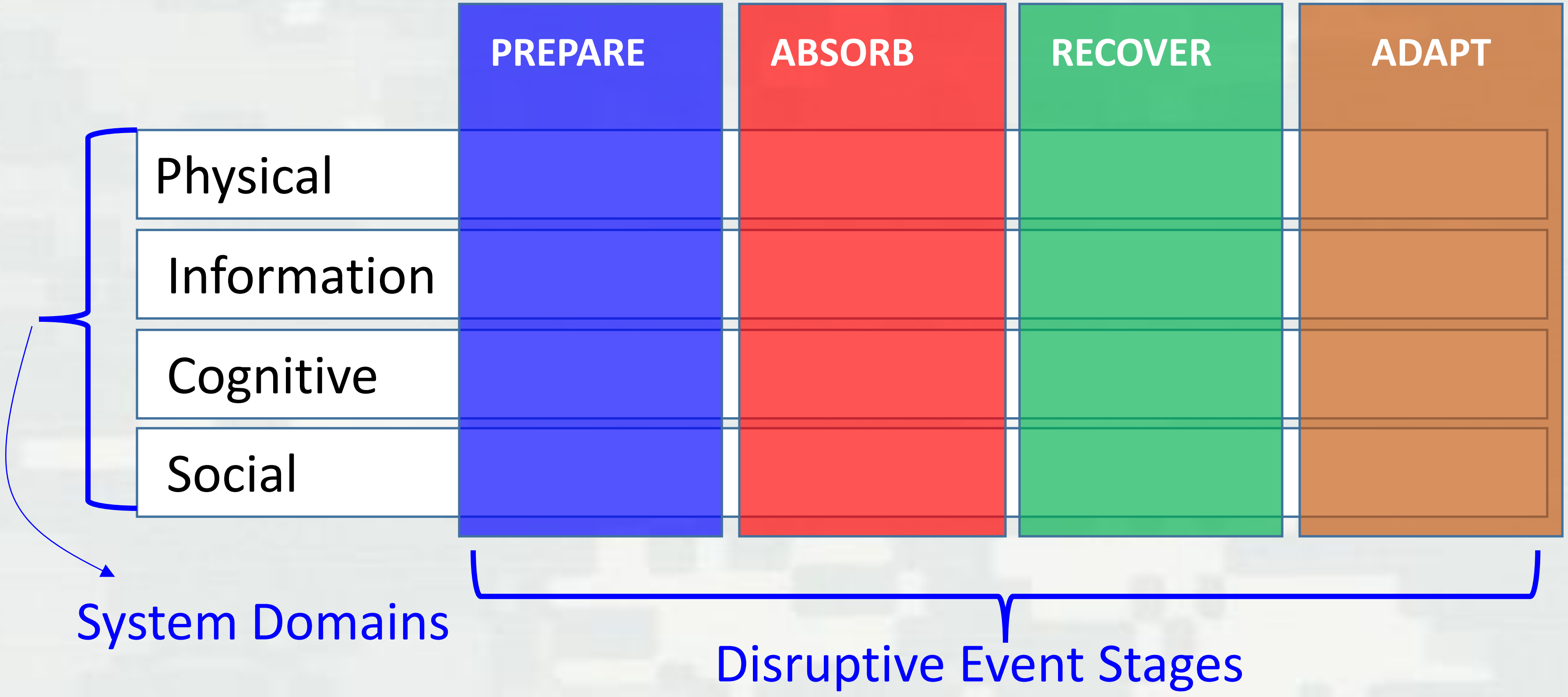
How to Quantify Supply Chain Resilience?



After Linkov and Kott, 2018

Presenting Qualitative Organization Characteristics

Either aggregated as a single, or set of, number(s), or presented as a matrix



Assessment using Stakeholder Values

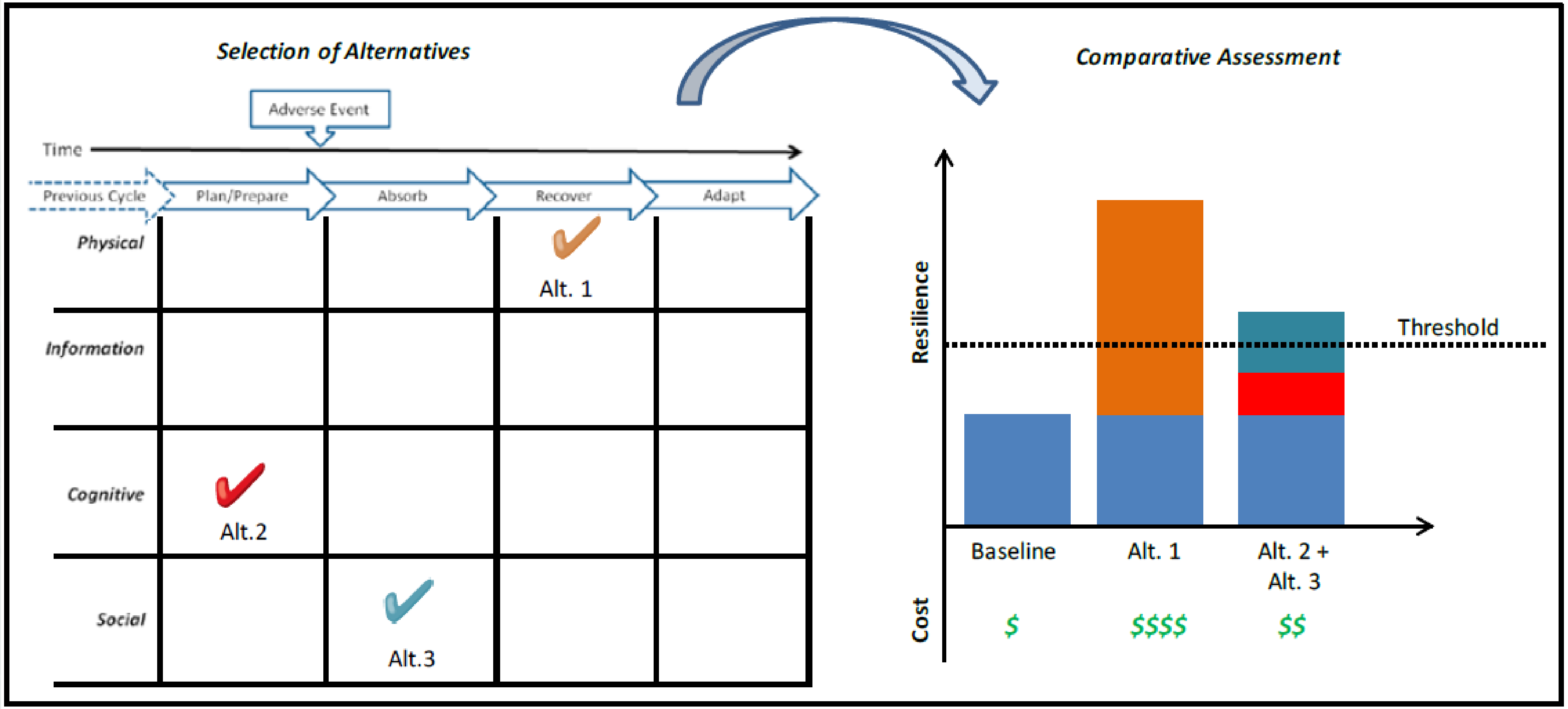


Figure 5: Comparative Assessment of Resilience-Enhancing Alternatives

Use developed resilience metrics to comparatively assess the costs and benefits of different courses of action

Results: Project Evaluation

- Baseline assessment can be used to evaluate proposed projects

	Prepare	Absorb	Recover	Adapt
Physical	71	16	60	10
Information	63	45	21	18
Cognitive	90	49	38	27
Social	82	54	12	52

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Project 1

	Prepare	Absorb	Recover	Adapt
Physical	+10	+18	+9	+32
Information	+8		+17	
Cognitive				
Social				

	Prepare	Absorb	Recover	Adapt
Physical	81	34	69	42
Information	71	45	38	18
Cognitive	90	49	38	27
Social	82	54	12	52

51

Project 2

	Prepare	Absorb	Recover	Adapt
Physical				
Information		+5	+15	+22
Cognitive				
Social	+3		+12	+21

	Prepare	Absorb	Recover	Adapt
Physical	71	6	60	10
Information	63	50	36	40
Cognitive	90	49	38	27
Social	85	54	24	73

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*Projects may have (+) or (-) in other matrices

Issues with Using Metrics-Based Approaches to Measure Resilience

Lack of Causal Model

Changing environments and circumstances may change correlating factors

Changing business and management plans may change how previously causal factors interact

May not work in circumstances different than under those they were designed for

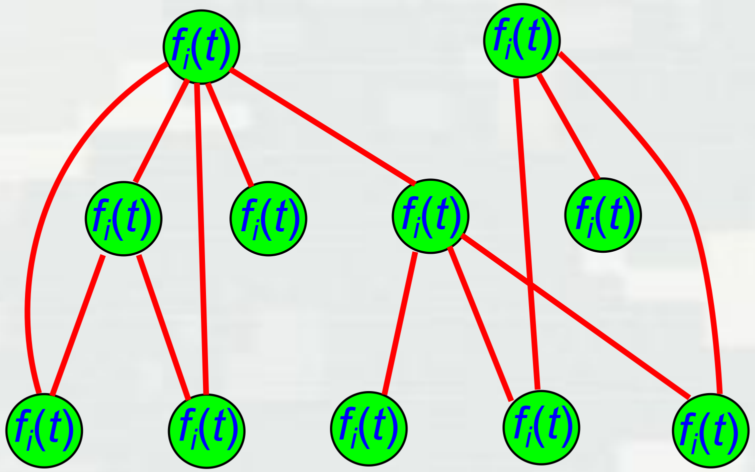
Network-based Resilience Theory?

System's *critical functionality* (K)

Network topology: *nodes* ($\mathcal{N}$) and *links* ($\mathcal{L}$)

Network *adaptive algorithms* ($\mathcal{C}$) defining how nodes' (links') properties and parameters change with time

A *set of possible damages* stakeholders want the network to be resilient against ($\boldsymbol{E}$)

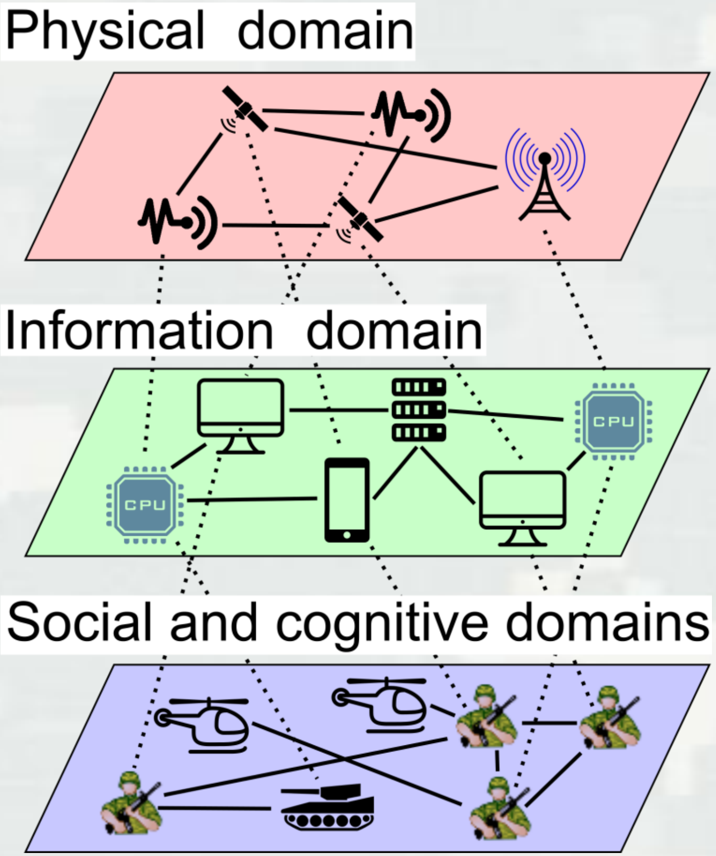


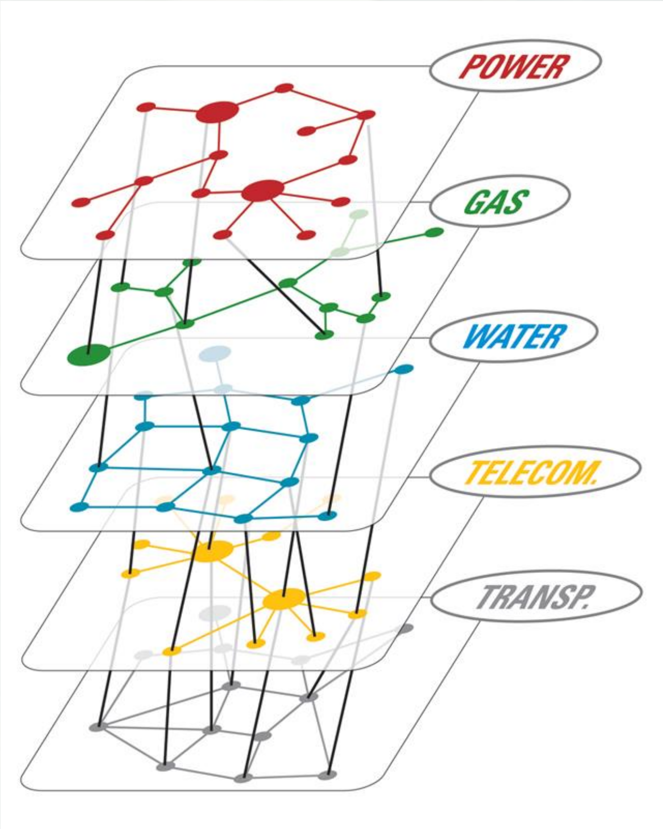
Ganin et al., 2016

$$R = f(\mathcal{N}, \mathcal{L}, \mathcal{C}, \boldsymbol{E})$$

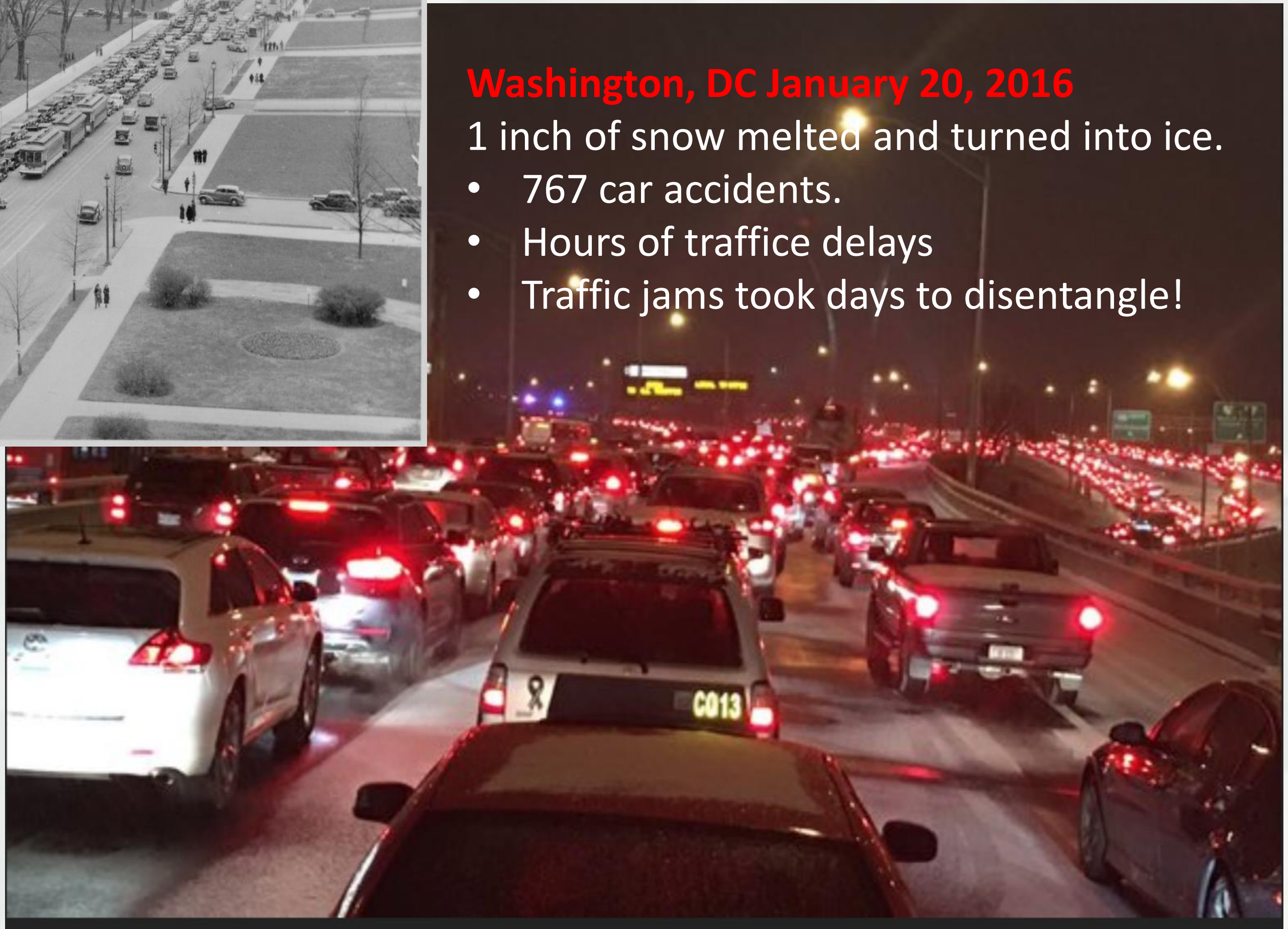
Network-based Approaches

Resilience can be quantified with a network science approach by considering the different domains as interdependent multiplex networks.





Resilience: Transportation Network



Network Resilience: Introduction

- video

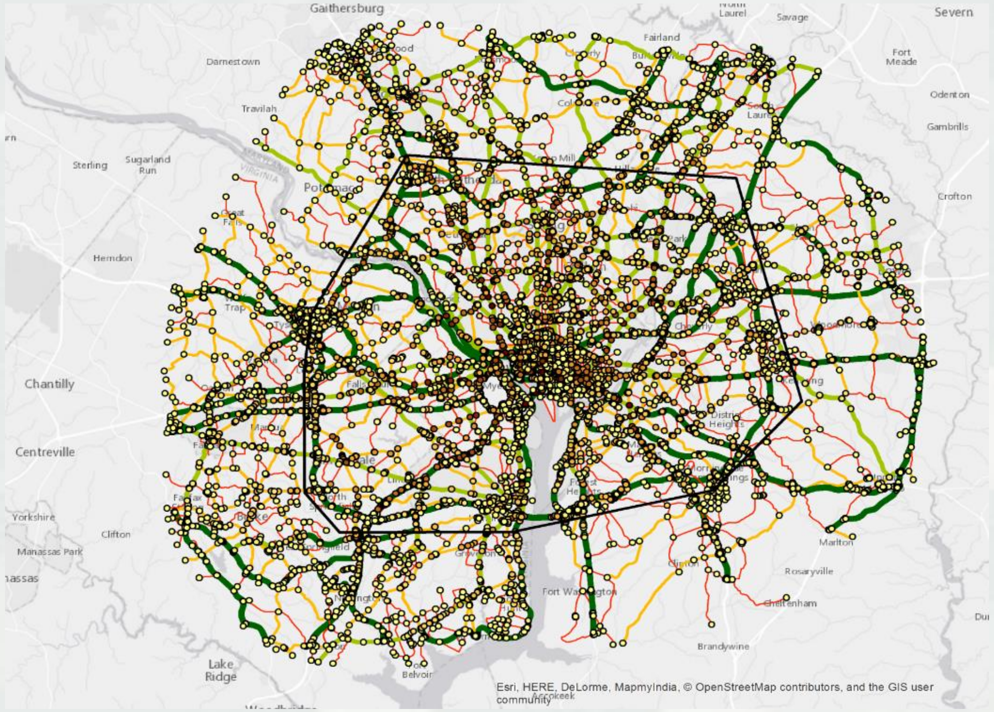
SCIENCE ADVANCES | RESEARCH ARTICLE v. 3, Dec 2017

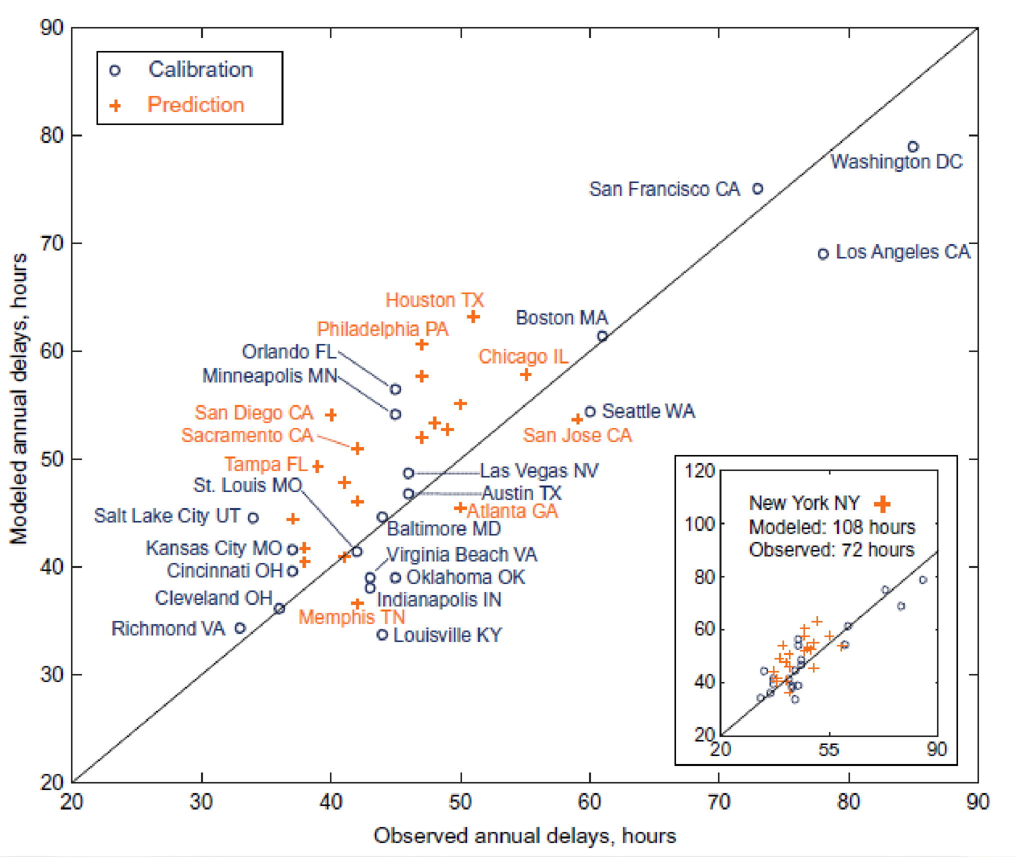
NETWORK SCIENCE

Resilience and efficiency in transportation networks

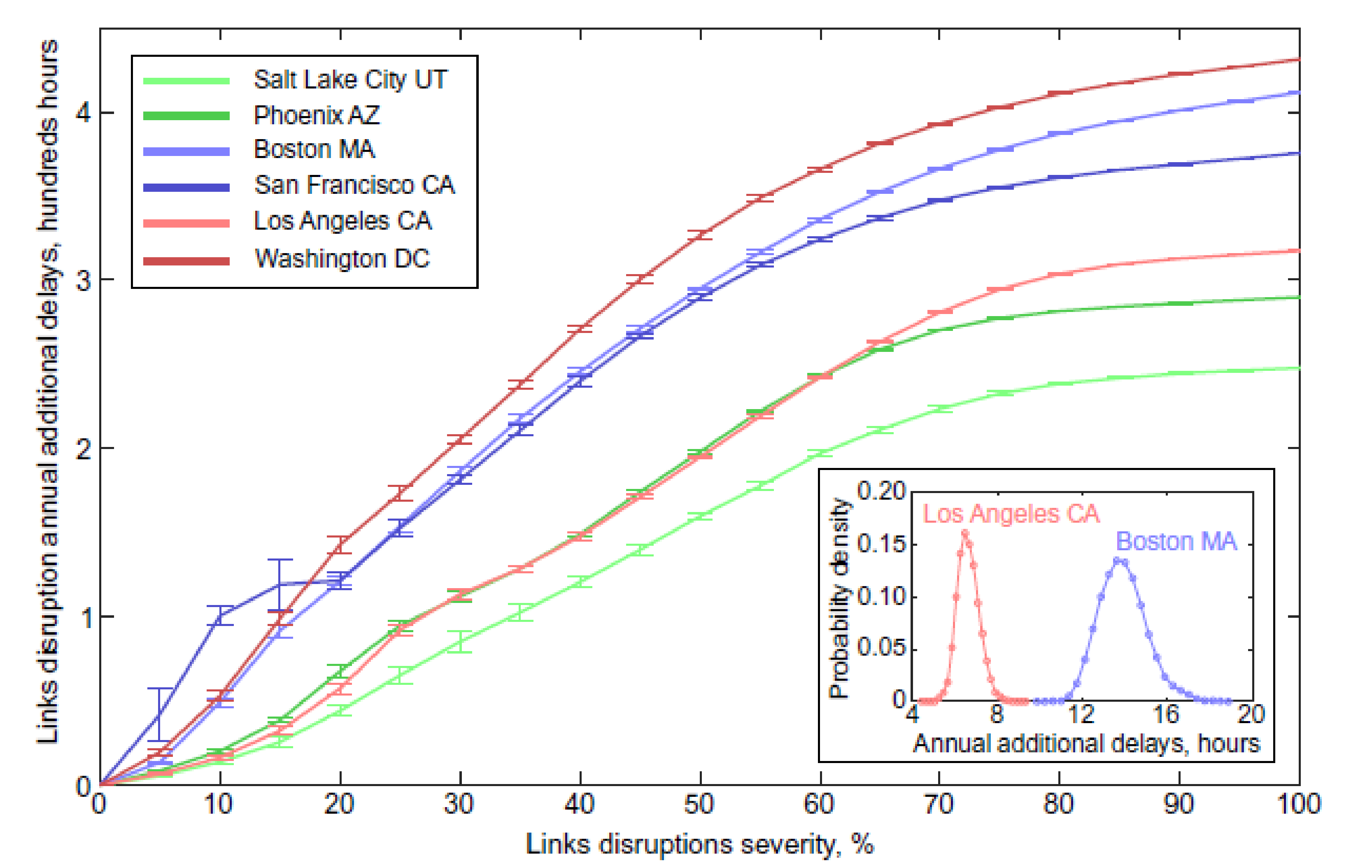
Alexander A. Ganin,[1,2] Maksim Kitsak,[3] Dayton Marchese,[2] Jeffrey M. Keisler,[4]
Thomas Seager,[5] Igor Linkov[2]*

40 US Cities with Different Traffic Delays

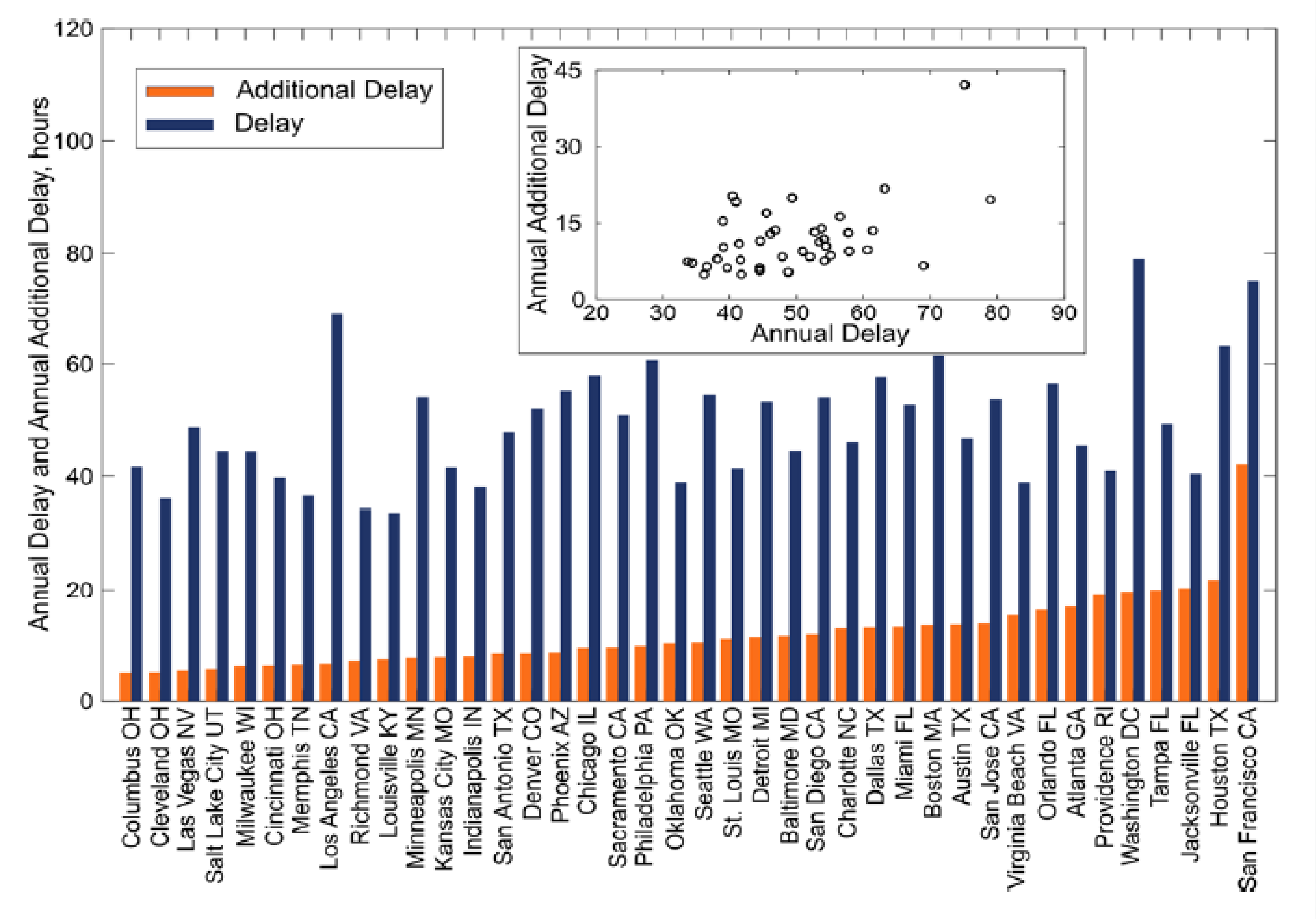




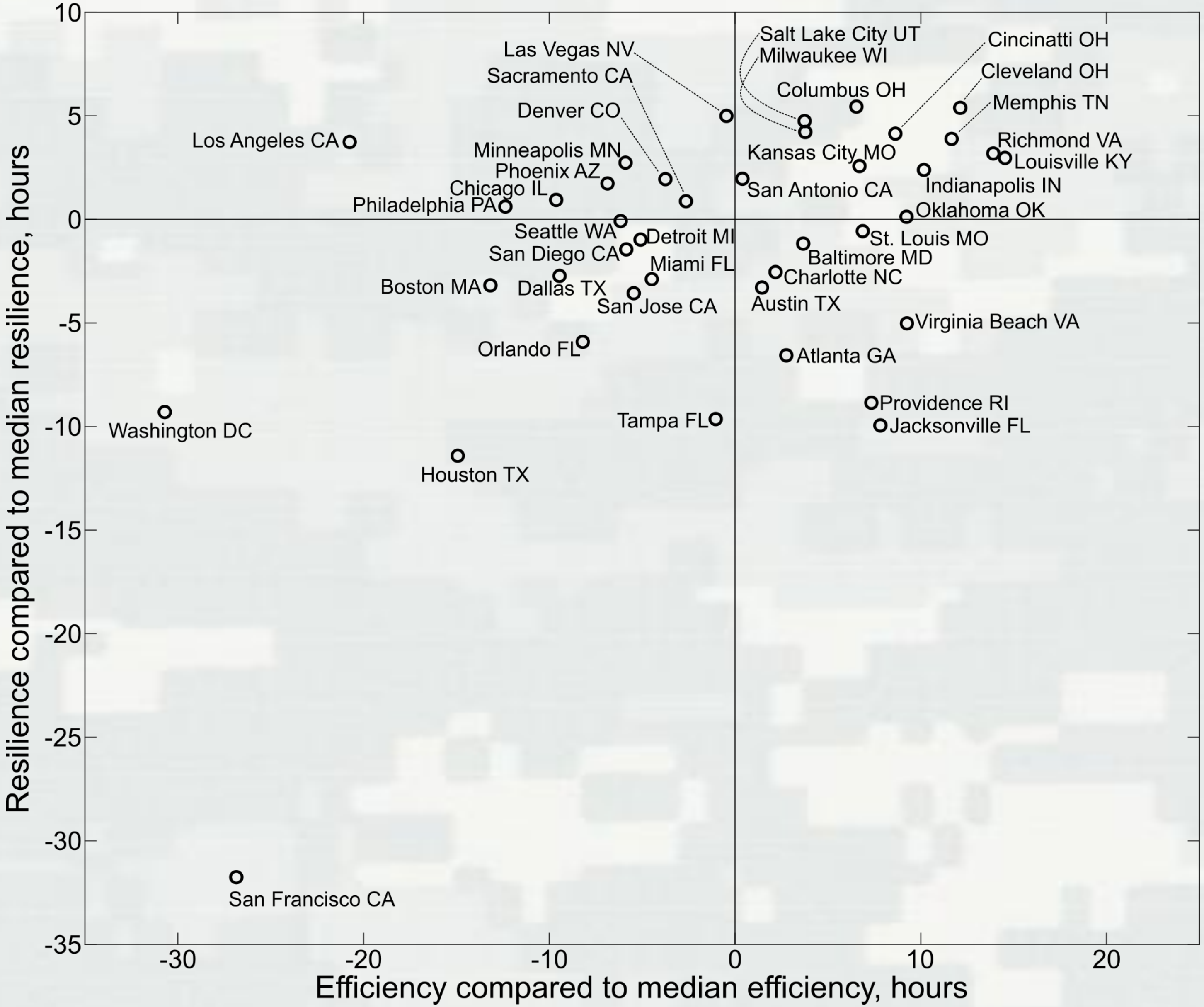
Transportation Networks in 40 Cities



Efficiency and Resilience don't always correlate.



Ganin et al., 2017



Resilience

Efficiency

Lack of Resilience: Financial Implications

Regional Economic Modeling (REMI)

REMI TranSight

Input-Output

Close analysis of inter-industry relationships

General Equilibrium

Estimate of long-run stability of the economy allows for analysis of policy decisions

Econometrics

Advanced statistical analyses underpinning the model

Economic Geography

Effects of geographic concentration of labor and industry

Integrated REMI economic modelling approach

1 Month of 5% Network Disruption: Atlanta

Browser

Summary

Economic Summary

1 month disruption in commuting network (5%)

Difference compared to

Standard Regional Control

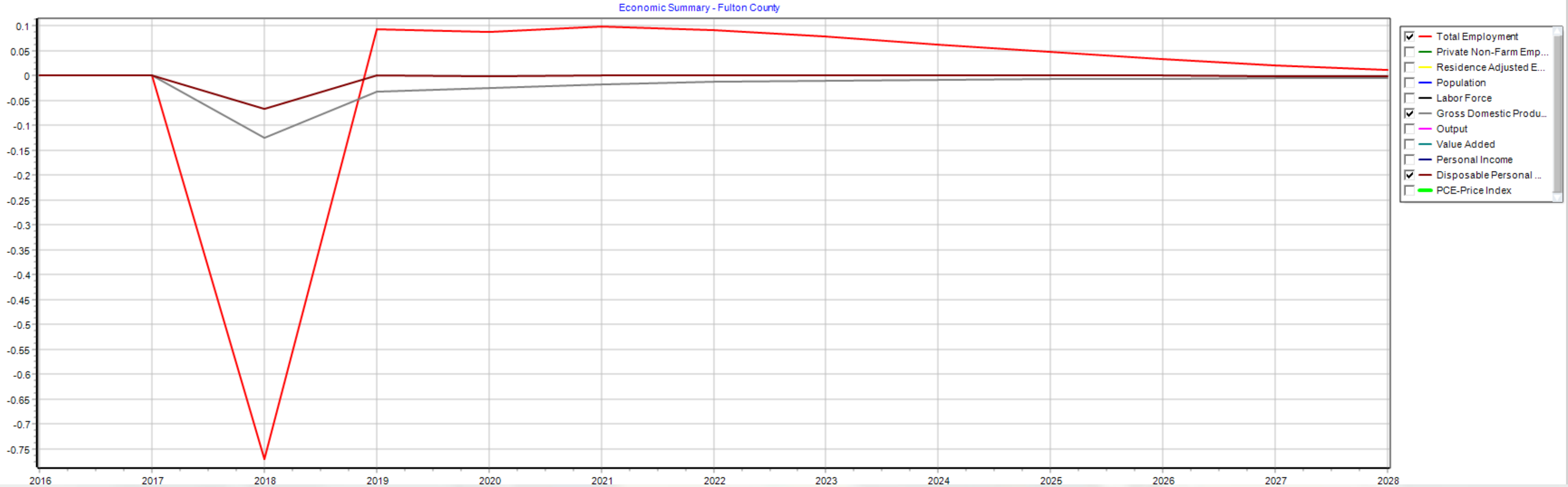
Total Employment

Employment comprises estimates of the number of jobs, full-time plus part-time, by place of work. Full-time and part-time jobs are counted at equal weight. Employees, sole proprietors, and active partners are included, but unpaid family workers and volunteers are not included.

Region

Fulton County

Category	Units	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Total Employment	Thousands (Jobs)	0.000	0.000	-0.770	+0.094	+0.088	+0.099	+0.092	+0.079	+0.063	+0.047	+0.033	+0.021	+0.012
Private Non-Farm Employment	Thousands (Jobs)	0.000	0.000	-0.732	+0.118	+0.105	+0.110	+0.100	+0.085	+0.068	+0.051	+0.036	+0.024	+0.015
Residence Adjusted Employment	Thousands	0.000	0.000	-0.859	+0.081	+0.020	+0.030	+0.029	+0.024	+0.017	+0.010	+0.004	-0.002	-0.006
Population	Thousands	0.000	0.000	-0.369	-0.240	-0.184	-0.139	-0.106	-0.083	-0.066	-0.055	-0.047	-0.041	-0.037
Labor Force	Thousands	0.000	0.000	-0.327	-0.137	-0.088	-0.053	-0.031	-0.017	-0.009	-0.005	-0.004	-0.004	-0.005
Gross Domestic Product	Billions of Fixed (2009) Dollars	0.000	0.000	-0.125	-0.033	-0.025	-0.017	-0.013	-0.010	-0.008	-0.007	-0.006	-0.006	-0.005
Output	Billions of Fixed (2009) Dollars	0.000	0.000	-0.209	-0.058	-0.044	-0.031	-0.023	-0.018	-0.014	-0.013	-0.011	-0.010	-0.009
Value Added	Billions of Fixed (2009) Dollars	0.000	0.000	-0.125	-0.033	-0.025	-0.017	-0.013	-0.010	-0.008	-0.007	-0.006	-0.006	-0.005
Personal Income	Billions of Current Dollars	0.000	0.000	-0.076	+0.001	-0.002	+0.000	+0.001	+0.001	+0.001	+0.000	0.000	-0.001	-0.001

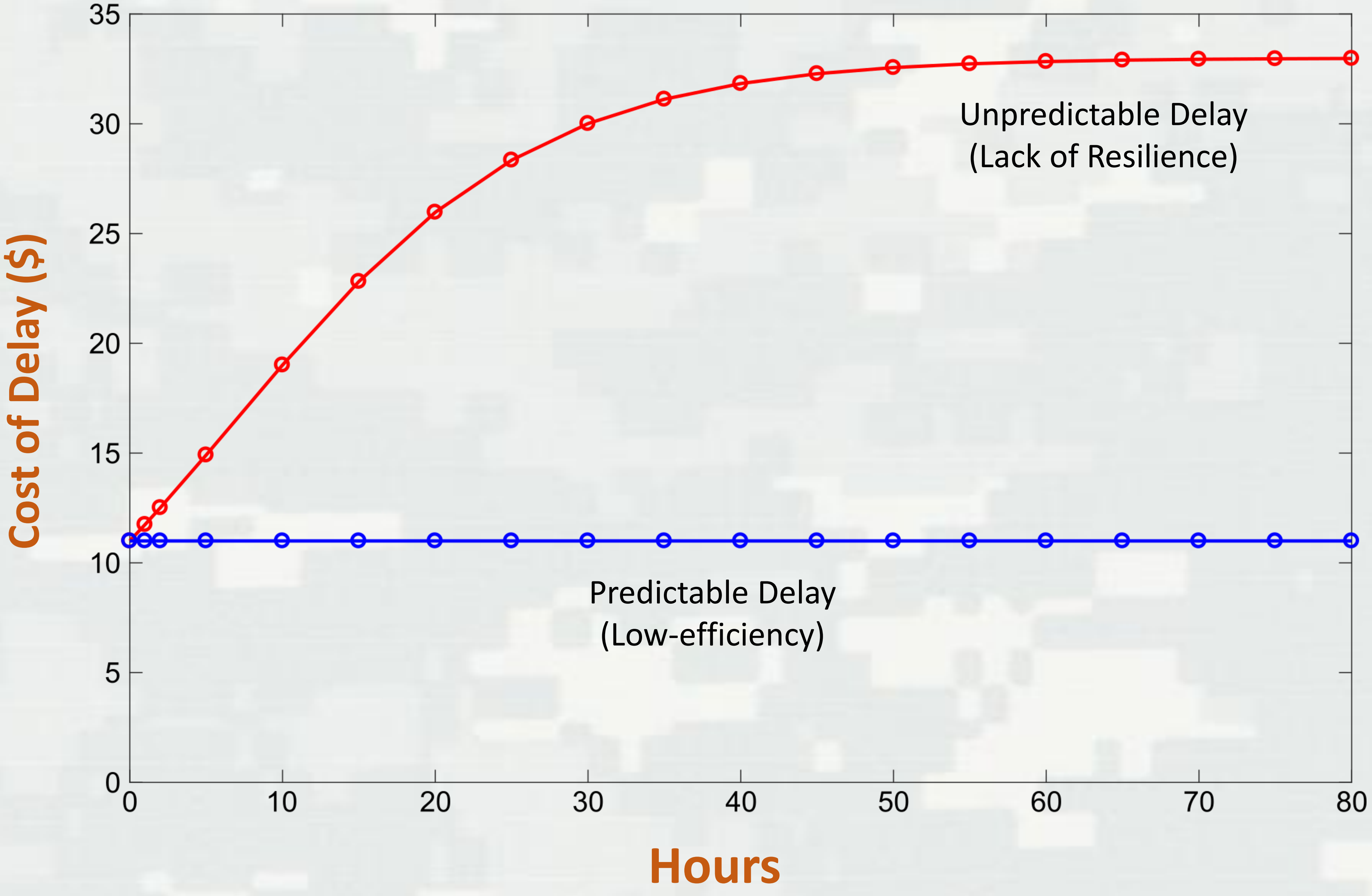


Browser

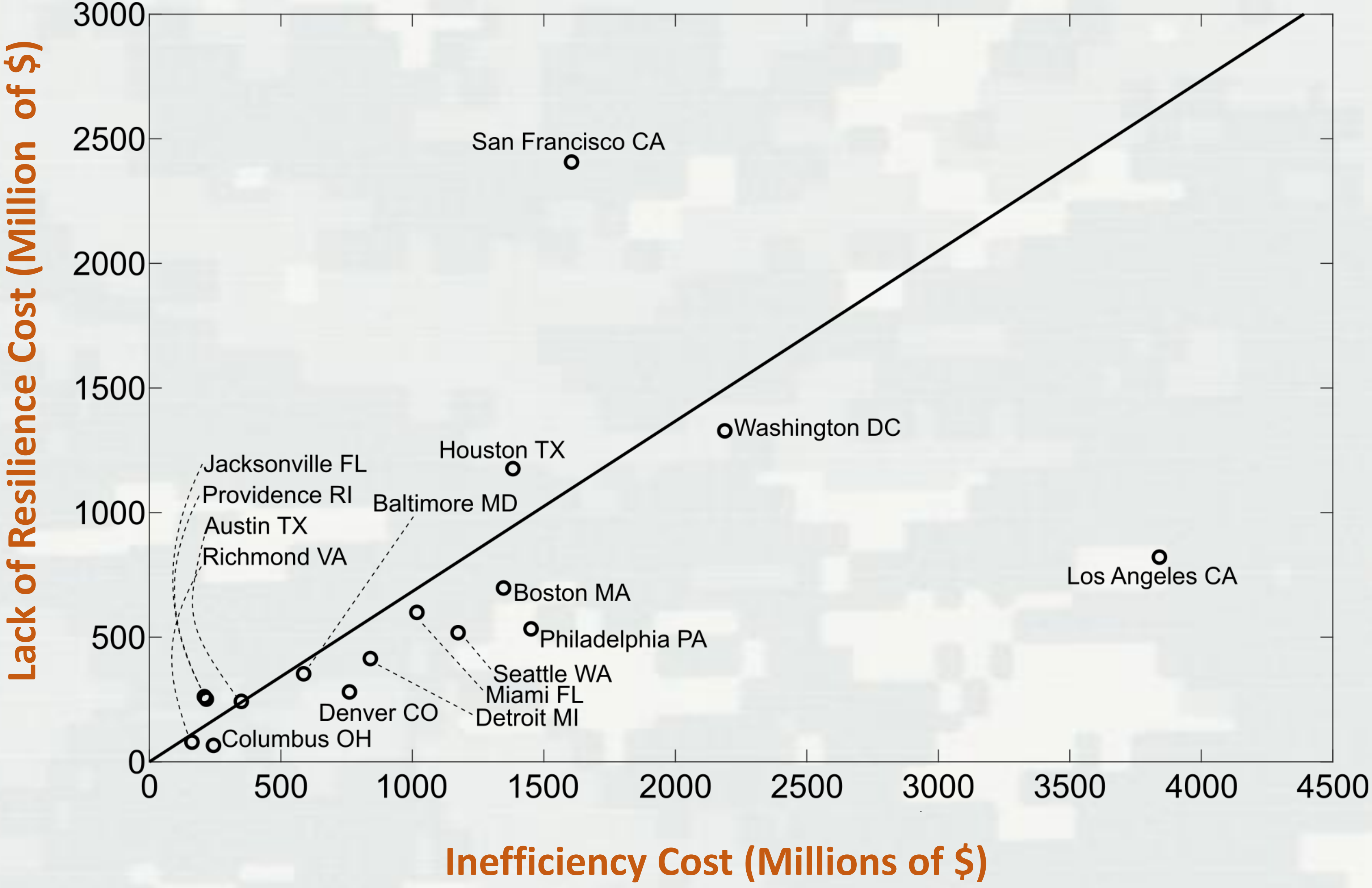
Report

- 770 jobs lost (0.07%)
- $125 million 2009 dollars in GDP lost (0.09%)
- $66 million current dollars in disposable personal income lost (0.09%)

Resilience Related Delays not equal Efficiency Related Delays

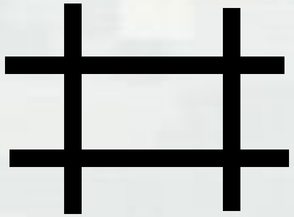


Aggregate Yearly Cost of Travel Delays



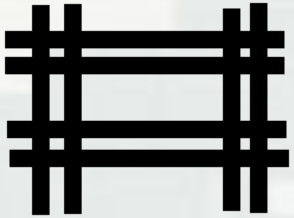
Why Bother?:

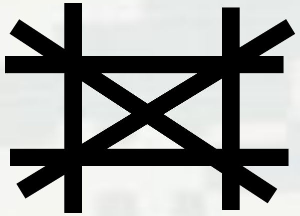
Managing Resilience is Different than Efficiency



Current System

Design to Maximize Efficiency



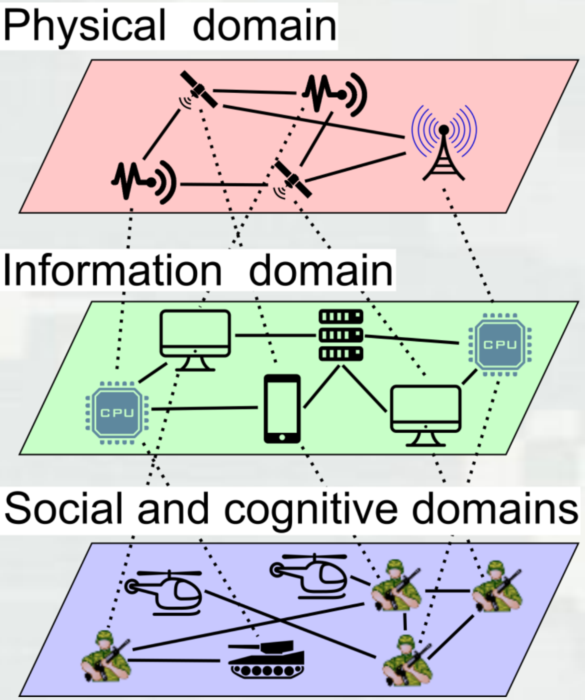


Design to Maximize Resilience

Real Networks are Interdependent

Military examples

A highly networked system is governed by *domains of warfare* that organize system components and establish a basis for measurement [1].



Civil examples

Modern infrastructure system are dependent on each other. Nodes pertaining to one infrastructure system affect nodes from the others and vice versa.

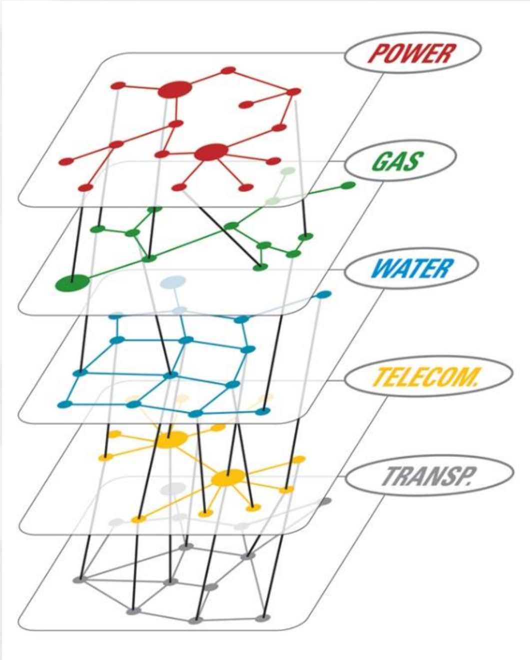


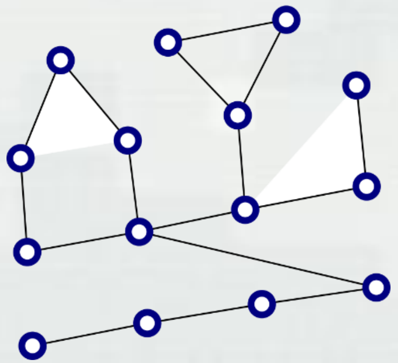
Illustration by L. Dueñas-Osorio et al [2].

1. D.S. Alberts and R.E. Hayes. *Power to the edge.* CCRP, 2005.
2. L. Dueñas-Osorio, A. Kwasinski. Quantification of lifeline system interdependencies after the 27 February 2010 Mw 8.8 Offs hore Maule, Chile, Earthquake. *Earthquake Spectra*, 2012.

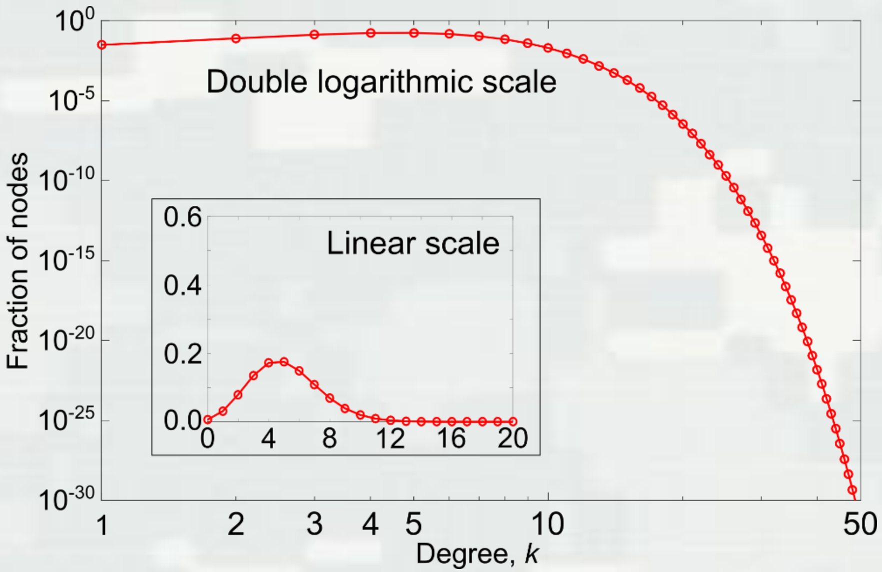
Random and Scale-free Networks

We consider two types of undirected networks: random and scale-free
The number of nodes in both networks is 200,000 and the number of links is 510,000
Average degree is 5.1

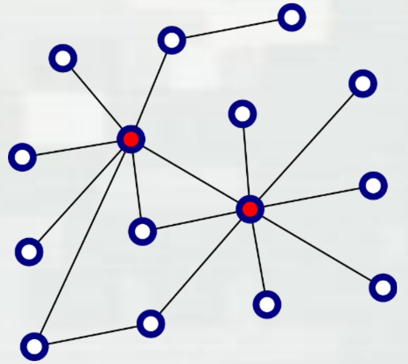
Random



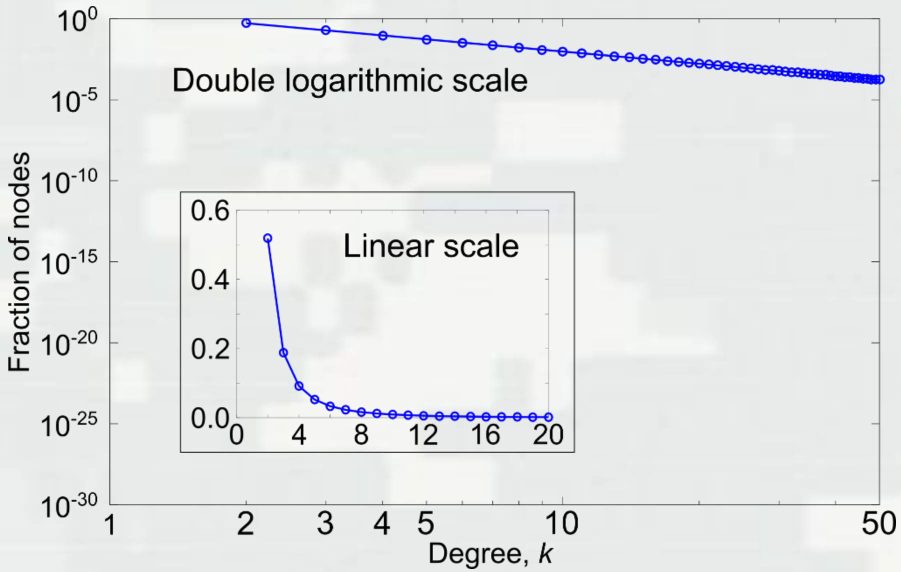
Links are distributed between nodes with equal probability



Scale-free

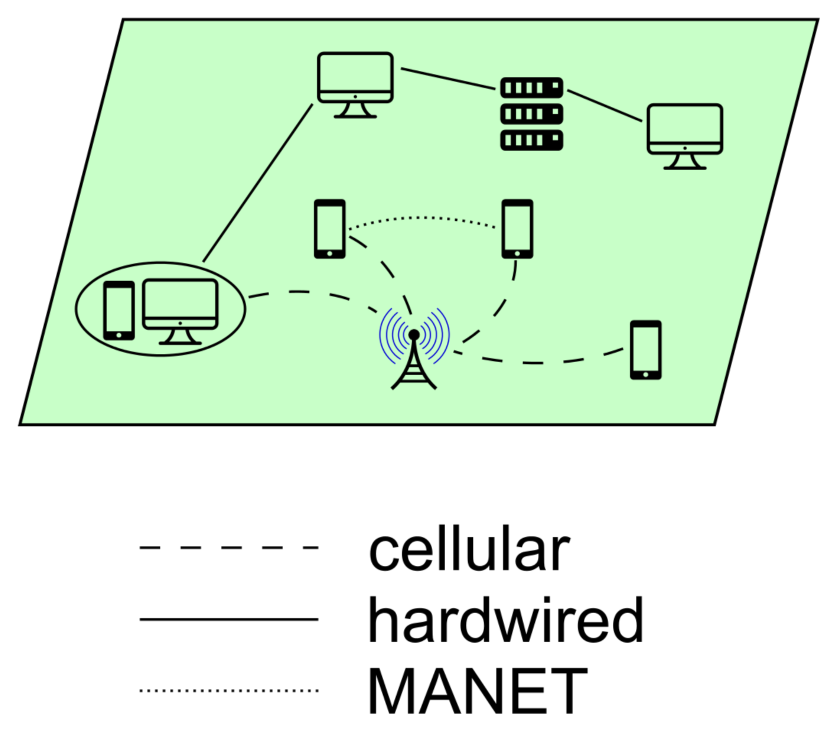


Links distribution favors highly connected nodes

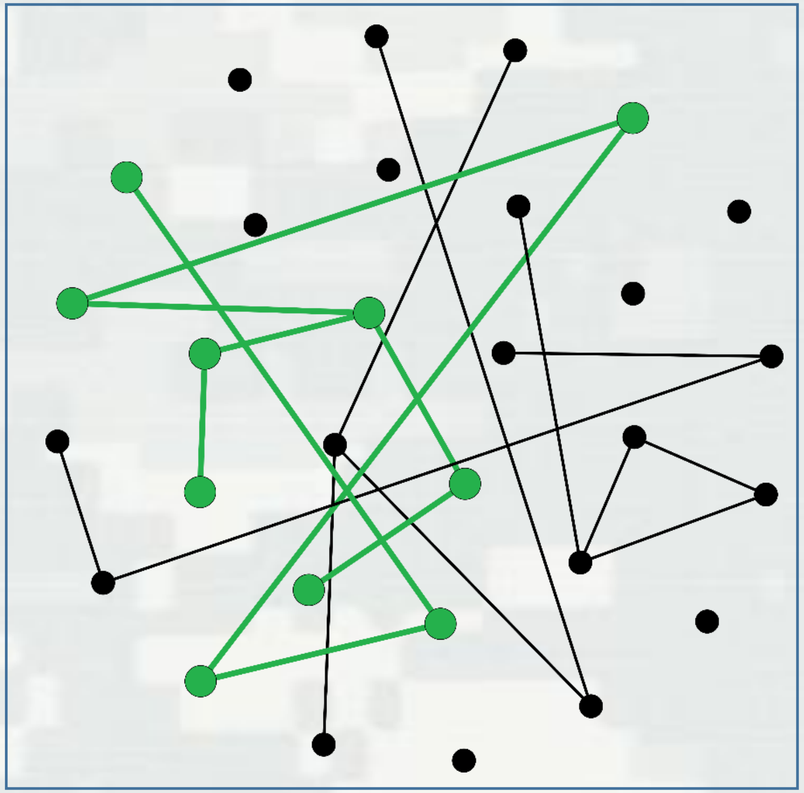


Importance of Connectedness

Conceptual Model

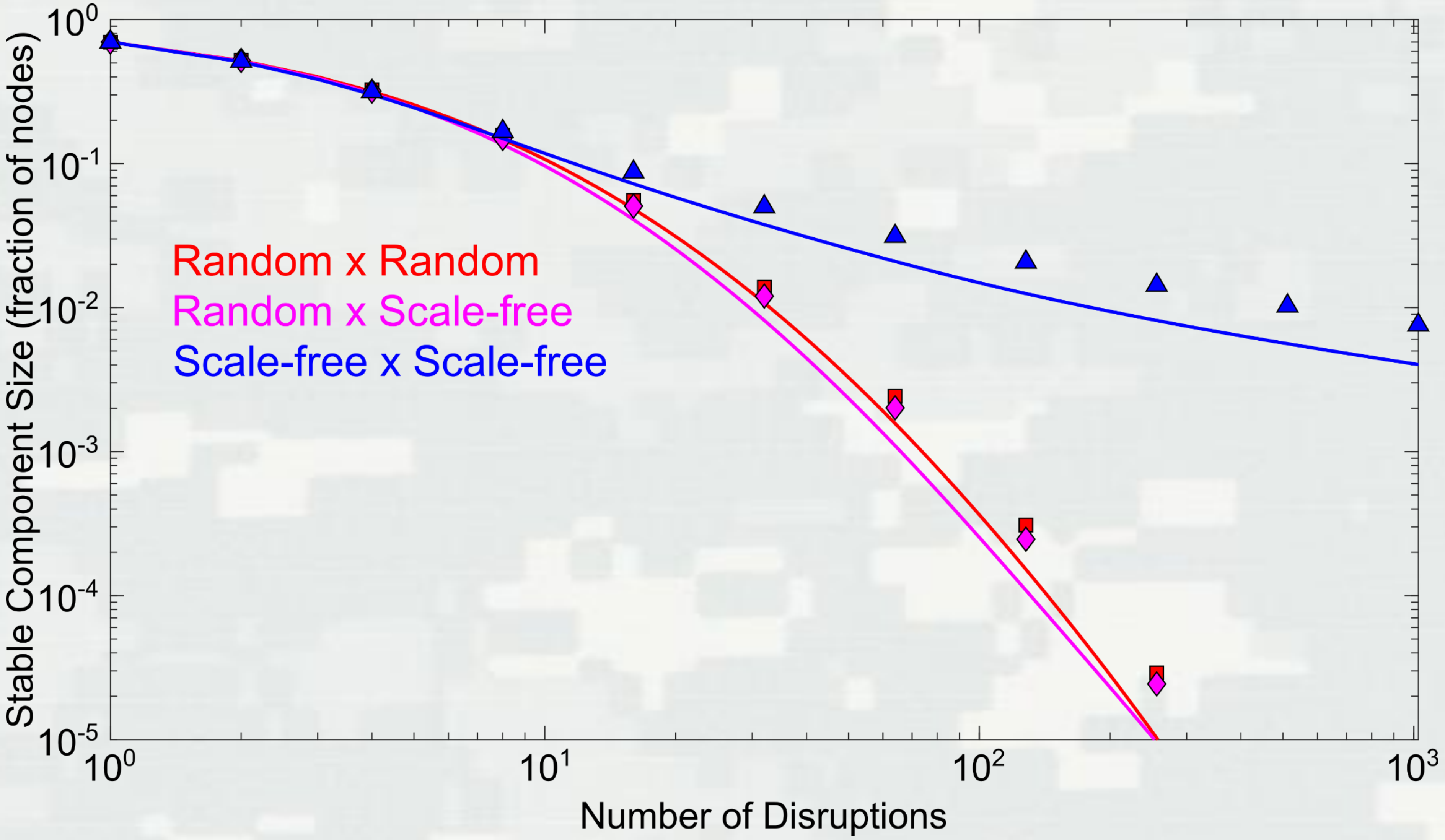


Graph representation

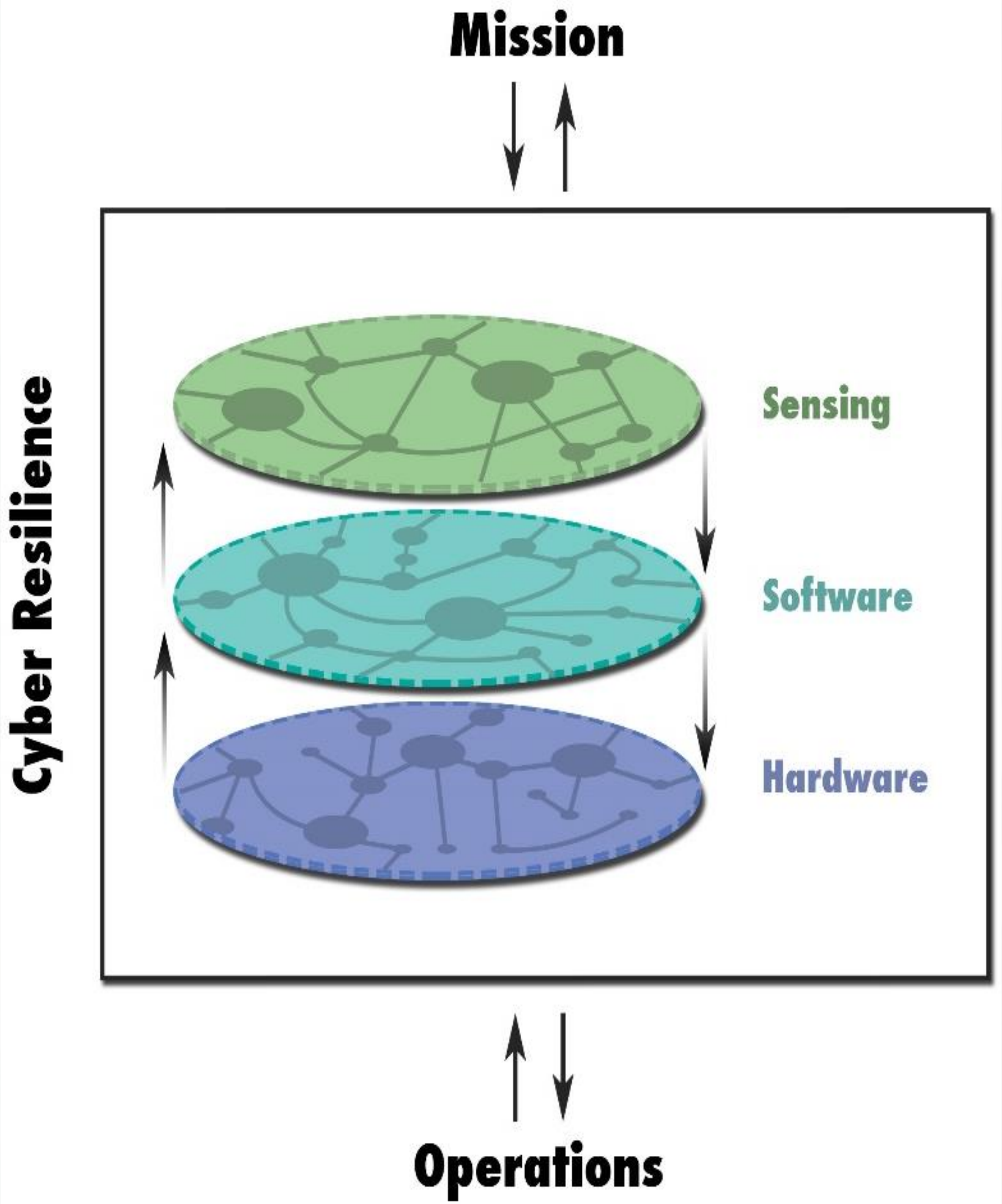


In undirected networks, typically there is a giant connected component (GCC) that fills most of the network – green nodes and links on the panel to the right. In certain infrastructure systems only nodes connected to the GCC can function normally.

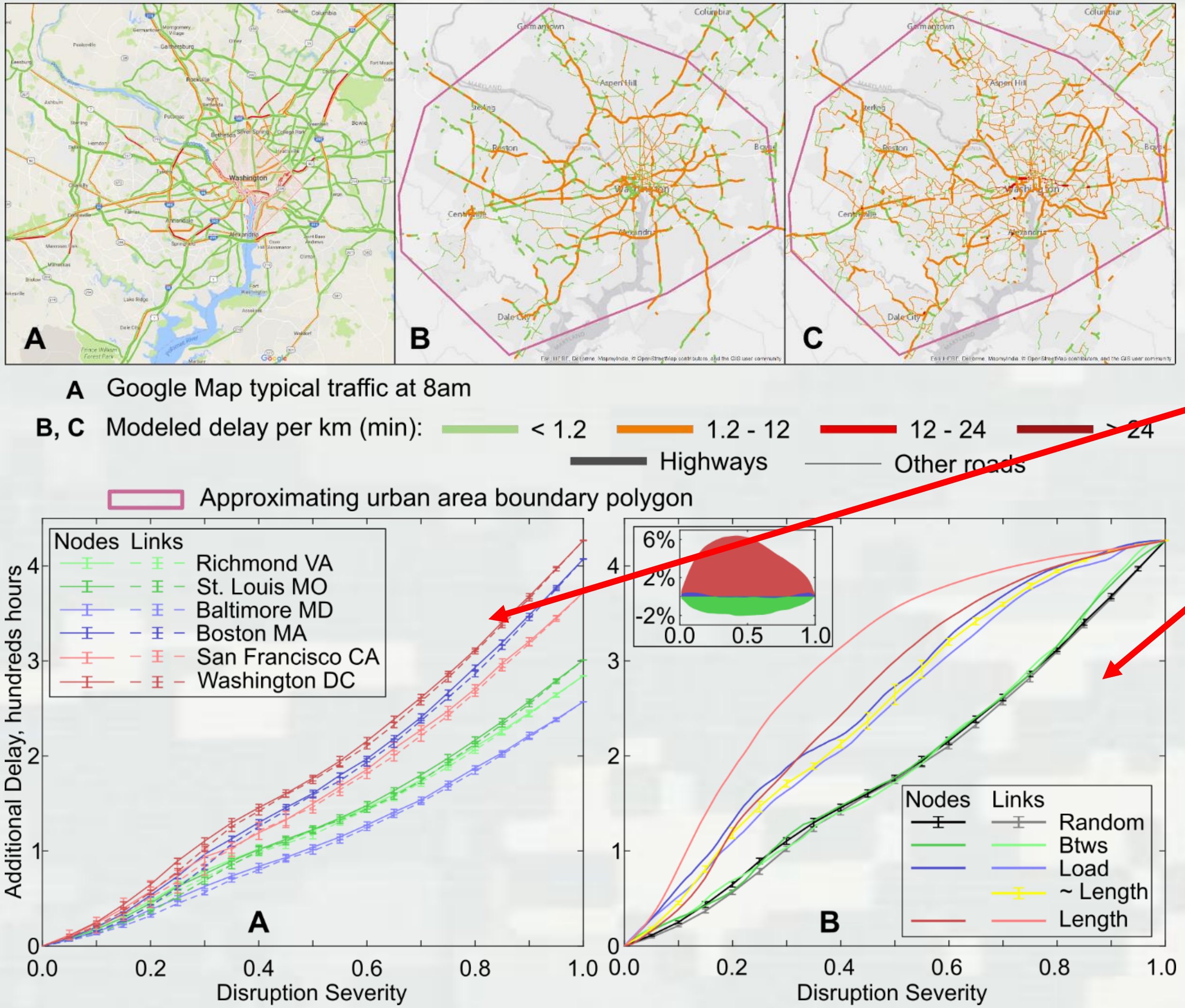
Connecting Two Networks



Connecting Several Networks: Cyber Resilience Domains



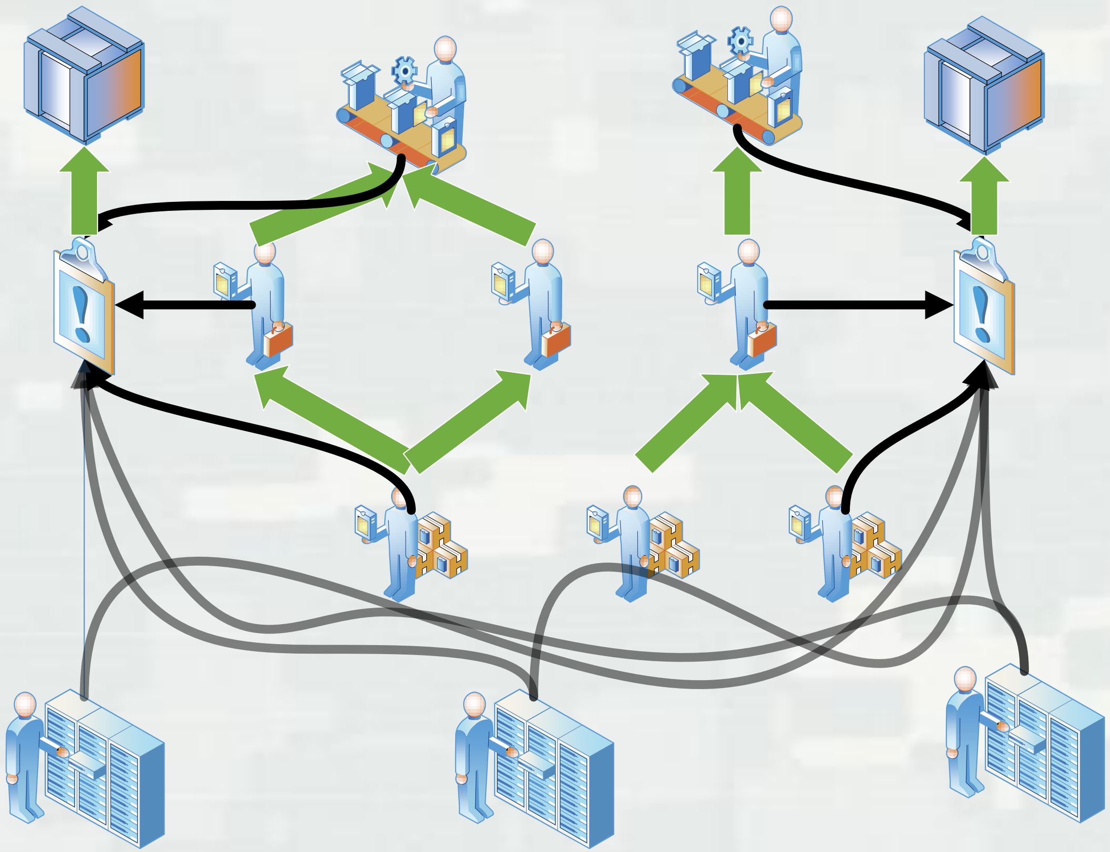
Cyber Attacks on Transportation



Washington, DC

After Ganin et al., 2018 (under review)

New Technologies: Blockchain for Supply Chains



- A distributed ledger which
  - Would contain all the information of a product’s materials, there sources and chain of ownership
    - As it is distributed falsifying or hiding chain of ownership is difficult

Blockchain with Distributed Ledger: Efficiency and Resilience

	Centralized Ledger	Blockchain with Distributed Ledger
Efficiency	Efficient	Not Efficient
Resilience	Not Resilient	Resilient

What Blockchain Can and Can Not Do

Blockchain-based distributed ledgers allow you to develop greater system trust in an otherwise trustless world

- The information domain benefit of blockchain-based distributed ledgers is the ability to quickly recover from hacking attempts and other disruptions - it is a significant improvement for fraud prevention.

Blockchain does not help when suppliers still demand to keep their sources as a trade secret

- They can often refuse adoption.

Blockchains only exist in the informational domain

- They do not, by themselves, change the other domains.

Environmental Science & Technology
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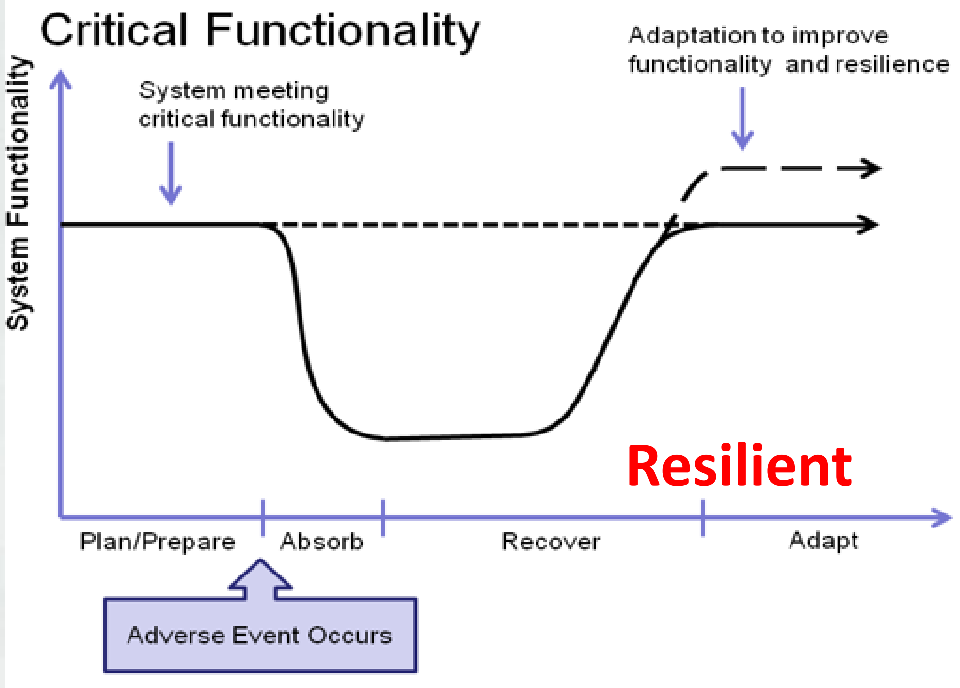
Can You Be Smart and Resilient at the Same Time?

Dayton Marchese and Igor Linkov*

DOI: 10.1021/acs.est.7b01912
Environ. Sci. Technol. 2017, 51, 5867−5868



Resilient

Smart

Promoting a holistic approach to resilience

Physical Resilience

- e.g. the International Transport Forum who

Economic and Financial Resilience

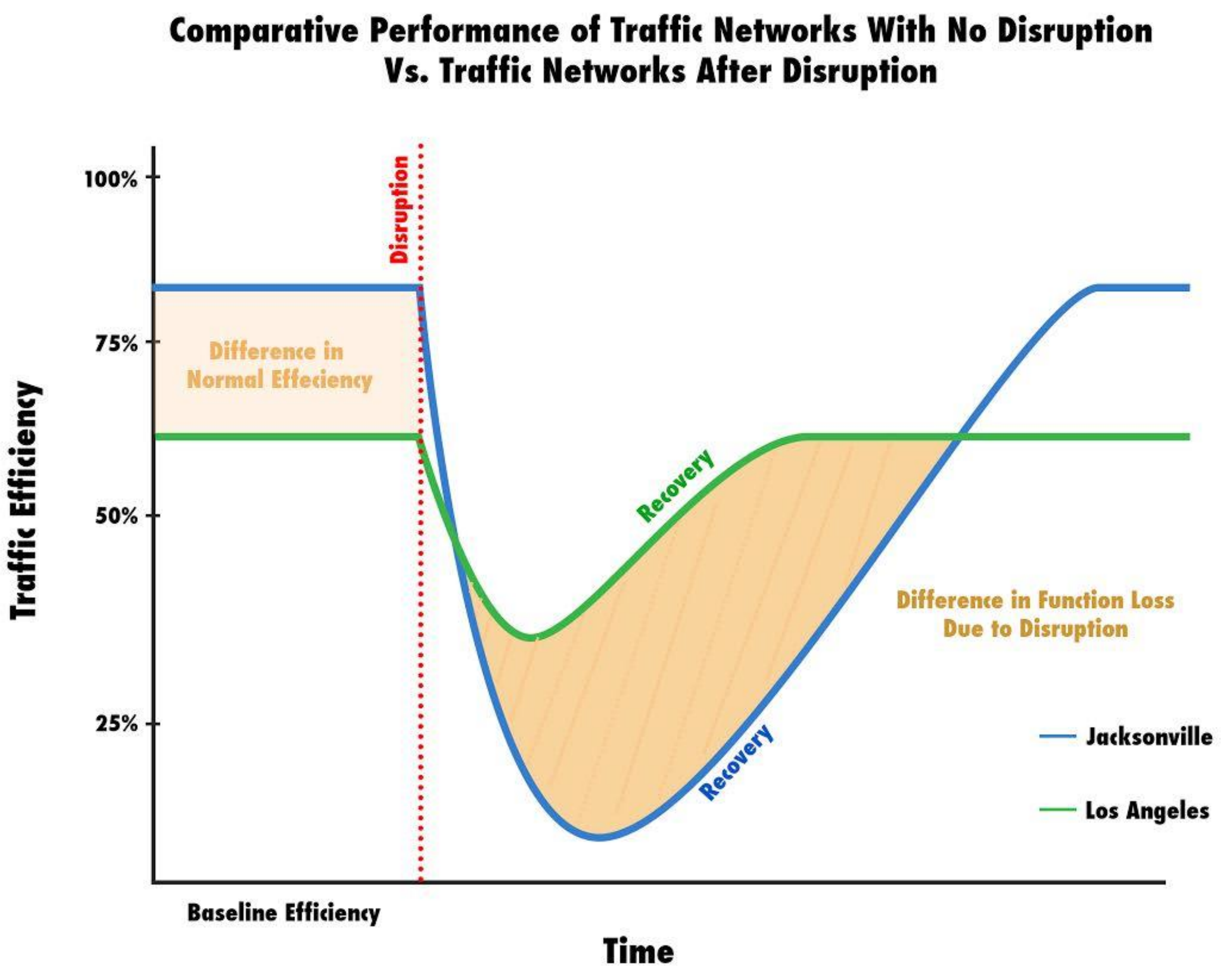
- resilience can be strengthened by implementing policies aimed at mitigating both the threats and consequences of severe crises (Economics Department)

Environmental Resilience

- including resilience to climate change - minimising consequences, design for safe failure, proactive management and ideas around

Social Resilience

- education, labour markets and social protection systems


Comparative Performance of Traffic Networks With No Disruption
Vs. Traffic Networks After Disruption
100%
75%
50%
25%
Traffic Efficiency
Disruption
Difference in
Normal Effeciency
Recovery
Recovery
Difference in Function Loss
Due to Disruption
Jacksonville
Los Angeles
Baseline Efficiency
Time

Risk-Resilience Integration

Top-Down
Decision Analysis/Social Science

Goal Identification and Problem Framing
-
What are the goals, alternatives, and constraints?

Decision Model
-
What are the criteria and metrics, How do we measure decision-maker values

Metrics Generation and Alternative Scoring
-
How does each alternative score along our identified criteria and metrics?

Management

Modeling

Data Collection

Bottom-Up
Risk Assessment/ Physical Sci

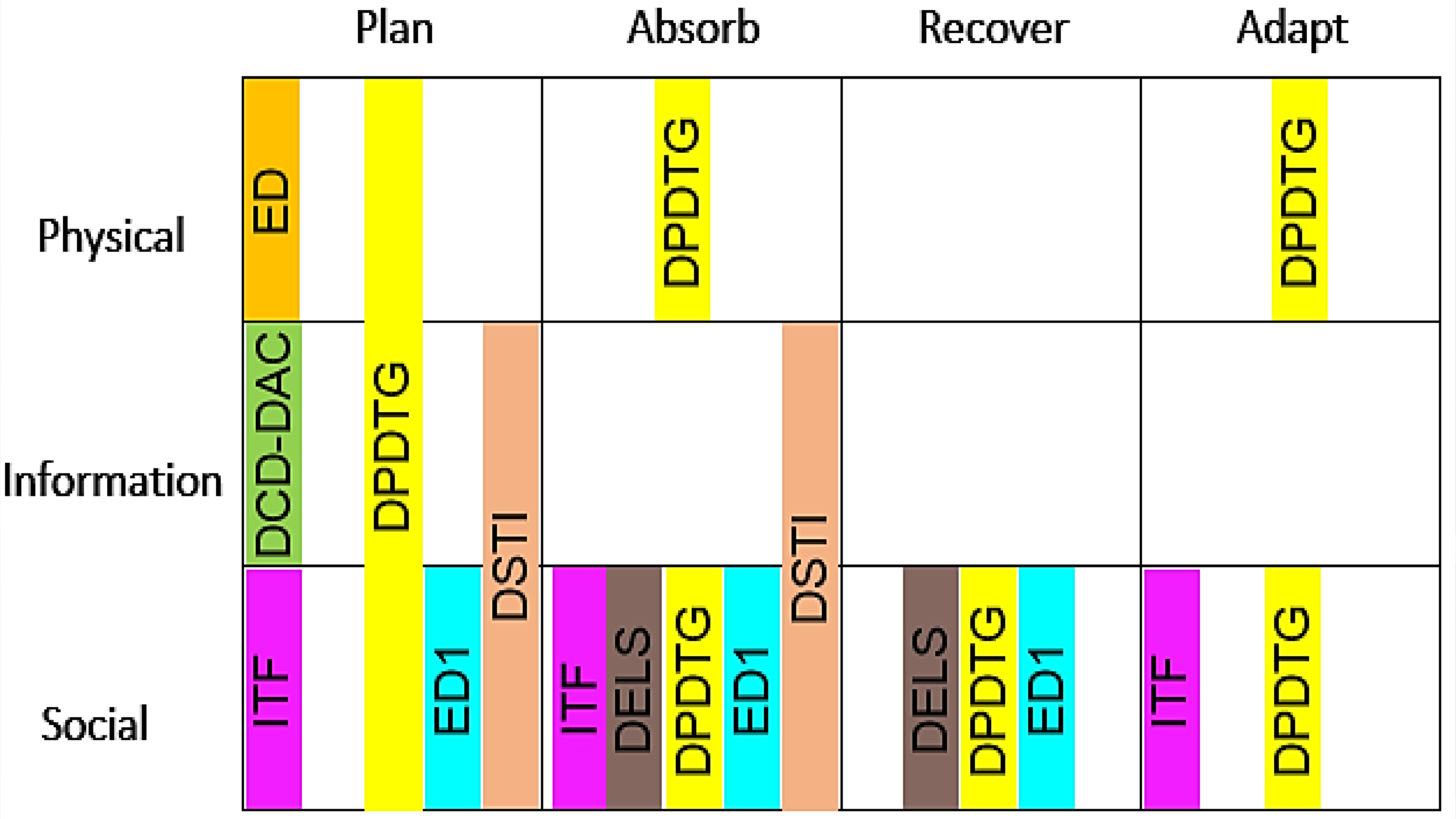
Risk Characterization
-
What are the risks relative to a threshold? How do they compare to other alternatives?

Physical/Statistical Model
-
What is the hazard?
What is exposure?

Data Collection
-
What are fundamental properties/mechanisms associated with each alternative?

Linkov et al., 2014

OECD/JRC/NIST Initiative



Contact: William Hynes, NAEC

TRB RESILIENCE COMMITTEES & RELATED TASK FORCE

Transportation Systems Resilience Section (ABR00)
Thomas Wakeman, Chair, twakeman@stevens.edu John Contestabile, Vice Chair, john.contestabile@jhuapl.edu

Scope: The Transportation Systems Resilience Section is part of the Policy and Organization Group. It consists of 3 committees that promote discussion among principals, disseminate research findings, and identify priority research topics in the area of transportation systems and services before, during, and after periods of increased stress, service disruptions, and human need.

Standing Committees of the Transportation Systems Resilience Section

Critical Transportation Infrastructure Protection (ABR10)
Laurel Radow, Chair, lradow2@gmail.com

Scope: The Committee will consider all threats and hazards to transportation infrastructure with a particular focus on terrorist threats and large-scale, or complex and catastrophic hazards.

ABR10 Subcommittees

ABR10(3) - Subcommittee on Physical Security
Rae Zimmerman, Chair, rae.zimmerman@nyu.edu Josh DeFlorio, Vice Chair, jdeflorio@panynj.gov

ABR10(8) - Subcommittee on Supply Chain
Maria Burns, Chair, mburns@Central.uh.edu Igor Linkov, Vice Chair, Igor.Linkov@usace.army.mil

ABR10(7) - Subcommittee on Cybersecurity
Michael Dinning, Chair, michael.dinning@dot.gov Doug Couto, Vice Chair, doug.couto28@gmail.com

Logistics of Disaster Response and Business Continuity (ABR20)
Anne Strauss-Wieder, Chair, strauss-weider@njtpa.org

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Science of the Total Environment 613–614 (2018) 1275–1283

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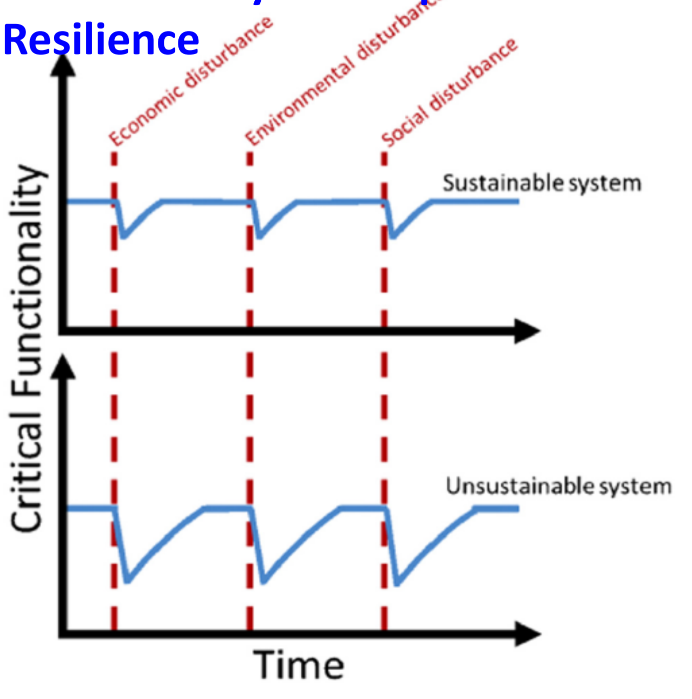
journal homepage: www.elsevier.com/locate/scitotenv

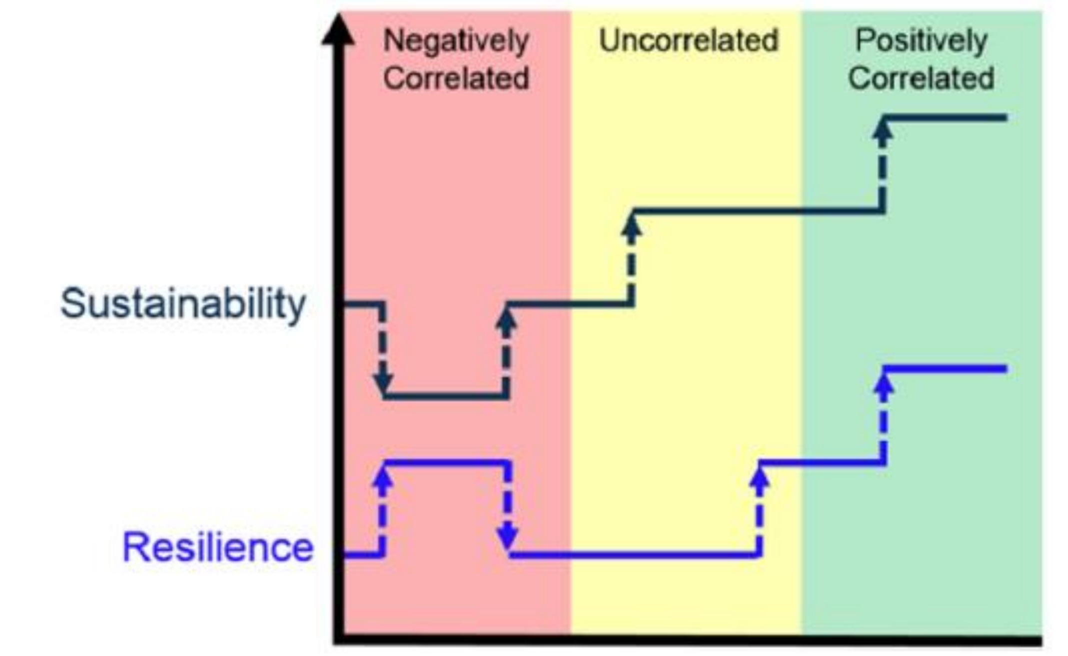
Resilience and sustainability: Similarities and differences in environmental management applications

Dayton Marchese [a], Erin Reynolds [a], Matthew E. Bates [a], Heather Morgan [b], Susan Spierre Clark [c], Igor Linkov [a,*]

Sustainability as component of Resilience



Sustainability and Resilience as Separate Goals



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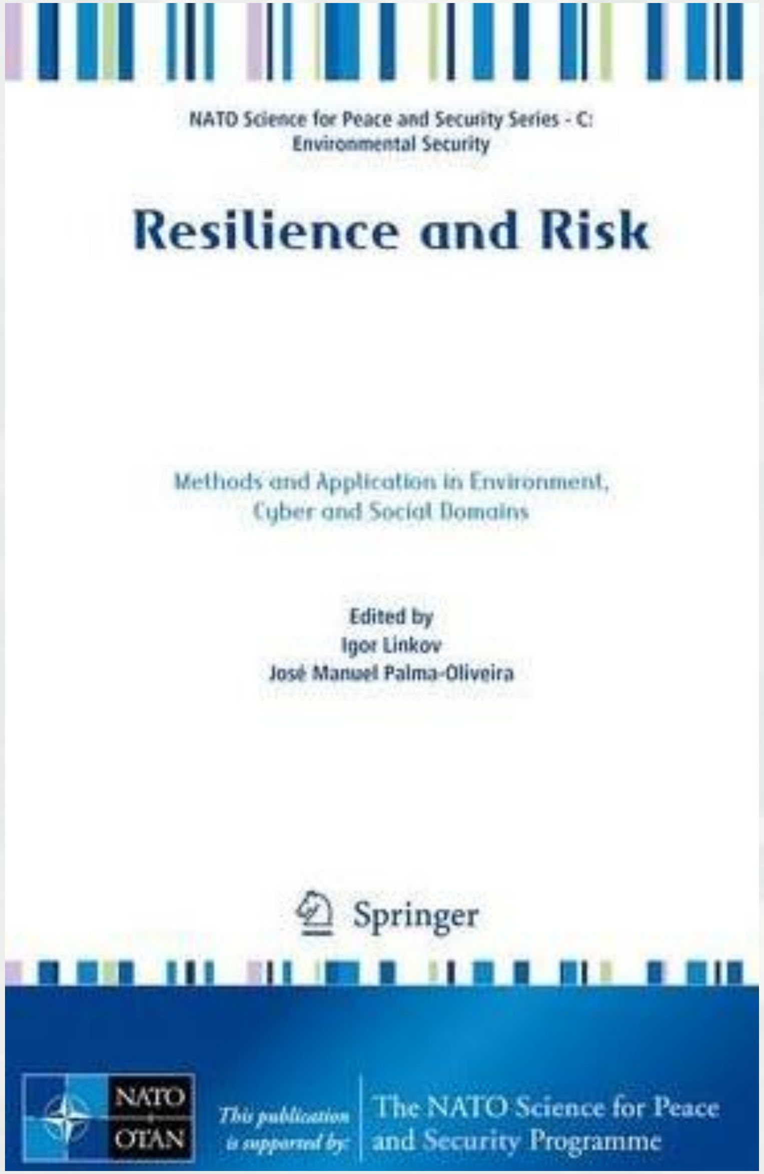

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DEVELOPMENT AND RESILIENCE

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- Emerging technologies and innovation
- Environment, ecology, climate
- Agriculture, food and water supply
- Human health and safety
- Law, policy and governance
- Business processes and standards
- Population and workforce behaviors
- Disaster preparedness and resilience
- Energy, transportation, logistics
- Poverty in rural and urban areas
- Infrastructure systems
- Economics, finance and fraud-related issues in enterprise and government
- Ethnic and socio-economic risks

Security and Resilience of Information Systems Affected by Hybrid Threats

NATO Workshop

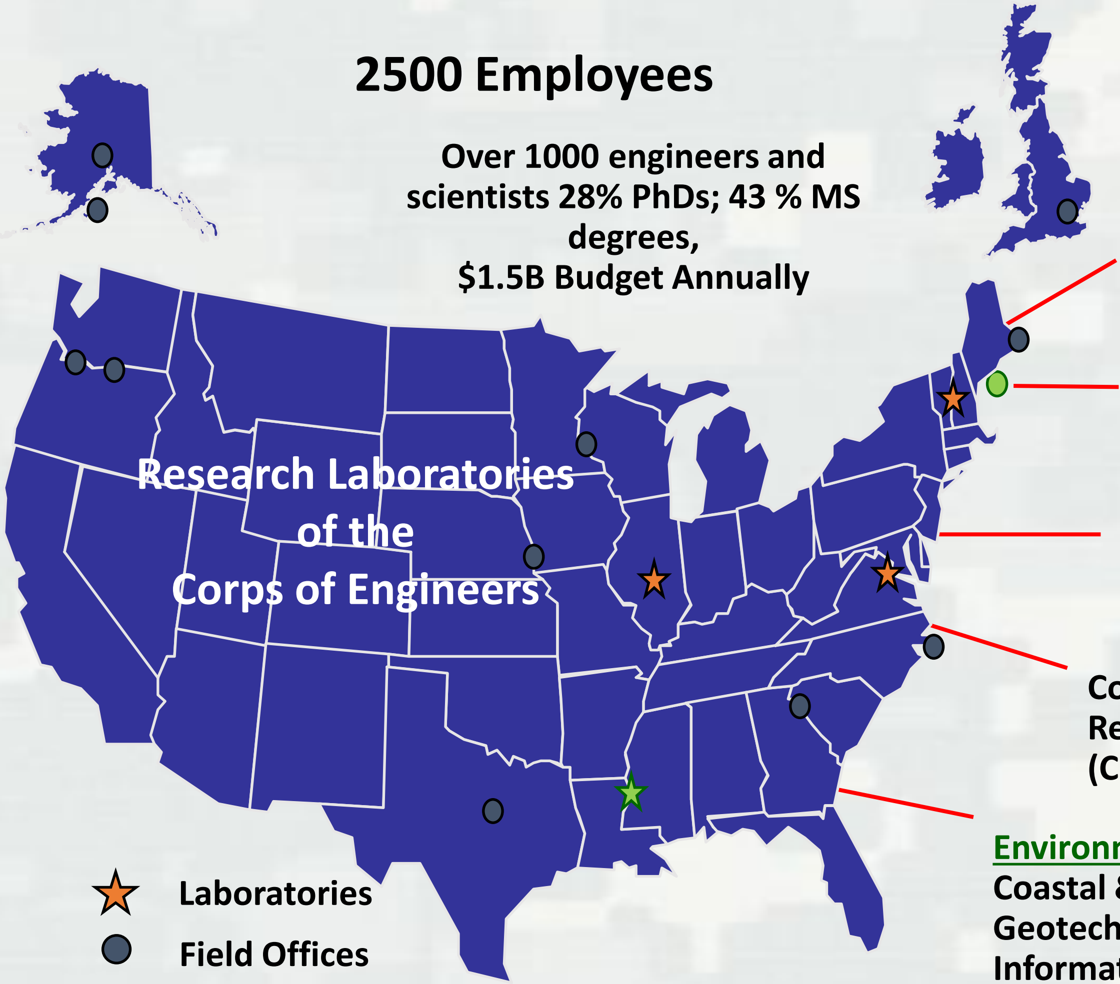
Estonia, 26-29 Aug 2018

Additional slides

US Army Engineer Research and Development Center

2500 Employees

Over 1000 engineers and scientists 28% PhDs; 43 % MS degrees,
$1.5B Budget Annually



Cold Regions Research Engineering Laboratory (Hanover, NH)

Risk and Decision Science Team Boston, MA)

Topographic Engineering Center (Alexandria, VA)

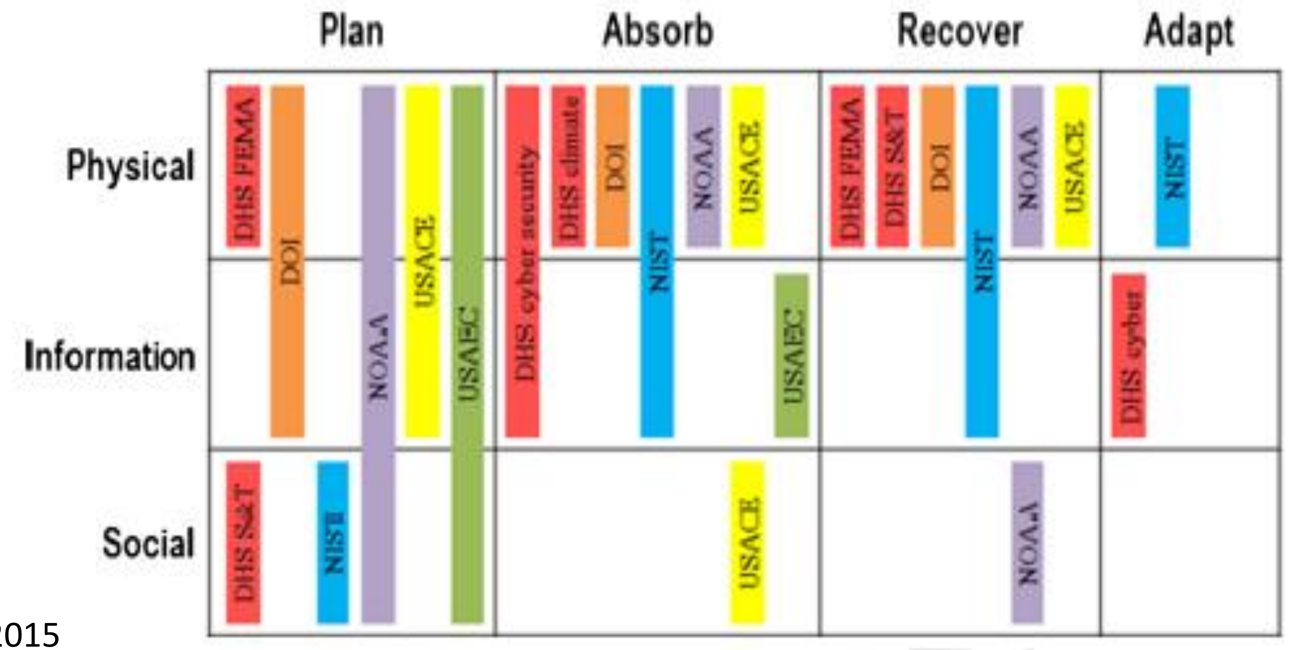
Construction Engineering Research Laboratory (Champaign, IL)

Environmental Laboratory
Coastal & Hydraulics Laboratory
Geotechnical & Structures Laboratory
Information Technology Laboratory
Headquarters (Vicksburg, MS)

How Extensive are Current US Agency Resilience Plans?

Environ Syst Decis

Fig. 1 Agency resilience actions addressed (relative to NAS definition) in physical, information, and social domains



Larkin, Fox-Lent, Linkov et al., 2015