This presentation does not necessarily reflect the views of the United States Government, and is only the view of the authors

Importance of Investment in Resilience: Global, Regional and Local Perspectives

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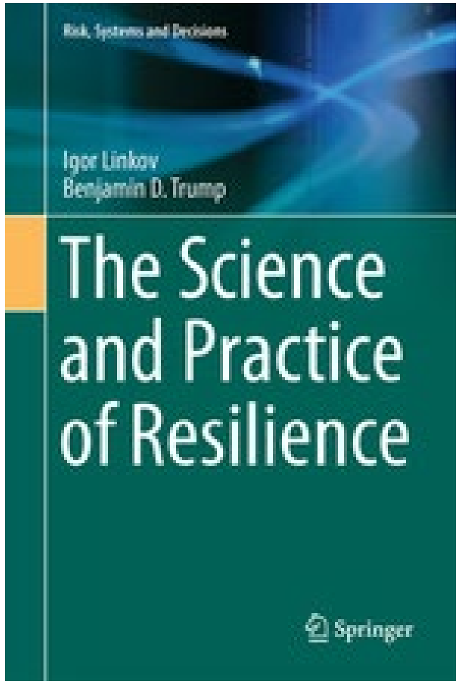
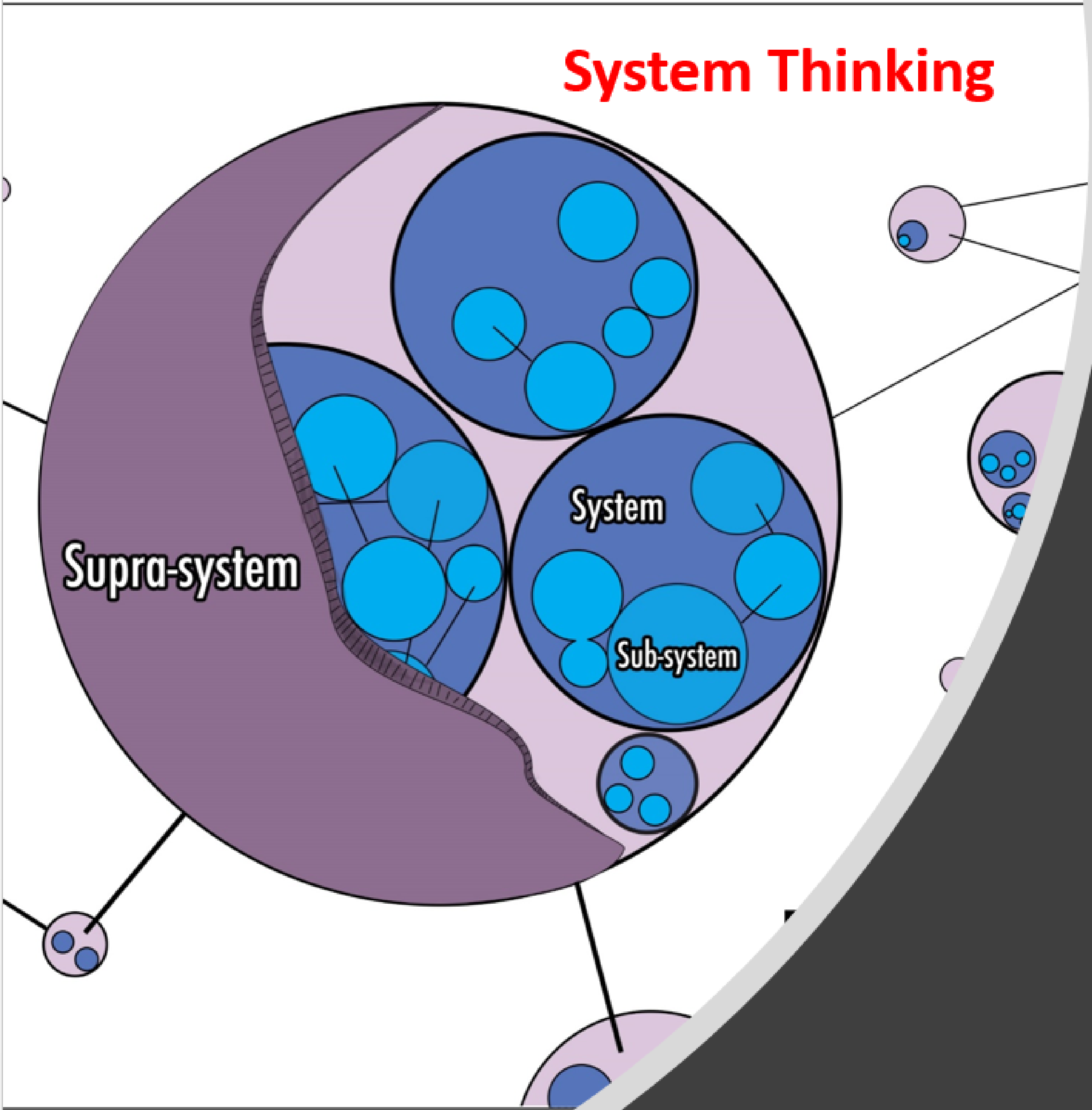
8 May 2025

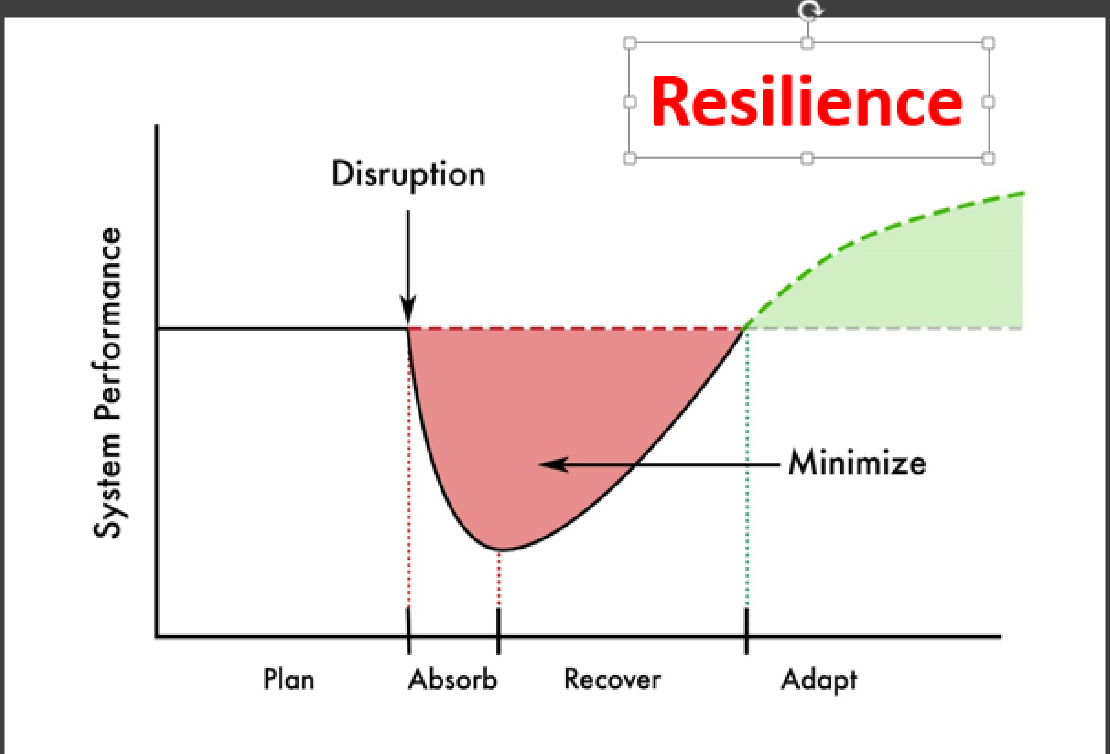
Main Ideas

- Infrastructure, Health and everything around us can be viewed as complex and adaptive system and **system analysis is necessary**
- Vulnerability, Risk and Resilience are different and **should be treated differently**
- Resilience can be quantified using **Metrics-based and Network Science tools**
- **Efficiency, Sustainability and Smartness are different**, have different economic impacts and ways to quantify and manage



What Makes Complex Systems (Communities) Susceptible to Threat?





After Linkov and Trump, 2019

Risk -- "a situation involving exposure to danger [threat]."

Security -- "the state of being free from danger or 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

Igor Linkov, Benjamin D. Trump *US Army Corps of Engineers, Concord, Massachusetts, USA.*
Jeffrey Keisler *University of Massachusetts Boston, USA.*
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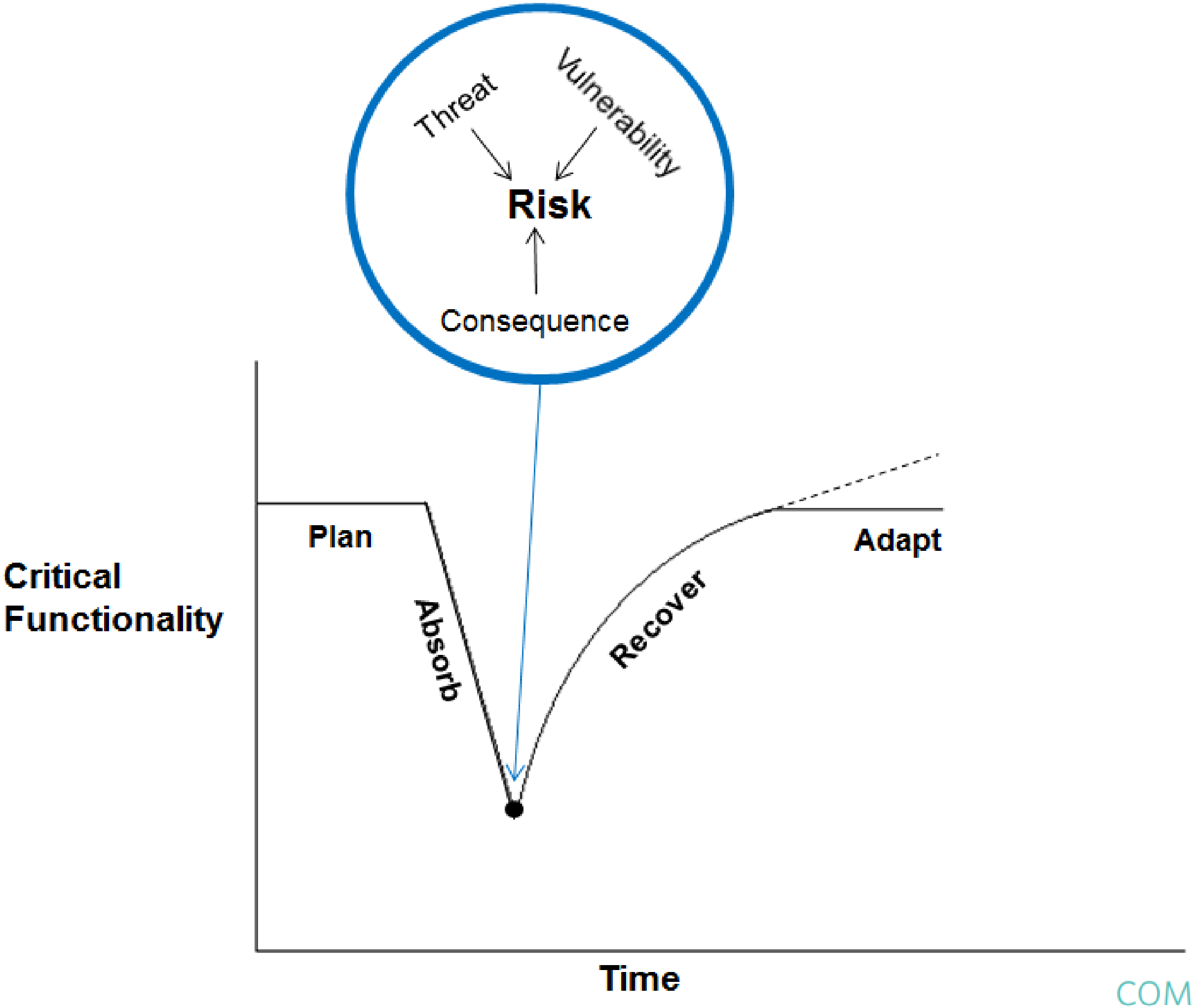
System Risk/Security and Resilience



Risk Analysis

System Resilience

Nature Climate Change 2014

COMMENTARY:

Changing the resilience paradigm

Igor Linkov, Todd Bridges, Felix Creutzig, Jennifer Decker, Cate Fox-Lent, Wolfgang Kröger,

Calls for 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

- - - - - - -

BY THE PRESIDENT OF THE UNITED STATES OF AMERICA

A PROCLAMATION

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

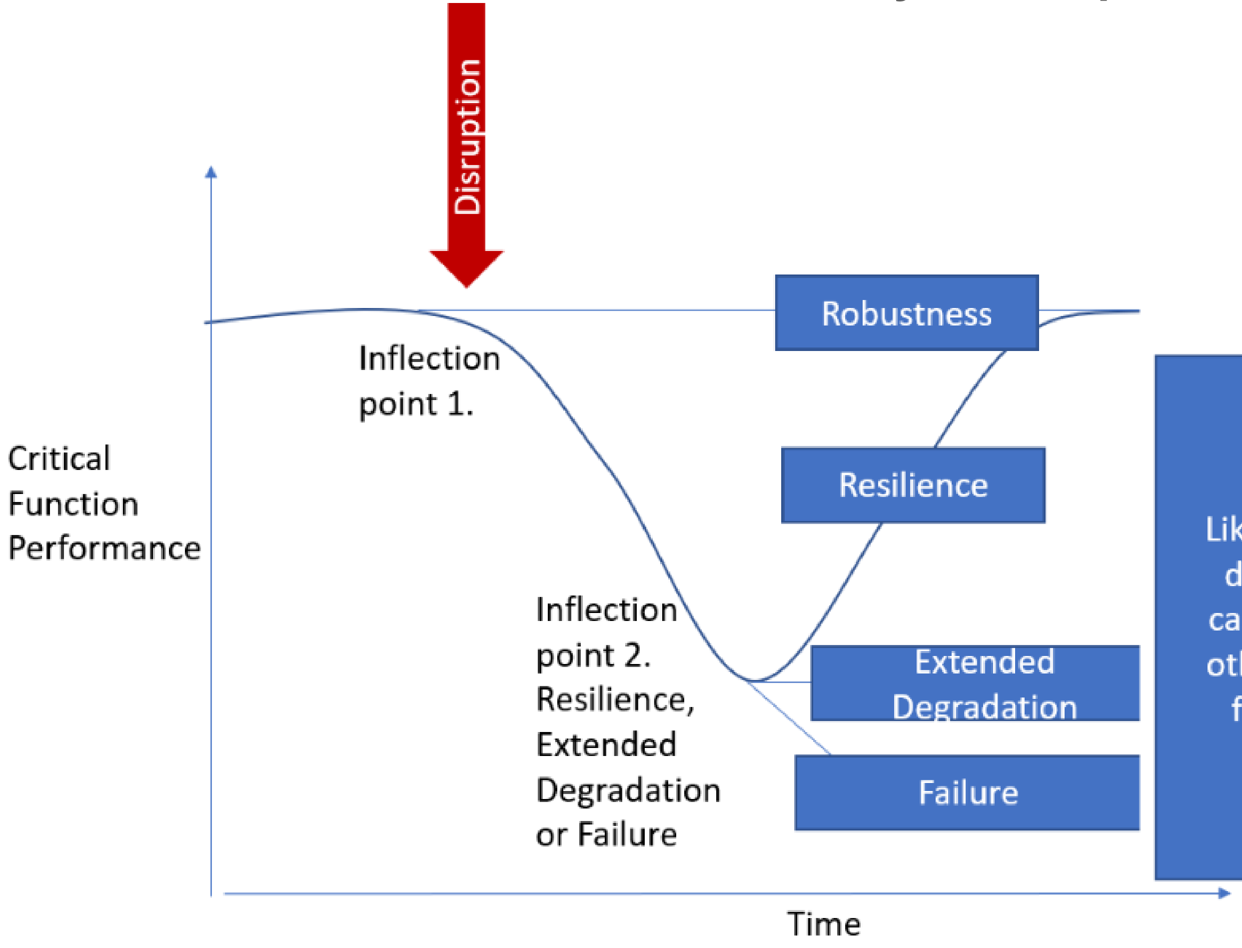
For Immediate Release May 11, 2017

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

EXECUTIVE ORDER

Crisis Management, Risk and Resilience

Risk~ Threat*Vulnerability*Consequence

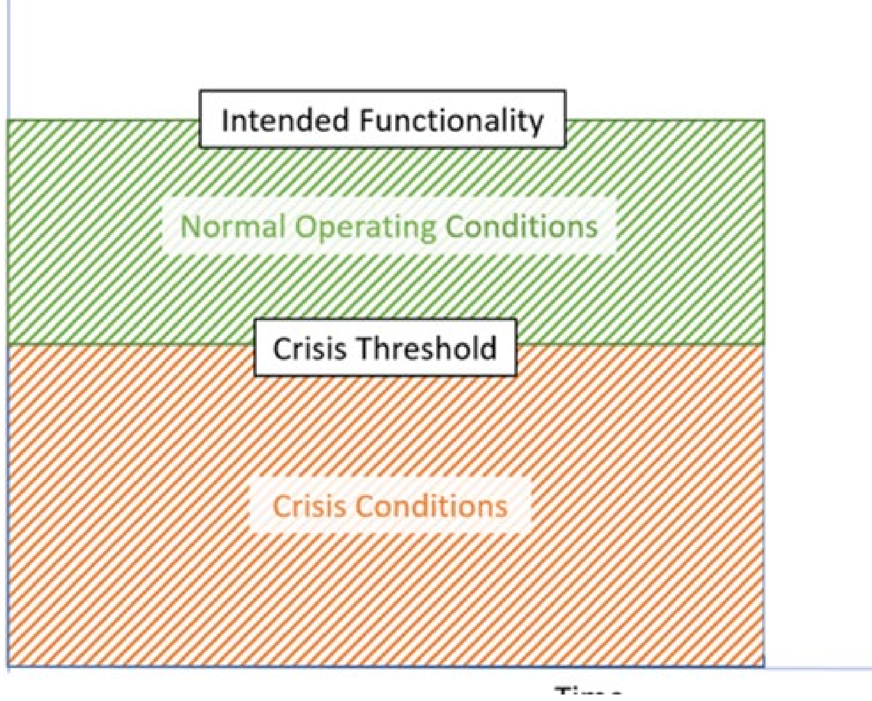



International Journal of Disaster Risk Science
https://doi.org/10.1007/s13753-023-00494-x
www.ijdrs.com
www.springer.com/13753

ARTICLE

Business Continuity Management, Operational Resilience, and Organizational Resilience: Commonalities, Distinctions, and Synthesis

S. E. Galaitsi[1] · Elizaveta Pinigina[1] · Jeffrey M. Keisler[2] · Gianluca Pescaroli[3] · Jesse M. Keenan[1,4] · Igor Linkov[1]



Galaitsi, Linkov et al, 2023

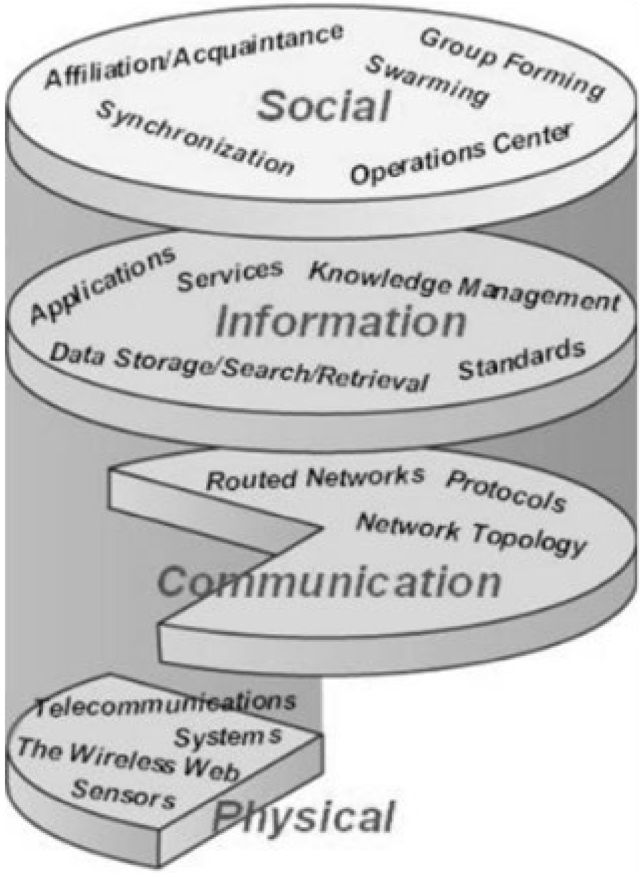
- Sec. 3. Updating Federal Policy to Save Lives and End the Subsidization of Mismanagement. (a) National Resilience Strategy. Within 90 days, … publish a National Resilience Strategy that articulates the priorities, means, and ways to advance the resilience of the Nation.
- (b) National Critical Infrastructure Policy. Within 180 days, recommend to the President the revisions, recissions, and replacements necessary to achieve a more resilient posture; shift from an all-hazards approach to a risk-informed approach; move beyond information sharing to action; and implement the National Resilience Strategy described in subsection (a) of this section.
- (c) National Continuity Policy. Within 180 days of the date of this order, … recommend to the President the revisions, recissions, and replacements necessary to modernize and streamline the approach to national continuity capabilities, reformulate the methodology and architecture necessary to achieve an enduring readiness posture, and implement the National Resilience Strategy described in subsection (a) of this section.

(e) National Risk Register. Within 240 days…, coordinate the development of a National Risk Register that identifies, articulates, and quantifies natural and malign risks to our national infrastructure, related systems, and their users.

(f) Federal National Functions Constructs. Within 1 year …, the Secretary of Homeland Security shall propose changes to the policies outlining this framework and any implementing documents to ensure State and local governments and individuals have improved communications with Federal officials and a better

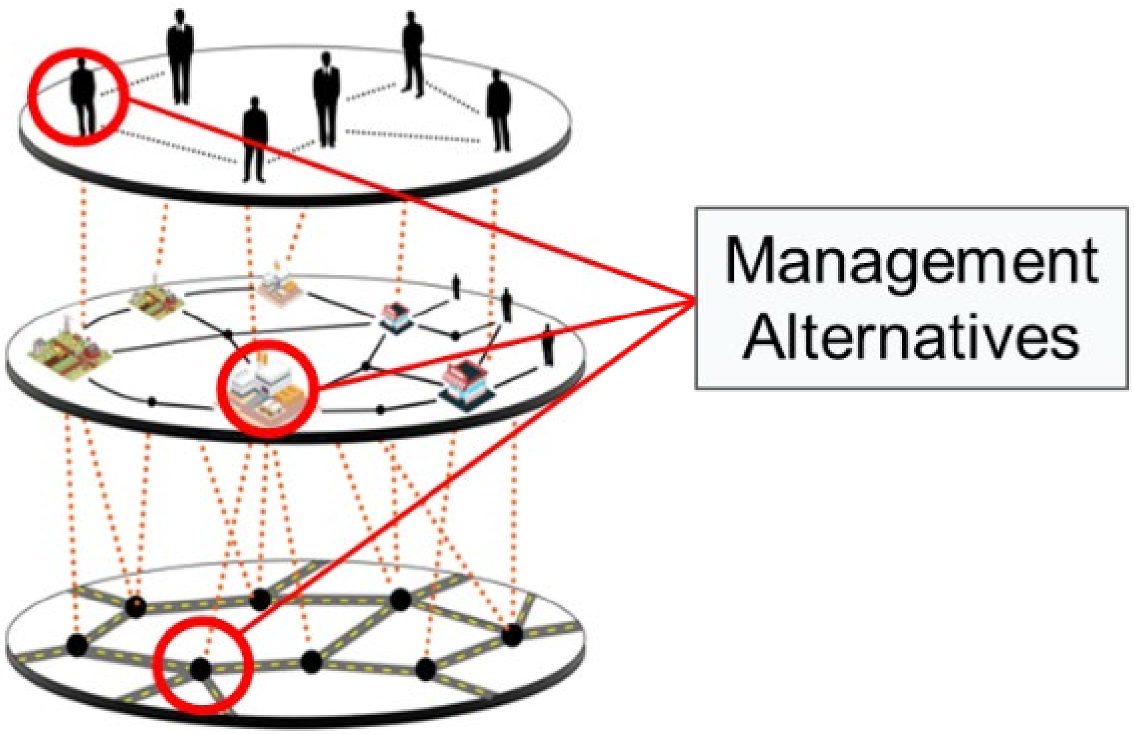
Vision for System Resilience

Real World



Model

Operations



The case for value chain resilience

Igor Linkov, Savina Carluccio, Oliver Pritchard, Áine Ni Bhreasail, Stephanie Galaitsi, Joseph Sarkis and Jeffrey M. Keisler

Management Research Review
© Emerald Publishing Limited
2040-8269
DOI 10.1108/MRR-08-2019-0353

Example 1: Global -- The Collapse of the Bronze Age 1200 to 1100 BCE

Contents lists available at ScienceDirect

Global Environmental Change

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

ELSEVIER

Are civilizations destined to collapse? Lessons from the Mediterranean Bronze Age

Igor Linkov[a,*], S.E. Galaitsi[a], Benjamin D. Trump[a,*], Elizaveta Pinigina[a], Krista Rand[a], Eric H. Cline[c], Maksim Kitsak[b,*]

Stability Rule: Region must be stable in both layers simultaneously

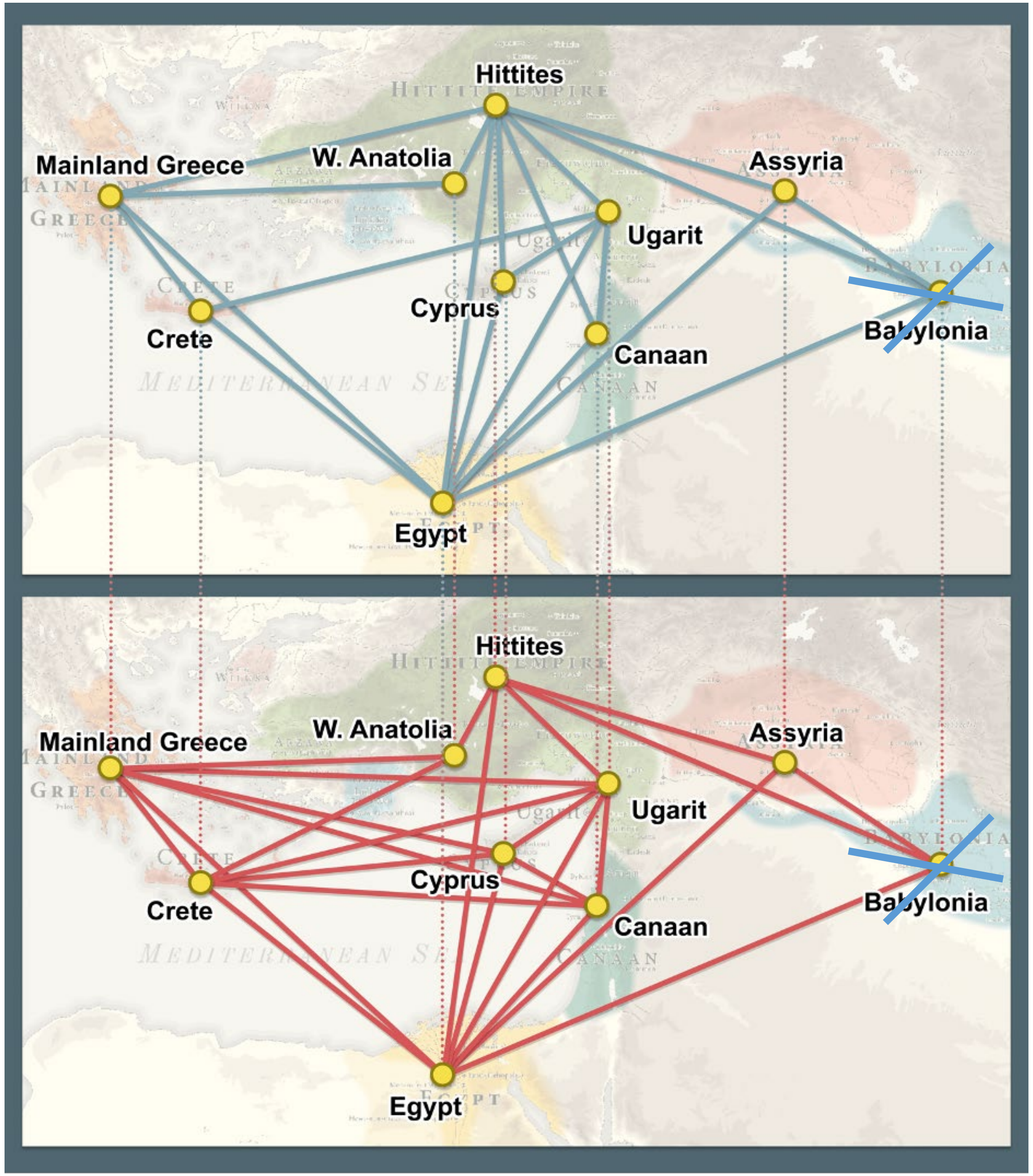
N = 10 regions

E_1 = 21 political ties

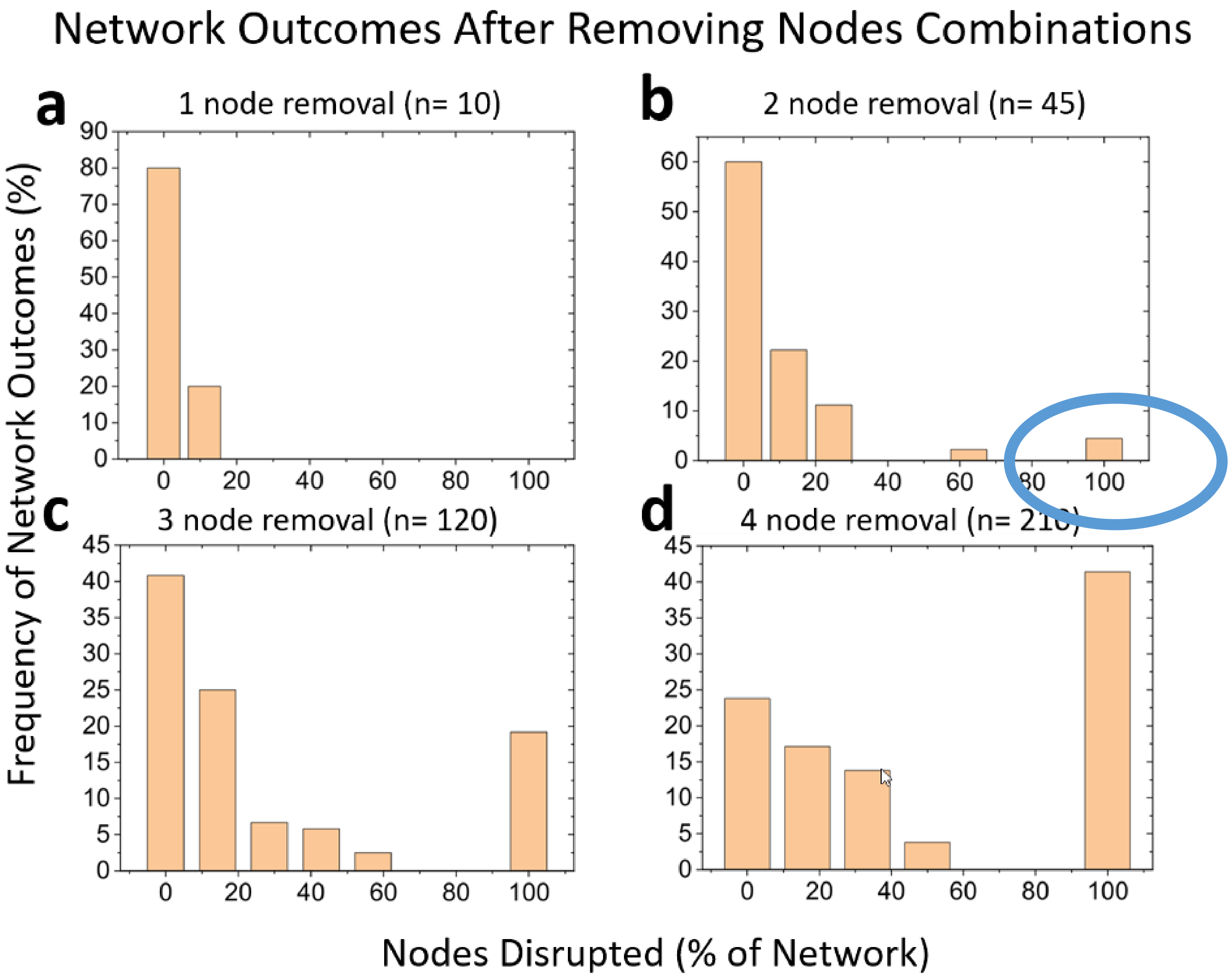
E_1 = 27 trade ties

Politics Layer

Trade Layer

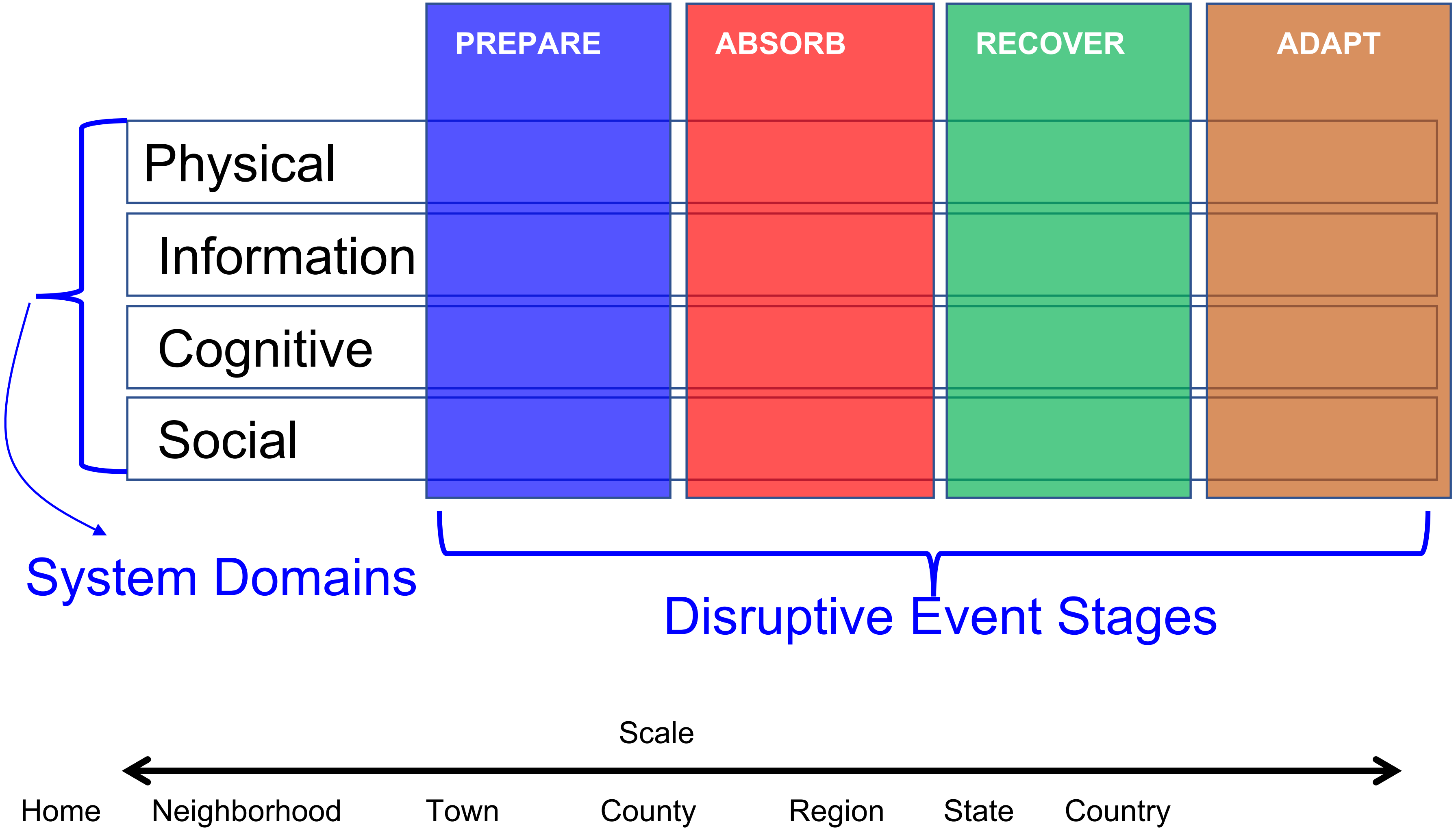


Stress-Test for the Bronze Age Network



Simultaneous failure of 2 regions can be catastrophic!

Resilience Matrix



Assessment using Stakeholder Values

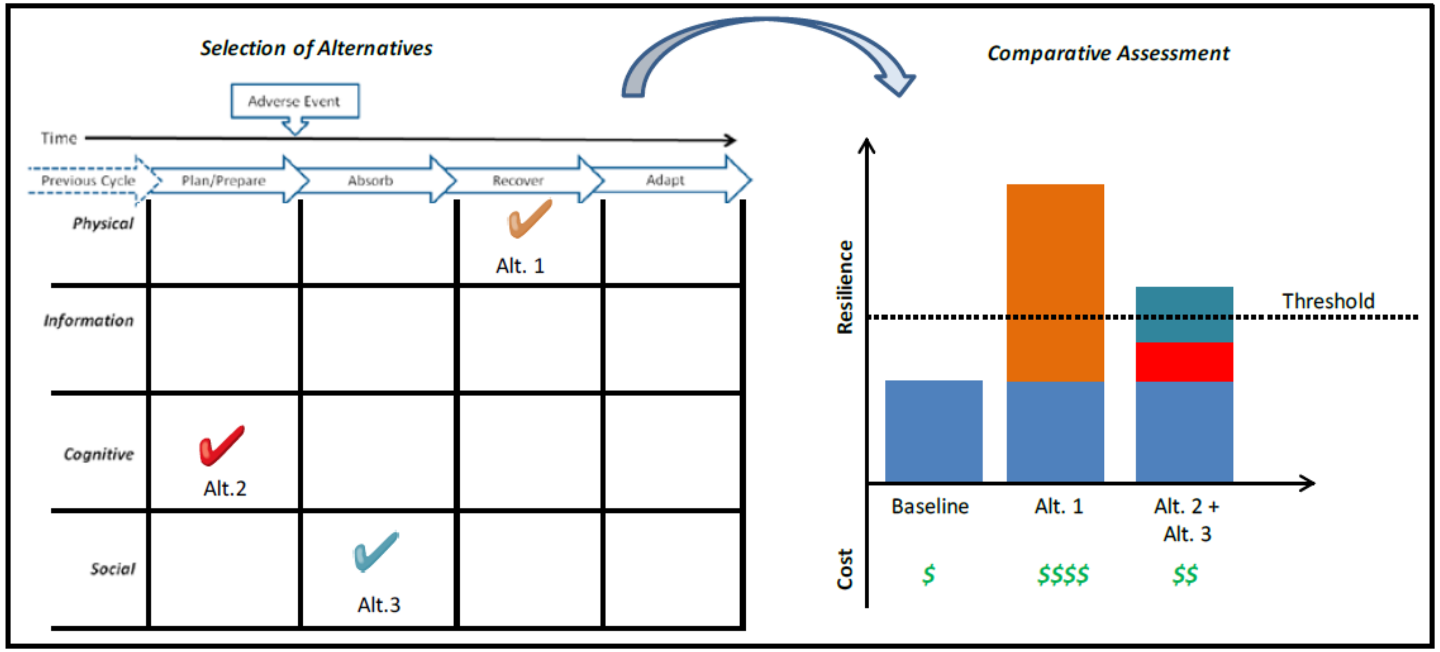


Figure 5: Comparative Assessment of Resilience-Enhancing Alternatives

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

After Fox-Lent et al., 2015

Contents lists available at ScienceDirect

Energy Policy

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

Short Communication

Metrics for energy resilience

Paul E. Roege[a], Zachary A. Collier[b], James Mancillas[c], John A. McDonagh[c], Igor Linkov[b,*]

Resilience Matrix: Energy

	Plan and Prepare for	Refs	Absorb	Refs	Recover from	Refs	Adapt to	Refs
Physical	Reduced reliance on energy/increased efficiency	A,B, E,F, H	Design margin to accommodate range of conditions	B,C, I,J,K	System flexibility for reconfiguration and/or temporary system installation	C,D, F,H, K	Flexible network architecture to facilitate modernization and new energy sources	C,D, F,K
	Energy source diversity/ local sources	A,E, F,H, K	Limited performance degradation under changing conditions	B,C, F,I,K	Capability to monitor and control portions of system	B,I, K	Sensors, data collection and visualization capabilities to support system performance trending	D,E, I,K
	Energy storage capabilities/ presaged equipment	B,H, K	Operational system protection (e.g., pressure relief, circuit breakers)	I,K	Fuel flexibility	C,D, E,F	Ability to use new/alternative energy sources	C,F, H
	Redundancy of critical capabilities	D,E, I,K	Installed/ready redundant components (e.g., generators, pumps)	D,I, K	Capability to re-route energy from available sources	C,D, F,I,K	Update system configuration/ functionality based upon lessons learned	C,D, L,F,I, K
	Preventative maintenance on energy systems	I,K	Ability to isolate damaged/ degraded systems/ components (automatic/ manual)	E,I,K	Investigate and repair malfunctioning controls or sensors	I	Phase out obsolete or damaged assets and introduce new assets	A,C, D,I, K
	Sensors, controls and communication links to support awareness and response	H,I, K	Capability for independent local/sub-network operation	D,K	Energy network flexibility to re-establish service by priority.	F,I,K	Integrate new interface standards and operating system upgrades	D,I, K
	Protective measures from external attack (physical/ cyber)	A,D, I,K	Alternative methods/ equipment (e.g., paper copy, flashlights, radios)	B,H, K	Backup communication, lighting, power systems for repair/recovery operations	I,K	Update response equipment/ supplies based upon lessons learned	D,L
Information	Capabilities and services prioritized based on criticality or performance requirements	B	Environmental condition forecast and event warnings broadcast	E,H, I	Information available to authorities and crews regarding customer/community needs/ status	D,I	Initiating event, incident point of entry, associated vulnerabilities and impacts identified	A,D, H,I, K
	Internal and external system dependencies identified	B,G, H	System status, trends, margins available to operators, managers and customers	D,E, H,I, K	Recovery progress tracked, synthesized and available to decision-makers and stakeholders	D,I	Event data and operating environment forecasts utilized to anticipate future conditions/ events	D,H, I,K
	Design, control, operational and maintenance data archived and protected	B,I	Critical system data monitored, anomalies alarmed	D,E, I,K	Design, repair parts, substitution information available to recovery teams	K	Updated information about energy resources, alternatives and emergent technologies available to managers and stakeholders	D,F, H,I
	Vendor information available	B	Operational/troubleshooting/ response procedures available	I,K	Location, availability and ownership of energy, hardware and services available to restoration teams	K	Design, operating and maintenance information updated consistent with system modifications	F,I,K

USACE Resilience Matrix Methodology

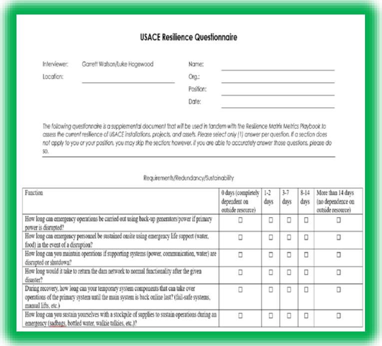
Resilience Matrix

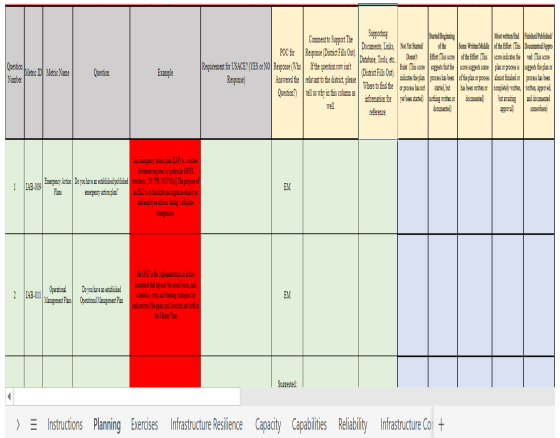
	Absorb	Recover	Adapt
Physical	System Performance/Functionality System Reliability Robustness Consequences of failure System Vulnerability Hazard Mitigation Measures Redundancy Back-up Systems Emergency Resources	Recovery Time Temporary Facilities Recovery Resources	Adaptive Capacity Infrastructure Condition Modularity
Information	Failure Detection Systems Hazard Forecasting Risk Assessment/Data Emergency Planning Mitigation Planning Disaster Propagation Models	Recovery Tracking Data Models for Recovery Scenarios Recovery Planning	Post-disaster data collection Adaptation Planning Plan Improvements
Social	Emergency Staffing Emergency Support Agreements Community Communication Staff Emergency Training	Community Recovery Assistance Contractor Agreements Recovery Agreements	Training Exercises Community Education Improved Legislation

Master Metrics

Metric Identification and Categorization						M	
Metric Name	Unit of Analysis	System Doma	Resilience Phas	Metric Category	Critical Function	Measure Full Name	Level of Detail
Risk Assessment Score	Capability	Physical	Absorb	System Vulnerability	FRM	Score from most recent Risk Assesment	Tier 2
Last Inspection Date	Capability	Information	Absorb	Risk Assessment	FRM	Years since the most recent comprehensive inspection of the dam	Tier 2
Last EAP Revision	Capability	Information	Adapt	Planning Improvements	FRM	Years since the most recent revision to the emergency action plan (EAP)	Tier 2
Last EAP Exercise	Capability	Social	Adapt	Training Exercises	FRM	Years since the most recent EAP exercise	Tier 2
Worst Case Consequences Estimate	Capability	Physical	Absorb	Consequences of Failure	FRM	Estimated economic cost for the worst-case dam failure scenario (Maximum High Pool - Breach)	Tier 2
Operations Plans	Capability	Information	Absorb	Mitigation Planning	FRM	Degree (1-5) of completeness of operations plan	Tier 1
Planning Review	Capability	Information	Adapt	Planning Improvements	FRM	Years since the most recent review and update of the operations plans	Tier 2
Emergency Exercises	Capability	Social	Adapt	Training Exercises	FRM	Years since the most recent emergency operation test exercise (or most recent emergency response)	Tier 2
After-Action Reports	Capability	Information	Adapt	Post-disaster Data Collection	FRM	% of exercises/events in the past 5-10 years where an after-action report was generated and reviewed by the district	Tier 2

Solicitation Template





Scorecard

	Absorb	Recover	Adapt
Physical	3.8	5.0	3.5
Information	4.4	3.8	4.4
Social	3.7	5.0	5.0

SRB-FRM Case Study

Measuring USACE Resilience in the Savannah Basin – manuscript for peer review

The Savannah Watershed serves as a critical component, crucial to the well-being of numerous communities and ecological systems. Leading in the maintenance of this significant resource is the United States Army Corps of Engineers (USACE). With an established history in water resource management, the USACE is responsible for executing a range of essential missions within the watershed. These include flood risk management, hydropower generation, aquatic ecosystem restoration, water supply, navigation infrastructure maintenance, and recreational land-use. This paper aims to examine the various roles of the USACE to guarantee mission assurance in this critical region. It places particular emphasis on the collaborative efforts between the USACE, local governance, and various stakeholders.

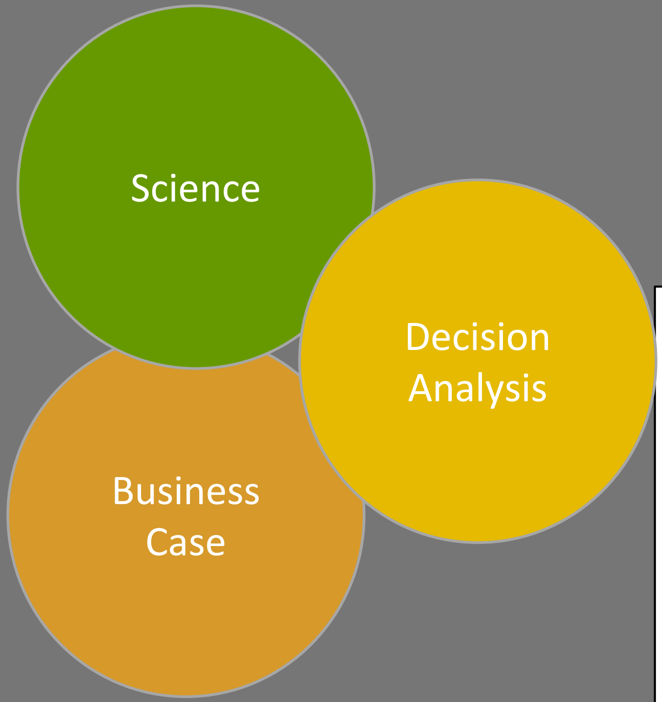
USACE Report

A Resilience Matrix Approach

to USACE MISSION in the Savannah Watershed

Academic Literature Review → Restructuring of Resilience Matrix → Development of Decision Support Tool → USACE Document Review → Development of Master Metrics → Development of Solicitation Survey → Development of Resilience Scorecard → Conducting/ Writing FRM Case Study → Compiling/ Writing Report on USACE Resilience → Development of a documented/published methodology for a transferrable/replicable process that provides a cost effective and accurate procedure that can be used to assess USACE and Community Resilience from infrastructure, to critical function, to mission.

Example 3 -Local
What does it mean to have a resilient transportation network?



Transportation Network Model
+
Regional Economic Models, Inc.

Contents lists available at ScienceDirect
Transportation Research Part D
journal homepage: www.elsevier.com/locate/trd
ELSEVIER

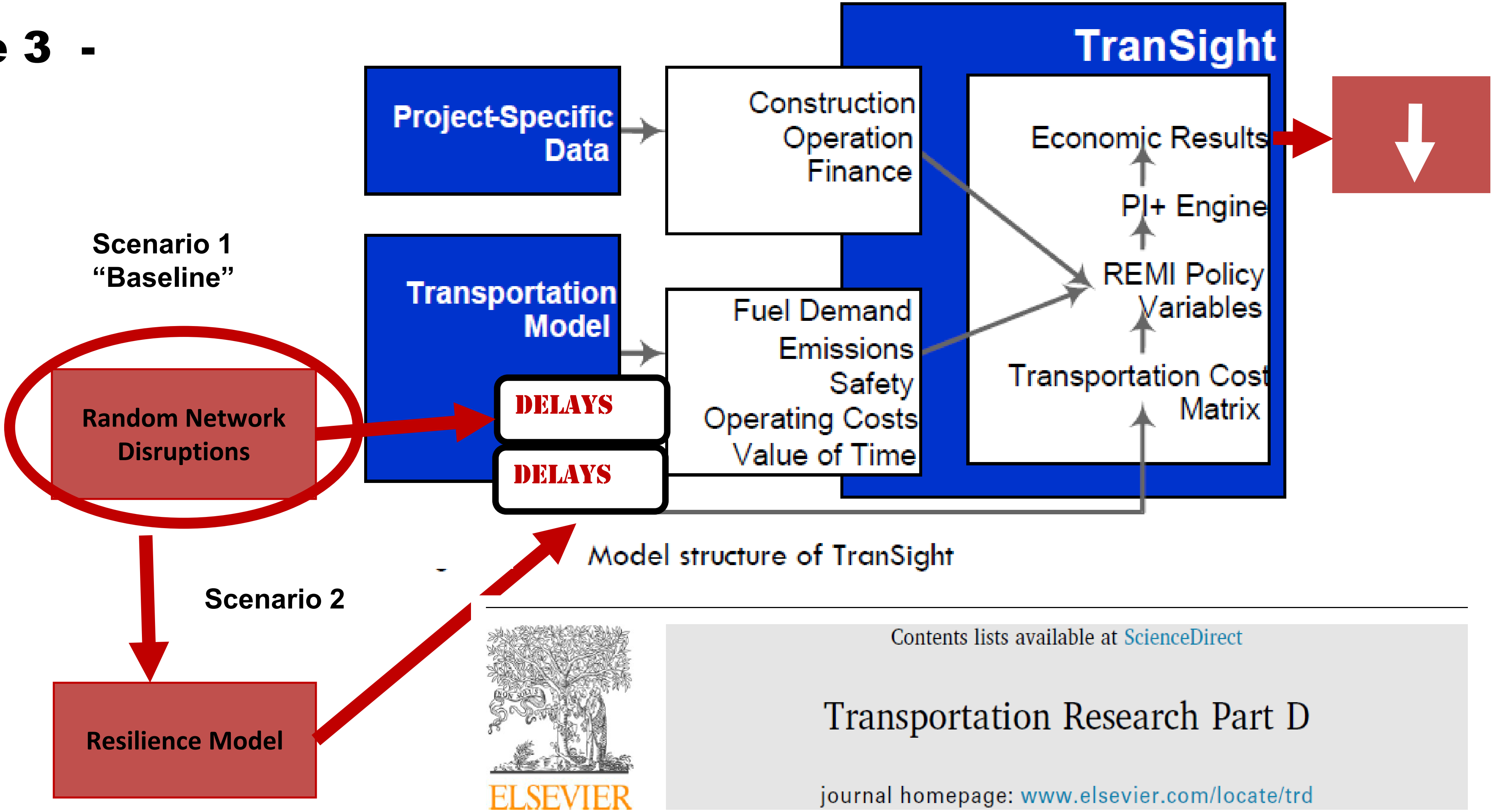
Lack of resilience in transportation networks: Economic implications

SCIENCE ADVANCES | RESEARCH ARTICLE
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]*

Example 3 - Local



Model structure of TranSight

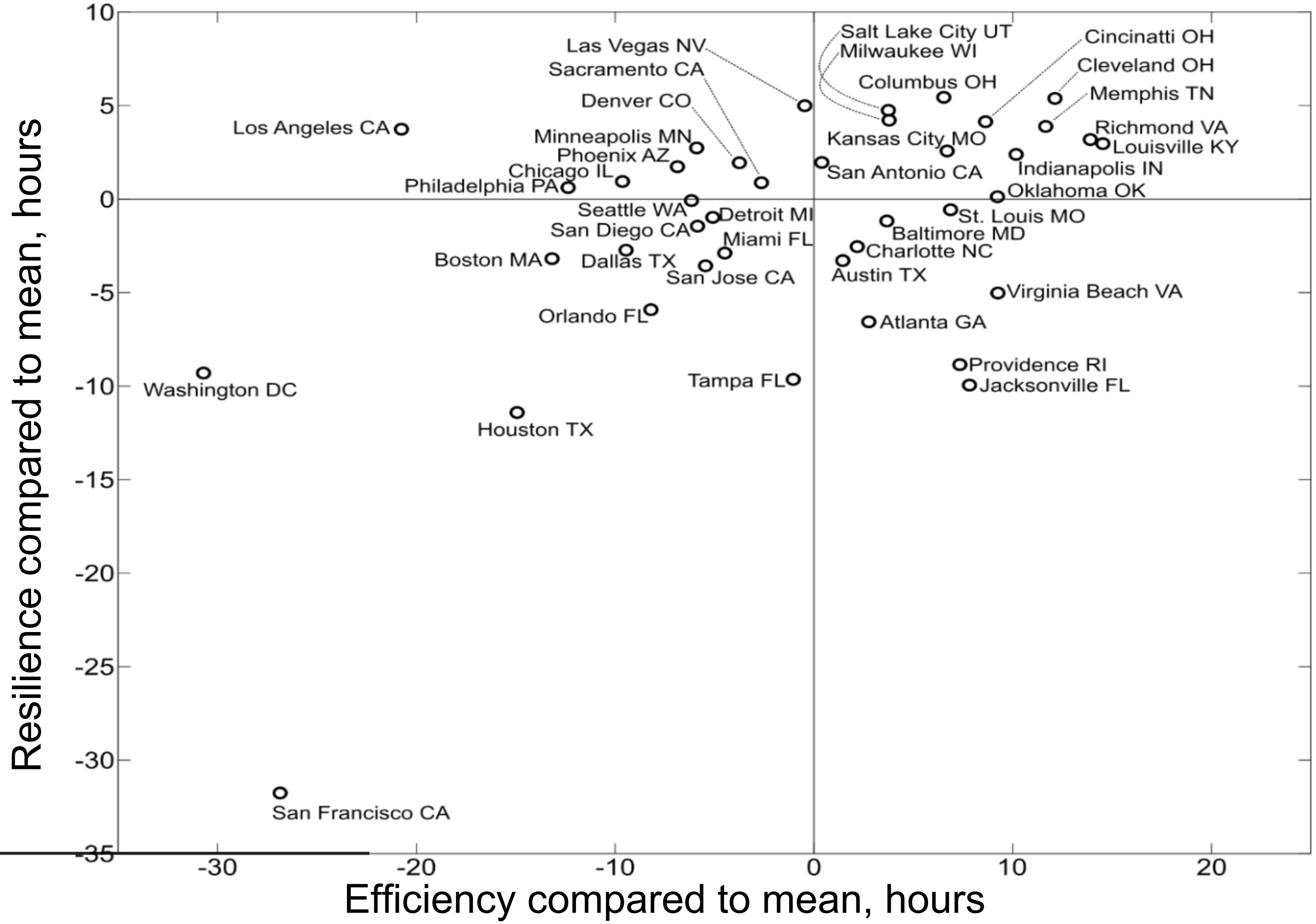
Contents lists available at ScienceDirect

Transportation Research Part D

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

Lack of resilience in transportation networks: Economic implications

Resilience vs Efficiency at 5% disruption



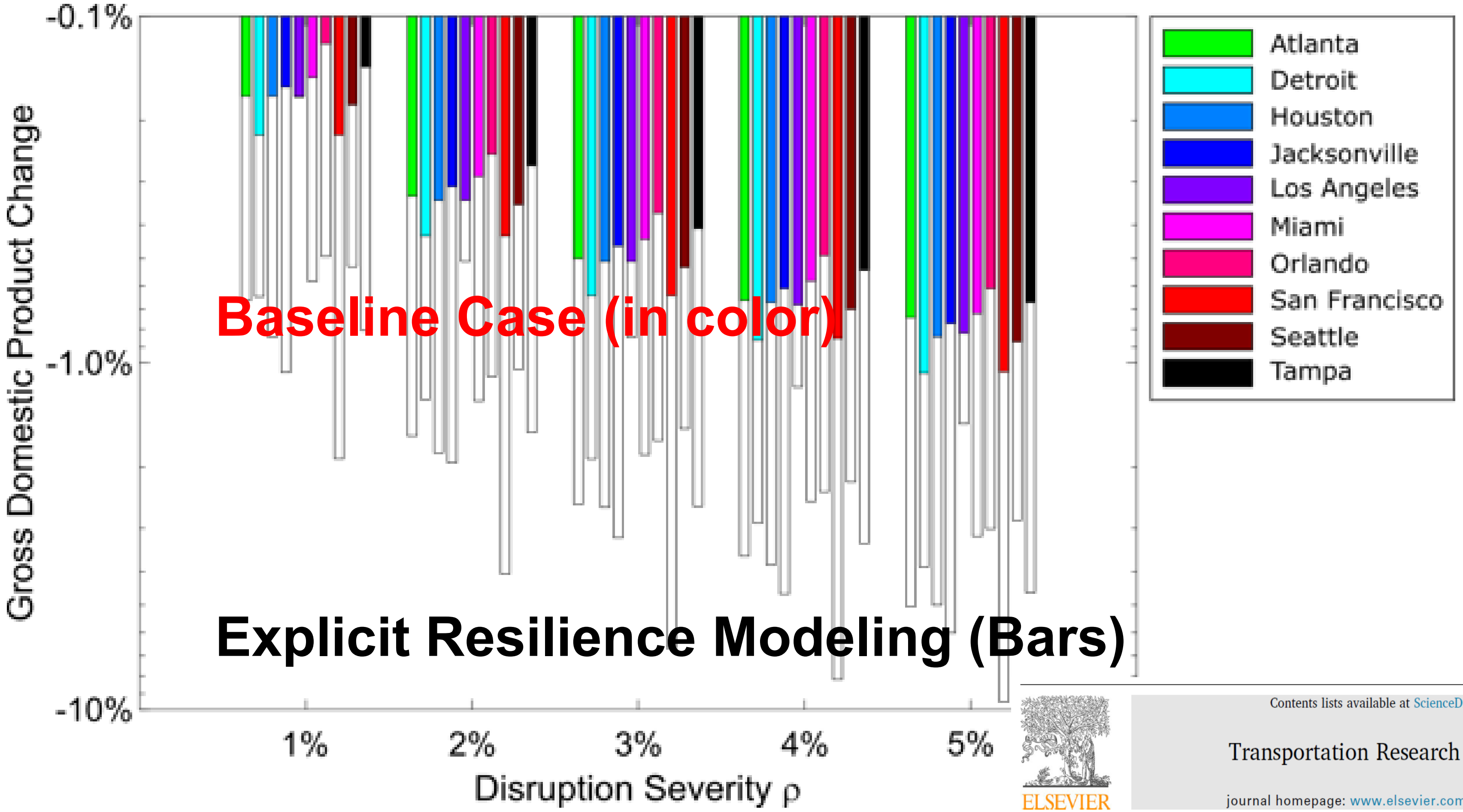
SCIENCE ADVANCES | RESEARCH ARTICLE

NETWORK SCIENCE 2017

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]*

Lack of Resilience: Impact on GDP



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Transportation Research Part D
journal homepage: www.elsevier.com/locate/trd

Lack of resilience in transportation networks: Economic implications

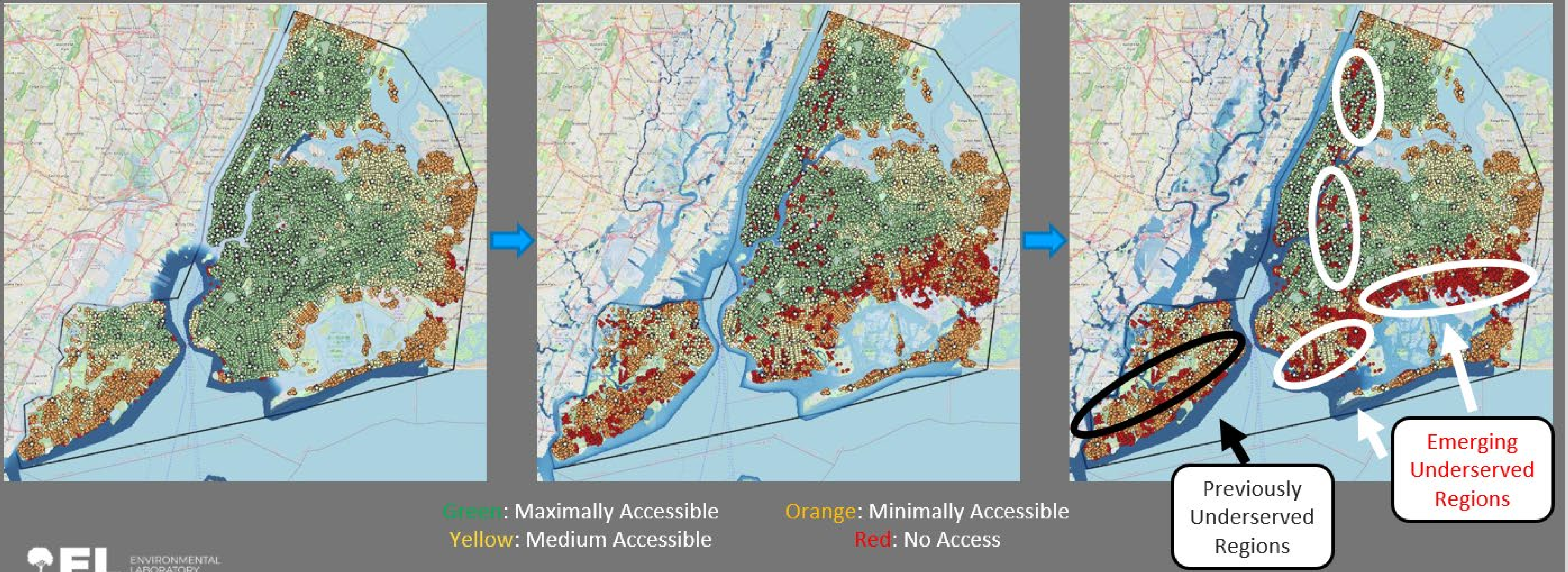
New York City Under Crisis: Which regions *lose* emergency services?

Transportation Research Interdisciplinary Perspectives
Volume 25, May 2024, 101111

Access to Emergency Services: A New York City Case Study

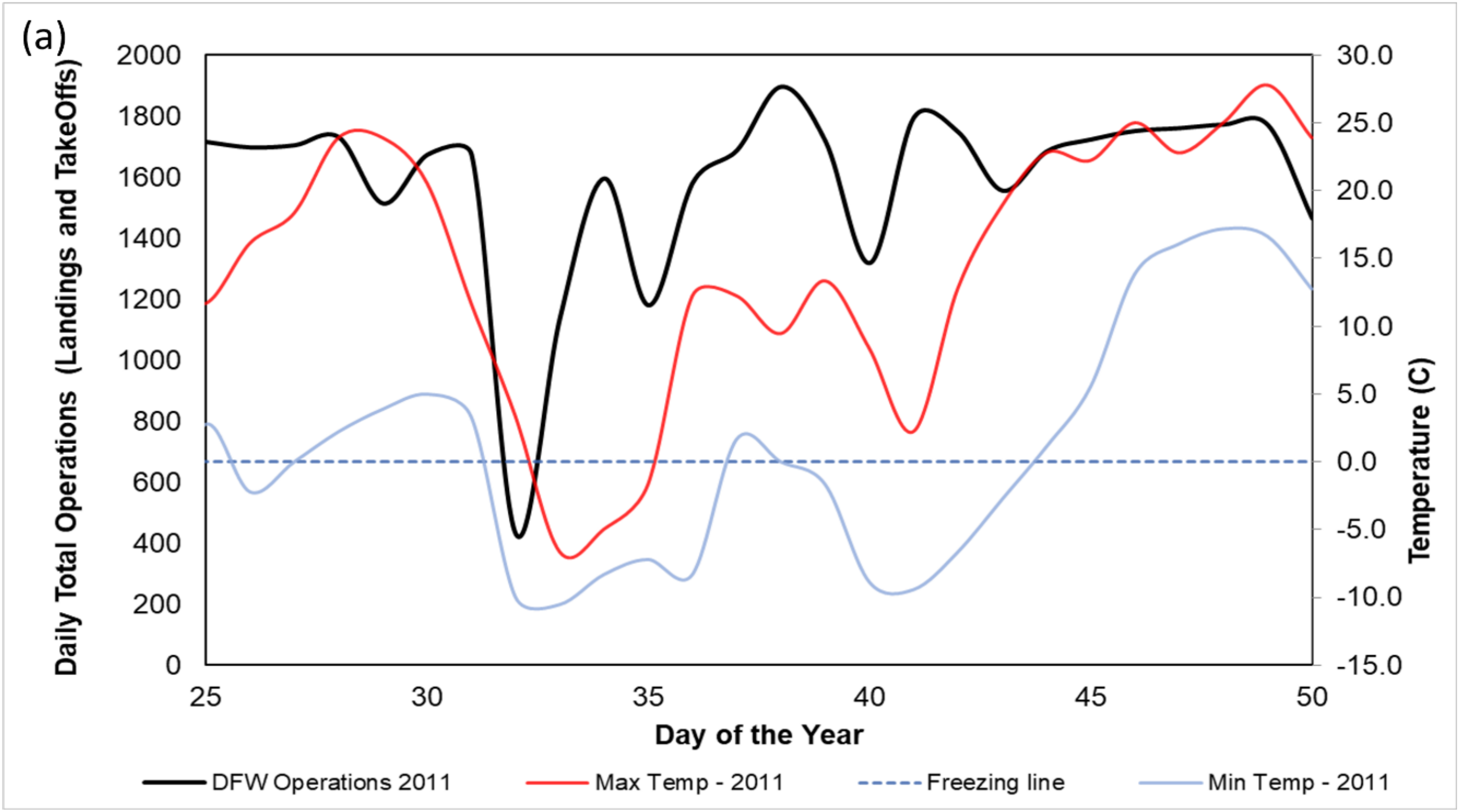
Sukhwan Chung [a], Madison Smith [a], Andrew Jin [a], Luke Hogewood [a], Maksim Kitsak [b], Jeffrey Cegan [a], Igor Linkov [a]

Beginning of the Flood | Intermediary Flood | Peak of the Flood



Green: Maximally Accessible
Yellow: Medium Accessible
Orange: Minimally Accessible
Red: No Access

Example 4: Asset Level - Freeze Events at Dallas Fort Worth (DFW) Airport in 2011



DFW Airport in 2011 and 2021

Example of Texas Polar Vortex:

- Electric demand shock
- Decreased capacity from lack of winterization and supply of natural gas
- Electric Reliability Council of TX forced to operate under emergency conditions until Feb. 19th, at which point 34,000 MW remained on forced outage
- How should proactive resilience corrective actions and network design be implemented?

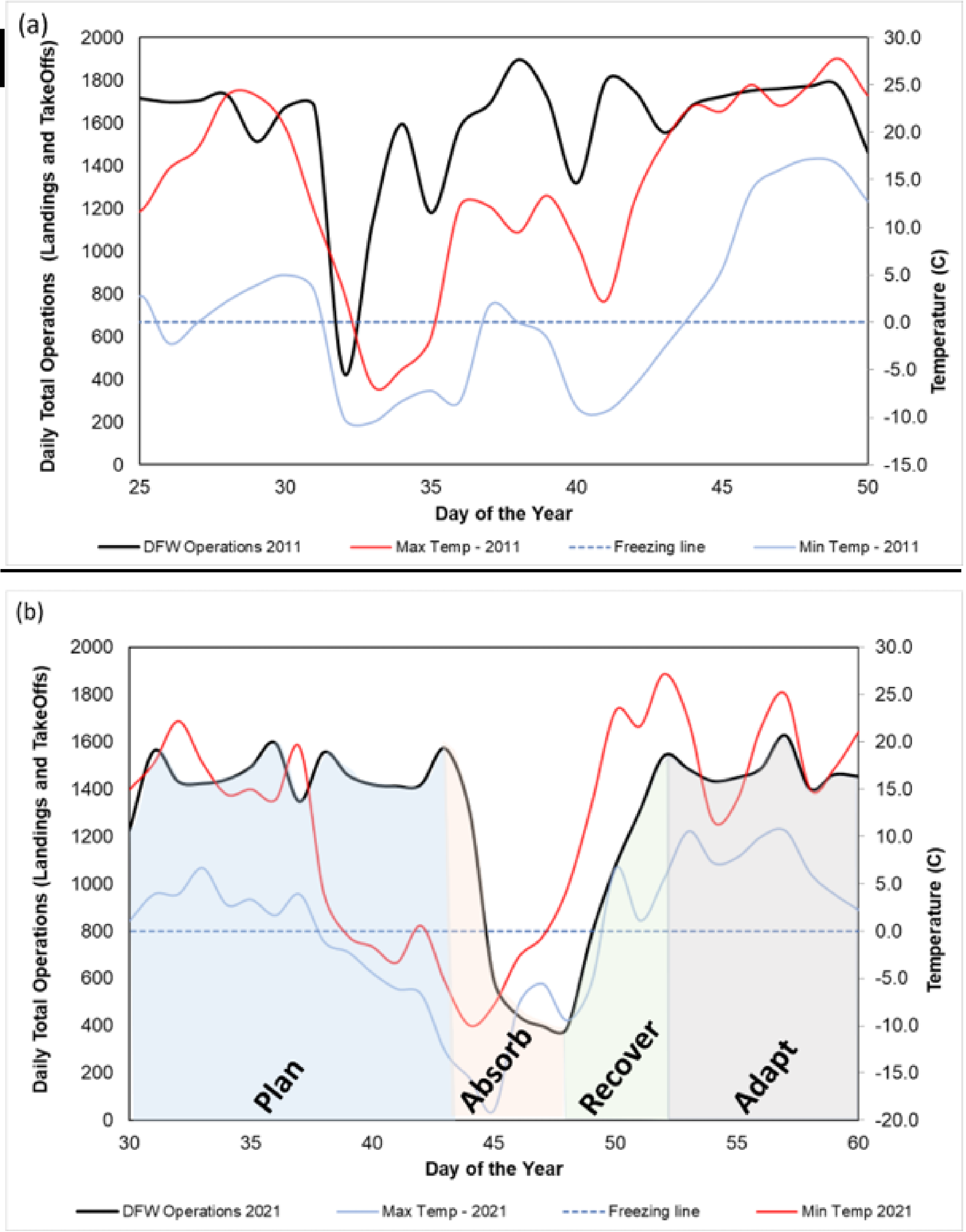
Received: 16 February 2022 | Accepted: 17 February 2022
DOI: 10.1111/1468-5973.12401

FORUM

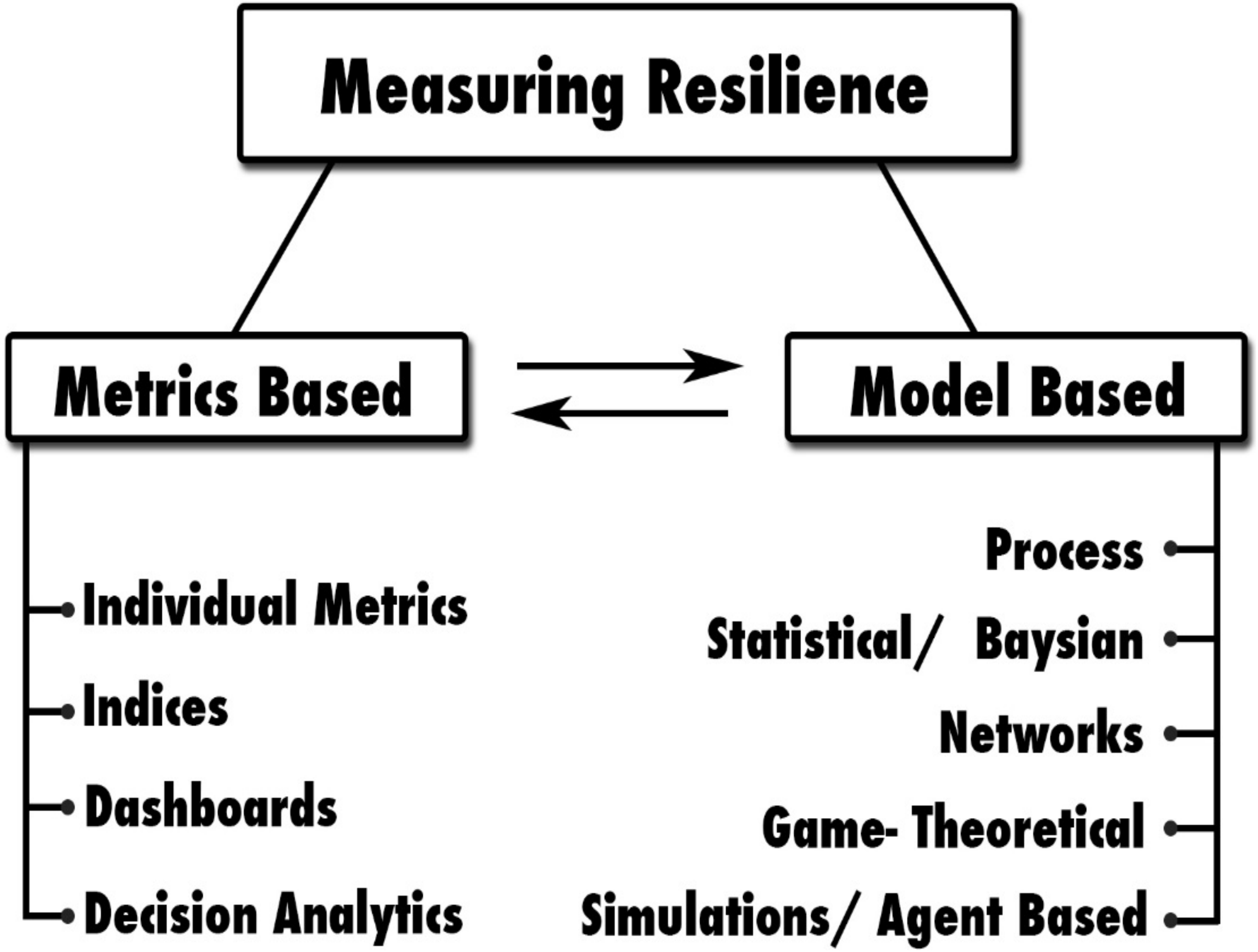
WILEY

International airports as agents of resilience

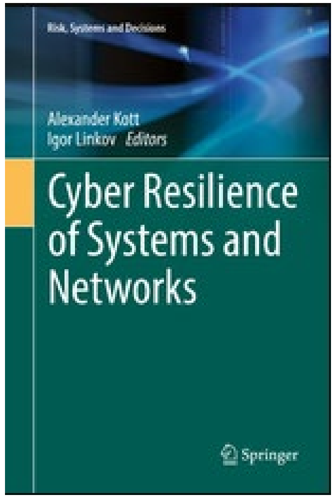
Robert Horton[1] | Gregory A. Kiker[2] | Benjamin D. Trump[3] | Igor Linkov[4]



How to Quantify Resilience?

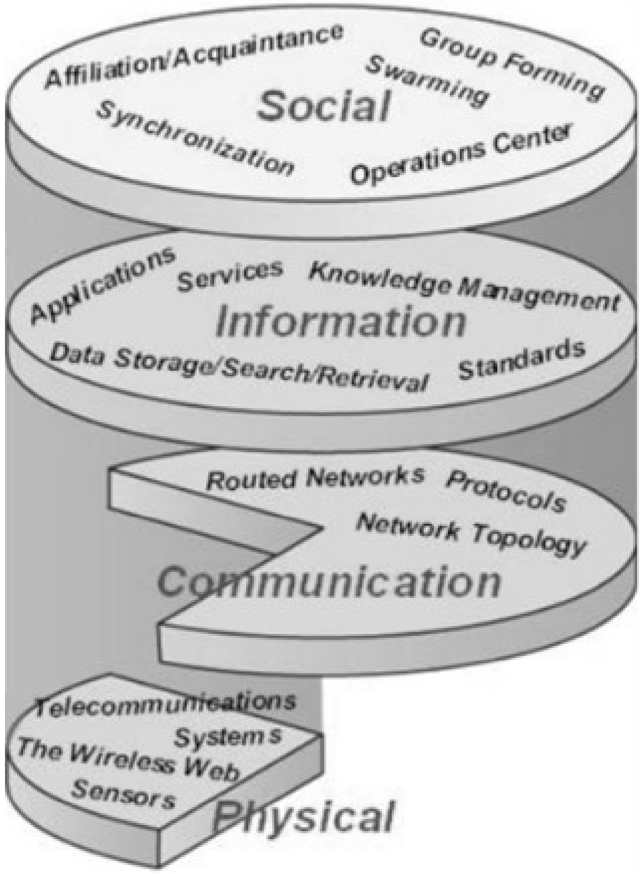


After 2019



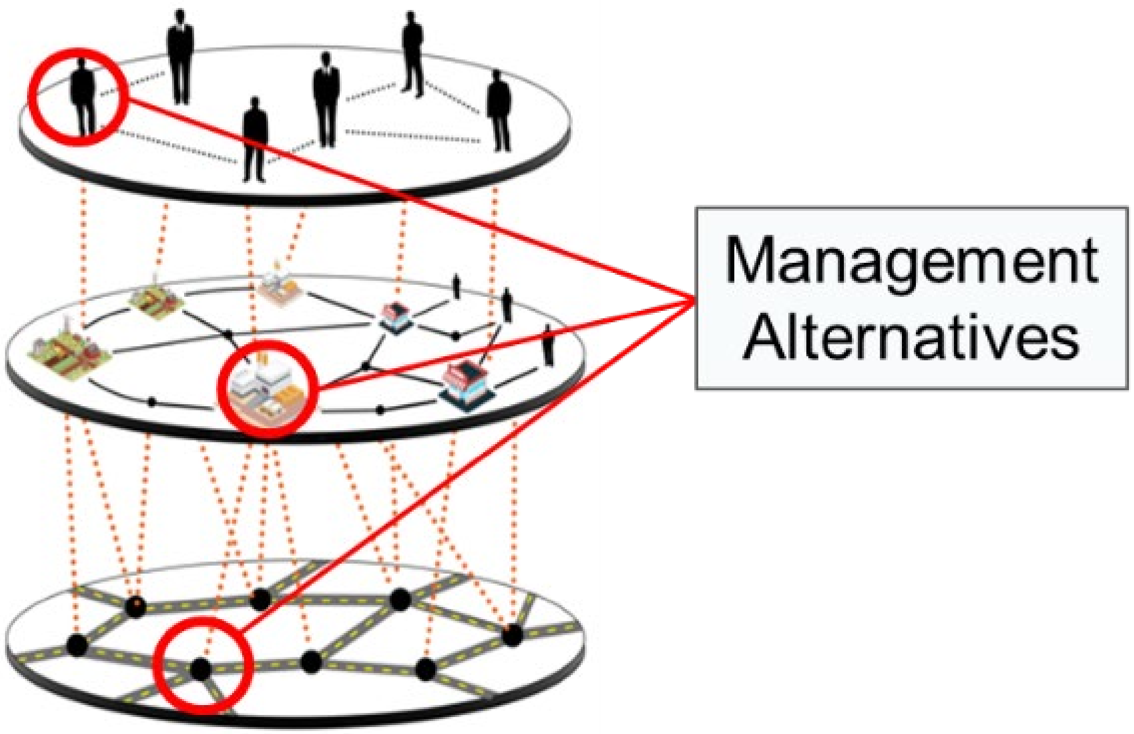
Vision for System Resilience

Real World



Model

Operations



The case for value chain resilience

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Management Research Review

2040-8269
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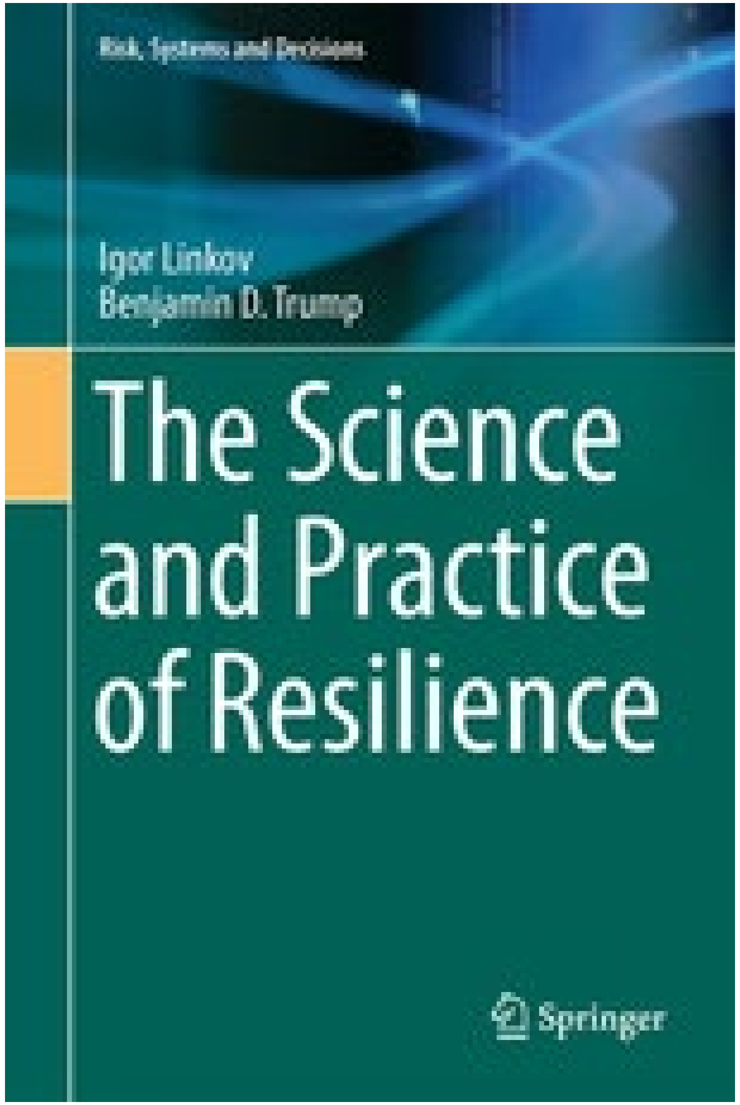
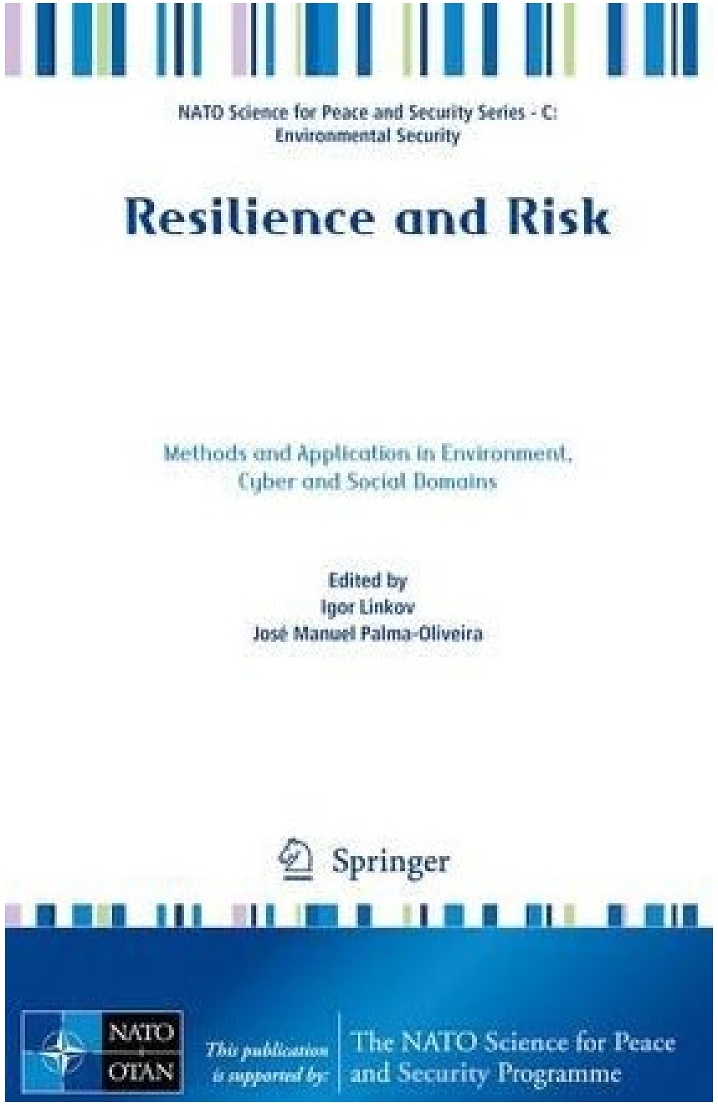

Risk, Systems and Decisions
Igor Linkov
Benjamin D. Trump
The Science and Practice of Resilience
Springer


NATO Science for Peace and Security Series - C: Environmental Security
Resilience and Risk
Methods and Application in Environment, Cyber and Social Domains
Edited by
Igor Linkov
José Manuel Palma-Oliveira
Springer
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This publication is supported by:
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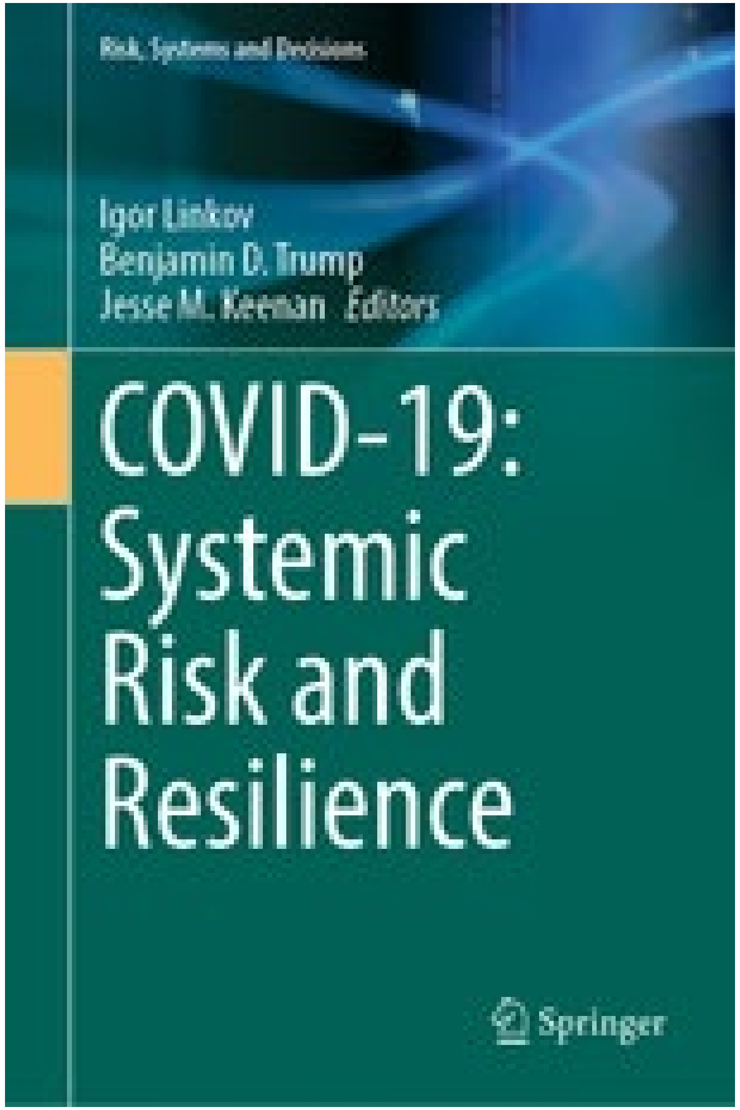
Risk, Systems and Decisions
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COVID-19: Systemic Risk and Resilience
Springer