Planning for Efficiency, Risk and Resilience in Supply Chains

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US Army Corps of Engineers;
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Honorary Professor, University of Southern Denmark

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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

Operations

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

Calls for Increased Resilience

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 infrastructures that underpin our national and economic security. America’s critical infrastructure is complex and diverse and includes 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 Resilience Month, we resolve to remain vigilant against foreign and domestic threats, and work together to fortify systems and networks.

The White House
Office of the Press Secretary

For Immediate Release

October 31, 2013

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

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
Further investment in risk/security will only yield marginal returns.

Governments and Industry must value and encourage resilience thinking.

Buying Down Risk vs Managing Resilience?

After Bostick et al 2018
Business Interruption and Supply Chain

Share of Business Interruption in Total Property Claims

Source: Zurich
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

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

Supply Chain Critical Functionality is a Product of Multiple Factors, Dependent on Context.
Trends in Supply Chain Resilience Research: Web of Science

![Graph showing the number of supply chain resilience papers published from 2007 to 2017. The number of papers increased significantly from 2014 onwards.]

![Graph showing the percentage of total supply chain papers that are focused on supply chain resilience. The percentage increased significantly from 2014 onwards.]
# Supply Chain Management: Just in Case (JIC) and Just In Time (JIT)

<table>
<thead>
<tr>
<th><strong>JIC</strong></th>
<th>Keep extra stock on hand in warehouses and facilitates to cover potential disruptions</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Have multiple possible suppliers with excess capacity and spare internal production capacity</td>
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<table>
<thead>
<tr>
<th><strong>JIT</strong></th>
<th>Better coordinatization deliveries and manufacturing to minimize stock on hand</th>
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<tbody>
<tr>
<td></td>
<td>Known to be used for early Model T production, but abandoned in favor of JIC</td>
</tr>
<tr>
<td></td>
<td>Developed in Japan in the 1960s</td>
</tr>
<tr>
<td></td>
<td>Migrated to America in the 1970s</td>
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</table>
Just in Case and Just in Time for Efficiency, Risk and Resilience

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

**JIT**
- Less Capital Held in Stock
- More Capital for Investment
- No Stock Buffer

Protection: Resilience and Risk
Efficiency
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?

<table>
<thead>
<tr>
<th>Paper</th>
<th>Plan</th>
<th>Absorb</th>
<th>Recover</th>
<th>Adapt</th>
<th>Data Source</th>
<th>Data Type</th>
<th>Resilience Metric</th>
<th>Supply Chain Model</th>
<th>Transportation Network Model</th>
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<td>Hasani and Khosrojerdi, 2016</td>
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</table>
Simulation is Complicated: Supply Chains are Multi-Level Networks
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

Supply Chain

Transportation
How to Quantify Supply Chain Resilience?

Measuring Resilience

Metrics Based
- Individual Metrics
- Indices
- Dashboards
- Decision Analytics

Model Based
- Process
- Statistical/ Bayesian Networks
- Game- Theoretical Simulations/ Agent Based

After Linkov and Kott, 2018
Presenting Qualitative Organization Characteristics

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

<table>
<thead>
<tr>
<th>System Domains</th>
<th>PREPARE</th>
<th>ABSORB</th>
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<td>Cognitive</td>
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<td>Social</td>
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Disruptive Event Stages
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

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**Project 1**

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**Project 2**

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<tr>
<td>Social</td>
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*Projects may have (+) or (-) in other matrices*
# Issues with Using Metrics-Based Approaches to Measure Resilience

<table>
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<tr>
<th>Lack of Causal Model</th>
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<tbody>
<tr>
<td>Changing environments and circumstances may change correlating factors</td>
</tr>
<tr>
<td>Changing business and management plans may change how previously causal factors interact</td>
</tr>
<tr>
<td>May not work in circumstances different than under those they were designed for</td>
</tr>
</tbody>
</table>
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 \((E)\)

\[ R = f(\mathcal{N}, \mathcal{L}, \mathcal{C}, E) \]

Ganin et al., 2016
Network-based Approaches

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

Physical domain

Information domain

Social and cognitive domains
Resilience: Transportation Network

Washington, DC January 20, 2016
1 inch of snow melted and turned into ice.
• 767 car accidents.
• Hours of traffic delays
• Traffic jams took days to disentangle!
Network Resilience: Introduction

- video
Resilience and efficiency in transportation networks

Alexander A. Ganin, Maksim Kitsak, Dayton Marchese, Jeffrey M. Keisler, Thomas Seager, Igor Linkov

40 US Cities with Different Traffic Delays
Transportation Networks in 40 Cities
Efficiency and Resilience don’t always correlate.

Ganin et al., 2017
Resilience compared to median resilience, hours

Efficiency compared to median efficiency, hours
Lack of Resilience: Financial Implications

Regional Economic Modeling (REMI)

**Input-Output**
Close analysis of inter-industry relationships

**Econometrics**
Advanced statistical analyses underpinning the model

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

**Economic Geography**
Effects of geographic concentration of labor and industry

**Integrated REMI economic modelling approach**
1 Month of 5% Network Disruption: Atlanta

- 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

- Predictable Delay (Low-efficiency)
- Unpredictable Delay (Lack of Resilience)
Aggregate Yearly Cost of Travel Delays

Inefficiency Cost (Millions of $)

Lack of Resilience Cost (Million of $)
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.

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

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

- Random x Random
- Random x Scale-free
- Scale-free x Scale-free

![Graph showing the relationship between Number of Disruptions and Stable Component Size (fraction of nodes)]
Connecting Several Networks: Cyber Resilience Domains
Cyber Attacks on Transportation

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, their sources and chain of ownership
- As it is distributed, falsifying or hiding chain of ownership is difficult
Blockchain with Distributed Ledger: Efficiency and Resilience

- **Efficient**
- **Not Efficient**
- **Resilient**
- **Not Resilient**

Centralized Ledger

Blockchain with Distributed Ledger
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.
Can You Be Smart and Resilient at the Same Time?

Dayton Marchese and Igor Linkov

Critical Functionality

System meeting critical functionality

Adaptation to improve functionality and resilience

Resilient

Smart
# Promoting a holistic approach to resilience

<table>
<thead>
<tr>
<th><strong>Physical Resilience</strong></th>
<th>e.g. the International Transport Forum who</th>
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<tbody>
<tr>
<td><strong>Economic and Financial Resilience</strong></td>
<td>resilience can be strengthened by implementing policies aimed at mitigating both the threats and consequences of severe crises (Economics Department)</td>
</tr>
<tr>
<td><strong>Environmental Resilience</strong></td>
<td>including resilience to climate change - minimising consequences, design for safe failure, proactive management and ideas around</td>
</tr>
<tr>
<td><strong>Social Resilience</strong></td>
<td>education, labour markets and social protection systems</td>
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</table>
Comparative Performance of Traffic Networks With No Disruption Vs. Traffic Networks After Disruption

Traffic Efficiency

Baseline Efficiency

Time

Difference in Normal Efficiency

Disruption

Recovery

Difference in Function Loss Due to Disruption

Jacksonville

Los Angeles
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?*

**Bottom-Up**
Risk Assessment/Physical Science

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

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

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

**Management**

**Modeling**

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
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,*
Additional slides
How Extensive are Current US Agency Resilience Plans?

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