



INFRASTRUCTURE, SAFETY,
AND ENVIRONMENT

Infrastructure and Supply Chain Resilience and Risk

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This Briefing Asks Three Questions Related to Resilience in the Supply Chain

- What is resilience?
- How do we characterize resilience?
- How can resilience be improved?

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- **What is resilience?**
- **Resilience is a property of the supply chain derived from its network characteristics**
- How do we characterize resilience?
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Many Define the Supply Chain As a Network of Contracts and Transactions

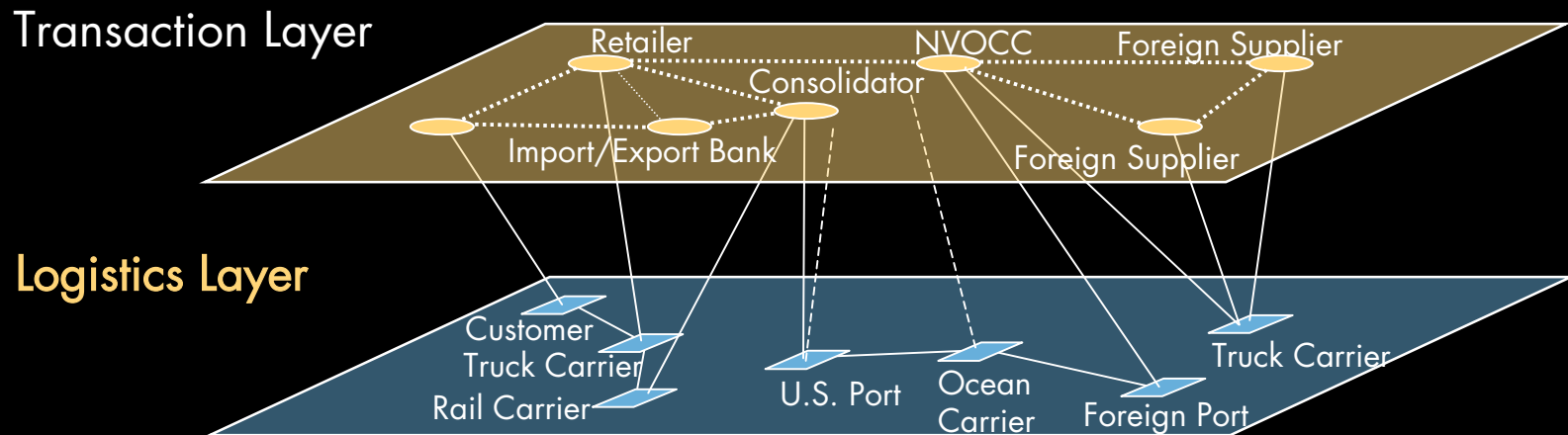
Transaction Layer



NVOCC Non-vessel Operating Common Carrier

Contractual Relationship

But the System Depends on a Logistics Layer to Transport Goods

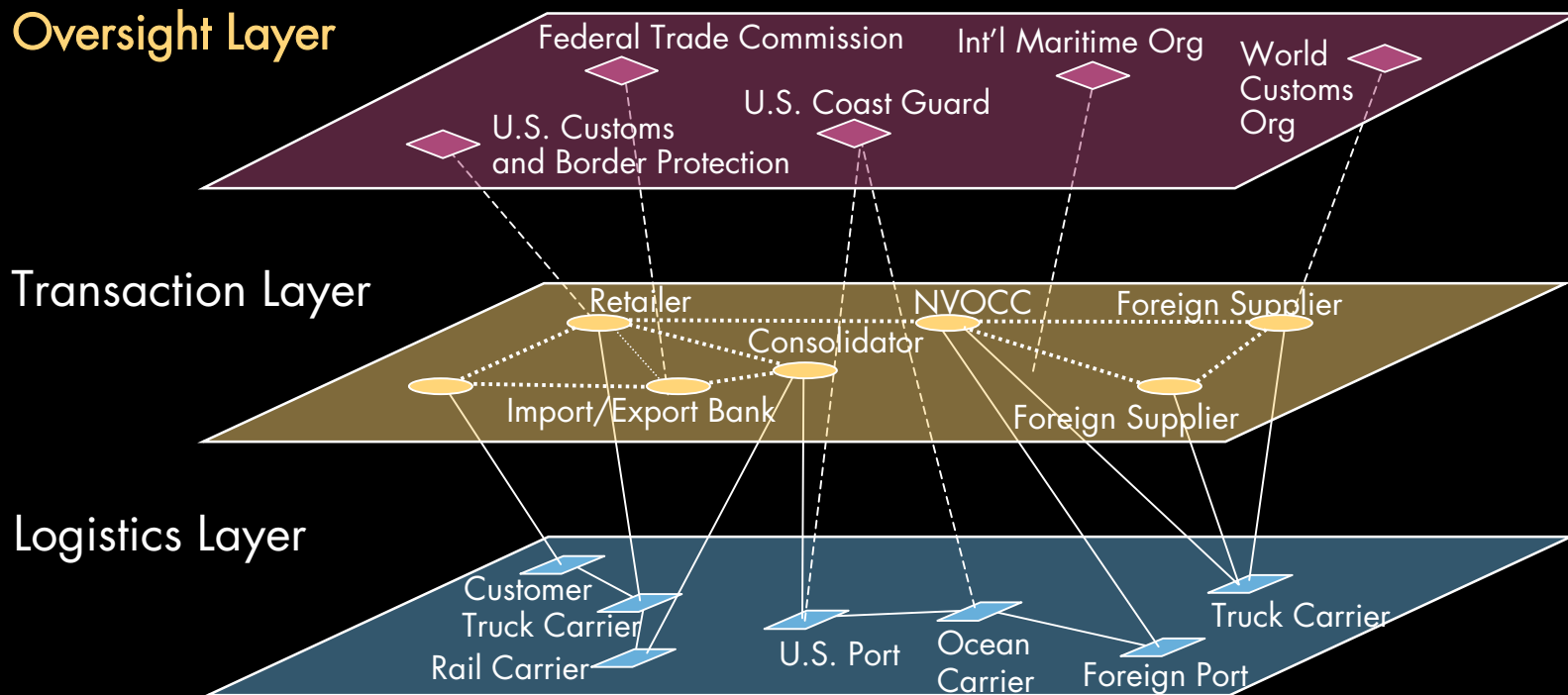


NVOCC Non-vessel Operating Common Carrier

Contractual Relationship
Physical Relationship

.....

An Oversight System Implements Rules of Behavior Within and Across Layers



NVOCC

Non-vessel Operating Common Carrier

Oversight or Regulatory Relationship

Contractual Relationship

Physical Relationship

.....

The Layered Supply Chain Has Five General Performance Characteristics

- Supply chain is designed to provide inexpensive transport
 1. Efficiency
 2. Shipment reliability
- Post-9/11 security requirements typically require increased knowledge of contents and location
 3. Shipment transparency
- Layered supply chain exhibits network properties for both public and private users and can be considered a public good
 4. Fault tolerance
 5. Resilience

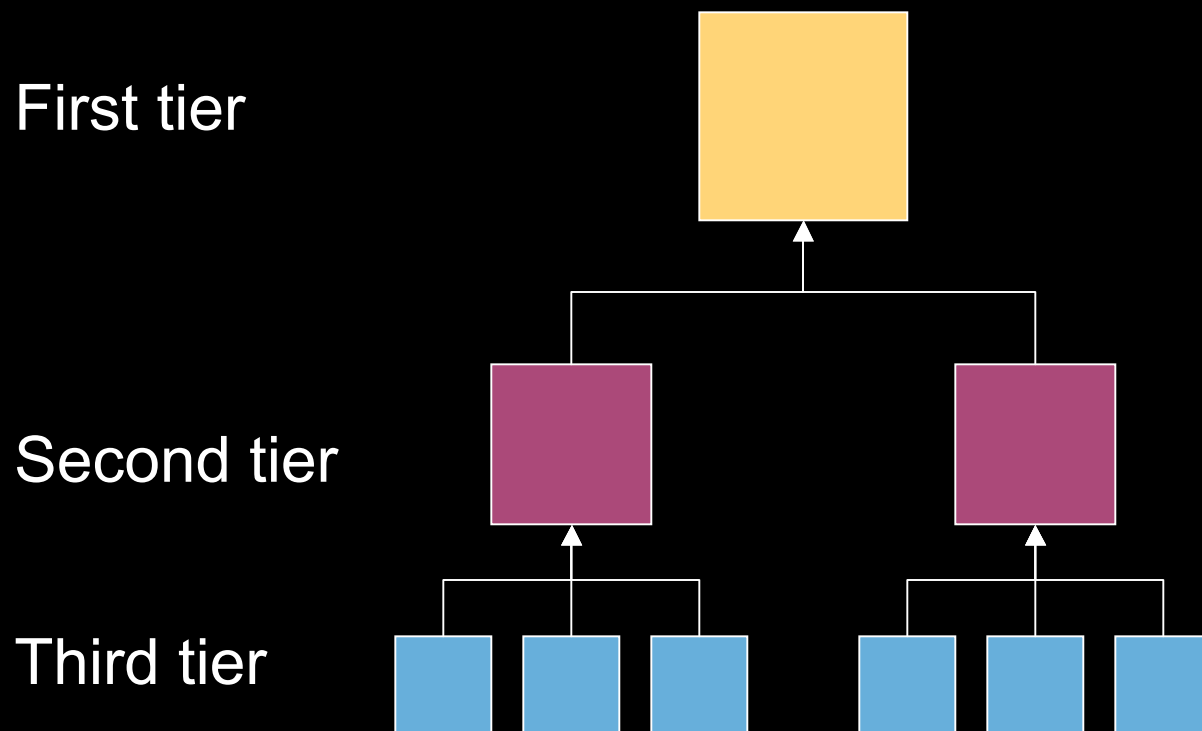
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Fault Tolerance and Resilience are Emergent Properties of the Supply Chain

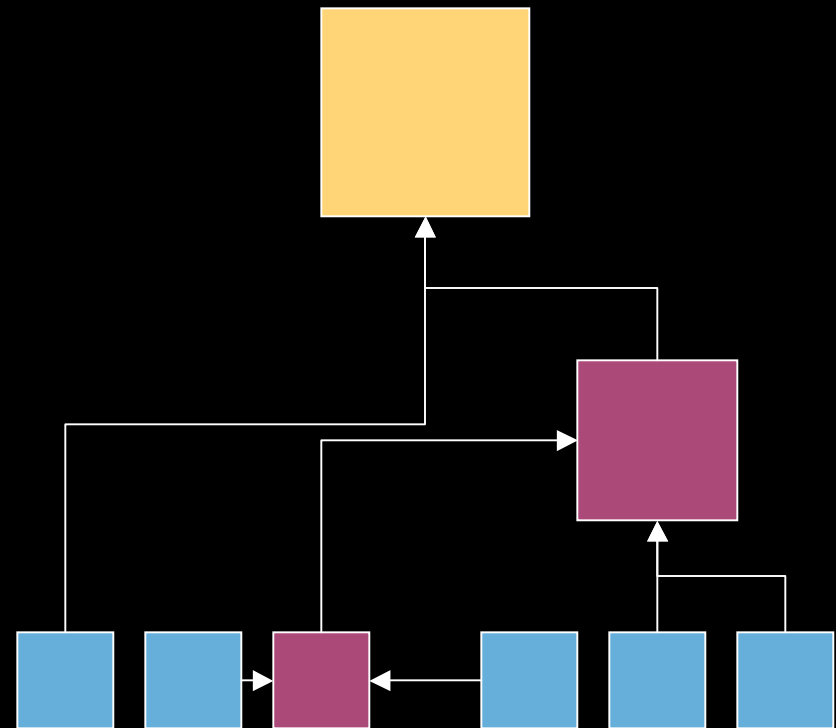
- Emergent properties come from a system as a whole and not an analysis of component parts
- Resilience in the supply chain is a result of the network properties of the Logistics and Transaction Layers
 - Connectedness
 - Redundancy
- The Oversight Layer may help to facilitate resilience
- Tools from social network analysis can help to identify critical nodes and give insight into vulnerabilities

A Typical Production Supply Chain is Hierarchical



Supply Chains Can Reorganize Hierarchy - Aisin Seiki Fire In Toyota Supply Chain

- Fire significantly damaged manufacturing capability of key brake component supplier
 - Immediate crisis due to 1-day inventory on hand
 - Toyota production shutdown
- Shifted production of key component to other suppliers, using resources from Toyota and its network
- Illustrates flexibility and ability to work outside of hierarchy



Traditional Network Analysis Assumes no Hierarchy of Nodes

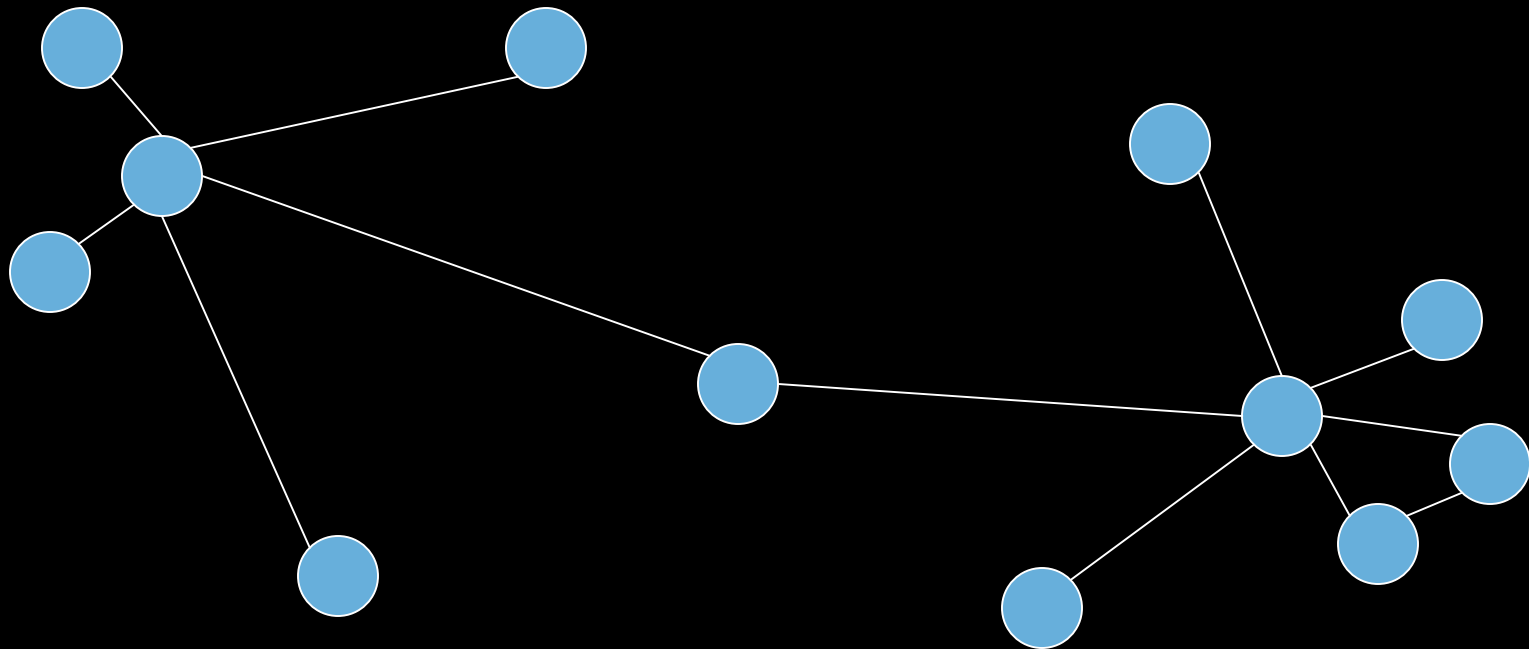
- Recent developments formalize the concept of “six degrees of separation” phenomenon
 - A person is a “node”
 - An relationship among two people is an “edge”
 - Most neighbors know each other’s neighbors and form “clusters”
 - Some people are “shortcuts” between clusters
 - The number of relationships connecting two arbitrary people is the “characteristic path length”
- Applied to many different networks
 - “Kevin Bacon Graph” of film actors
 - Western States Power Grid

Most Networks Grow Continuously

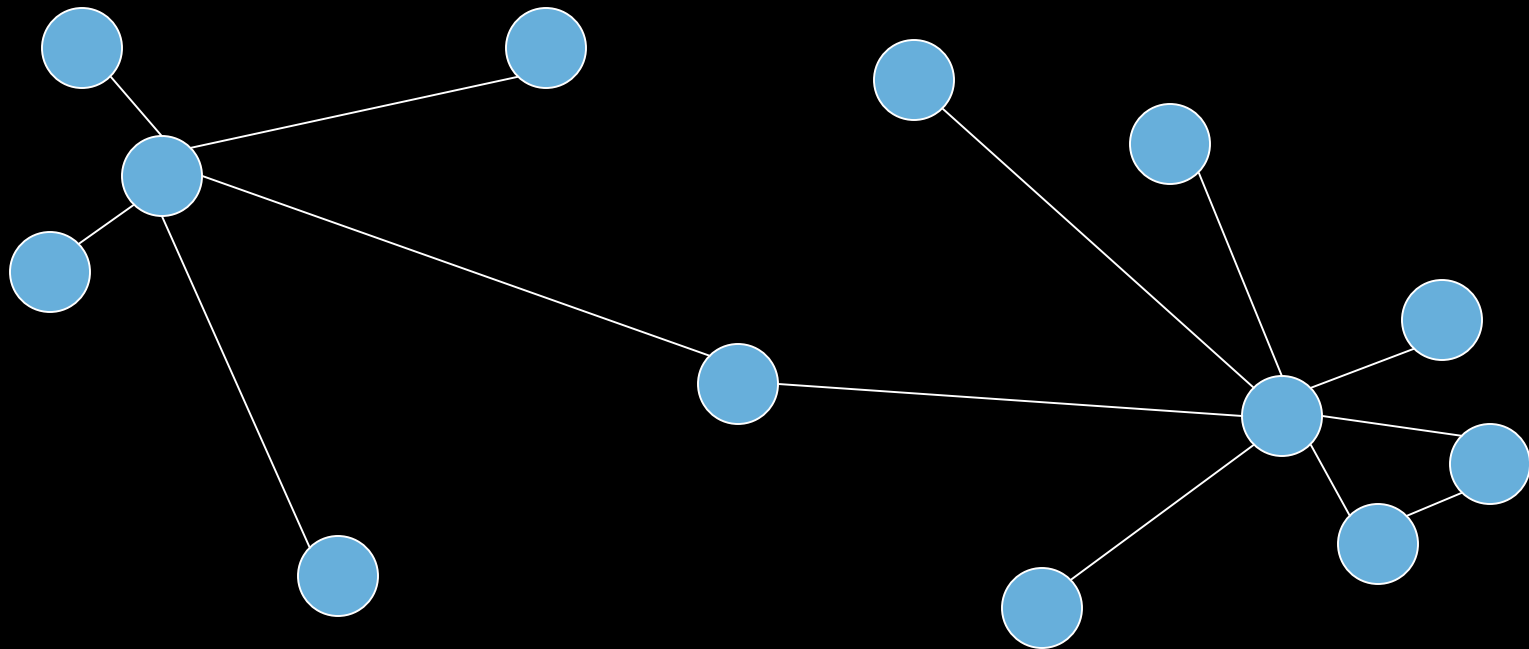
- **New nodes are created all of the time**
- **New nodes tend to attach to well connected nodes**
 - Natural phenomenon among people, businesses, etc.
 - Well connected nodes become better connected
 - Networks are typically “Small Worlds”
- **Actual networks tend to exhibit special characteristics**
 - Best connected nodes are hubs that make investments to support additional growth
 - Network is resilient to random disruptions - e.g. isolated storms
 - Network may become disconnected to targeted disruptions at the best connected nodes
- **Over time the network becomes “rigid”**
 - New nodes and edges reinforce the structure
 - Vulnerability increases

A Picture is Worth a Thousand Words

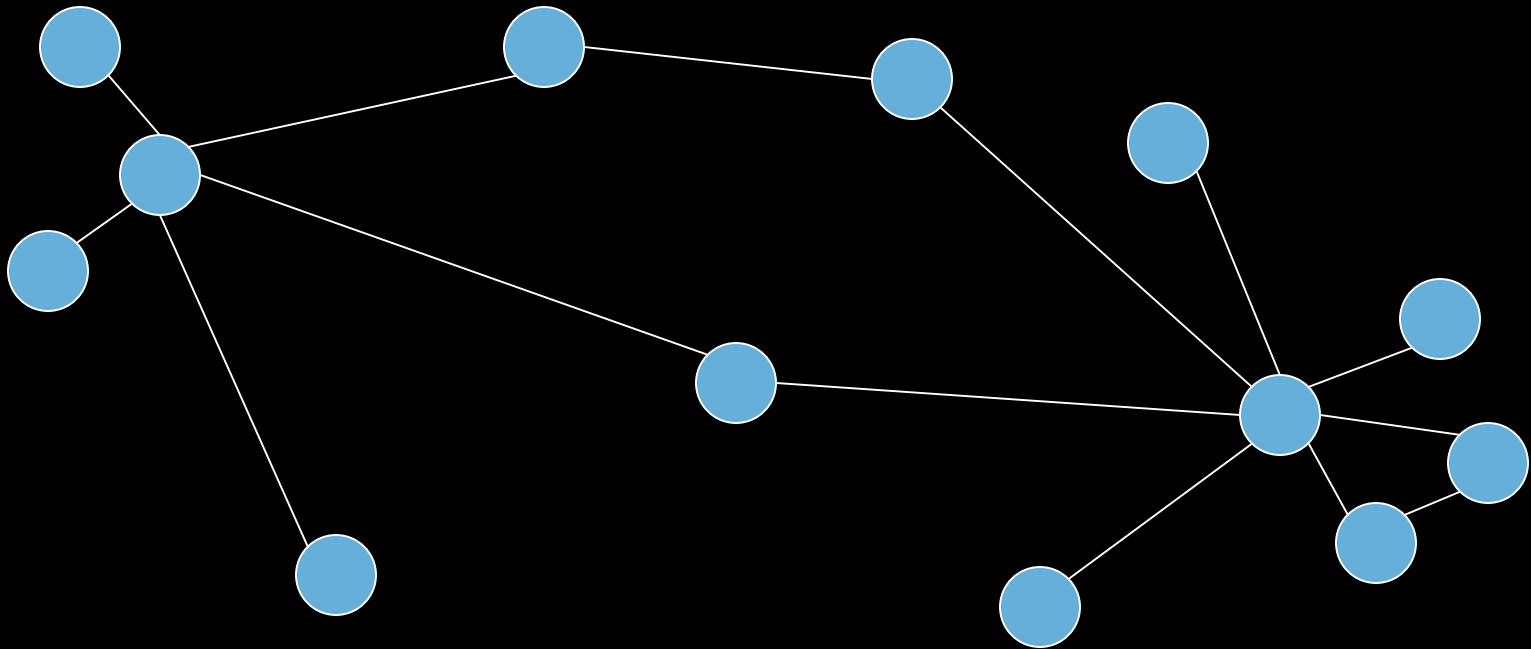
Start with a Connected Network With Two Clusters



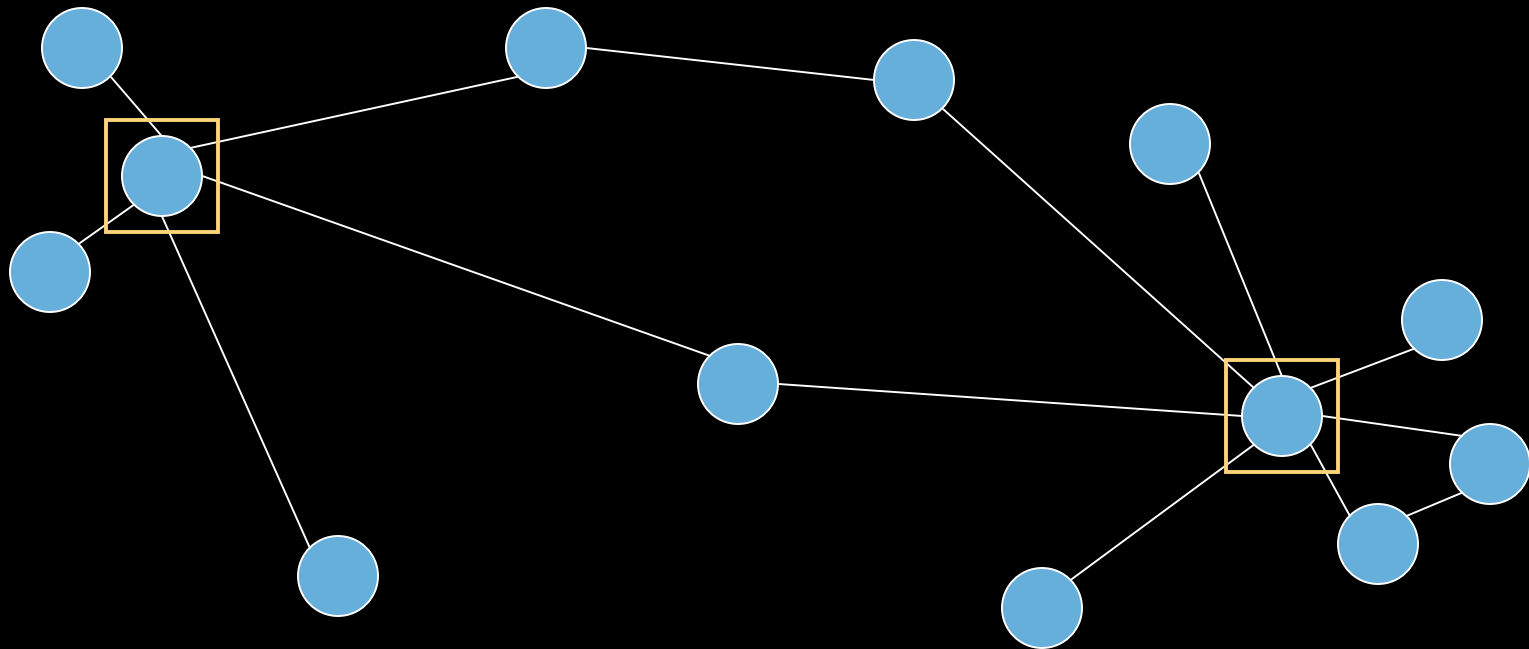
A New Node Will Tend to Connect to a Well Connected Node



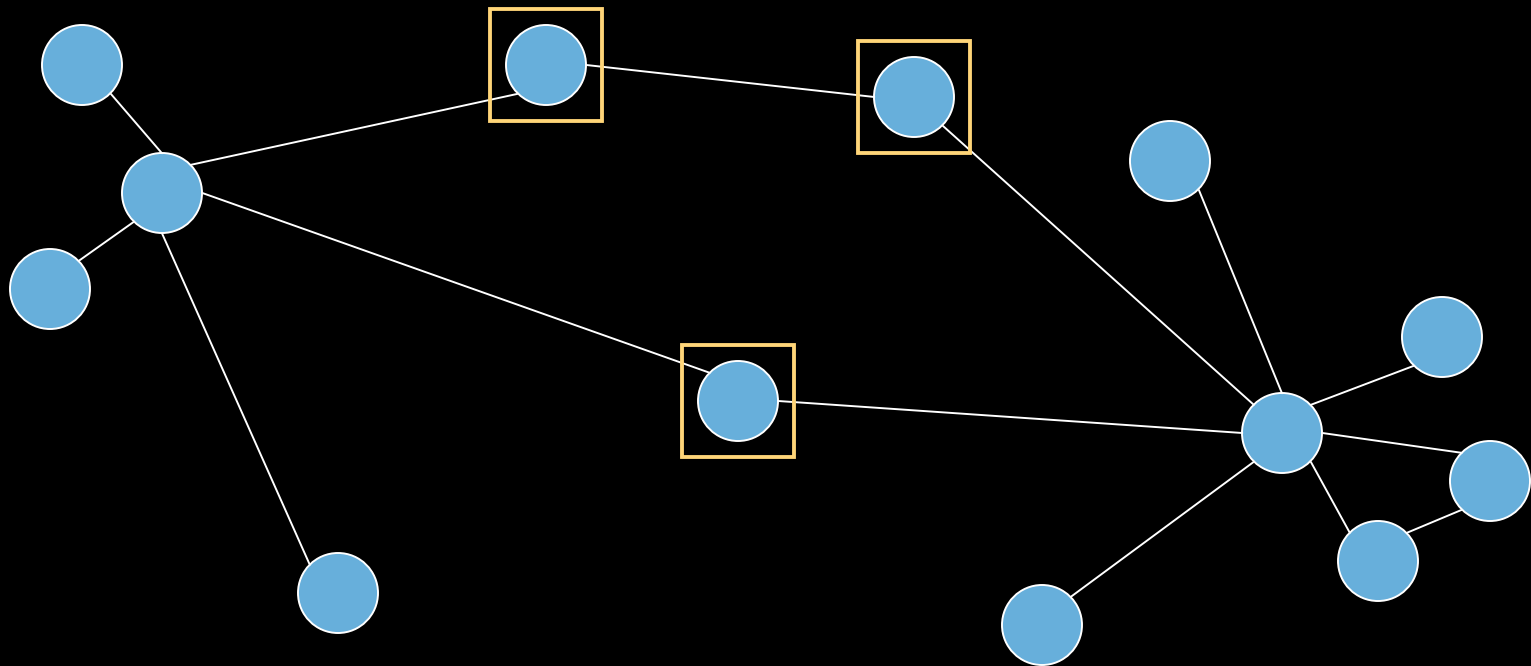
And May Choose to Connect to a Not-So-Well Connected Node



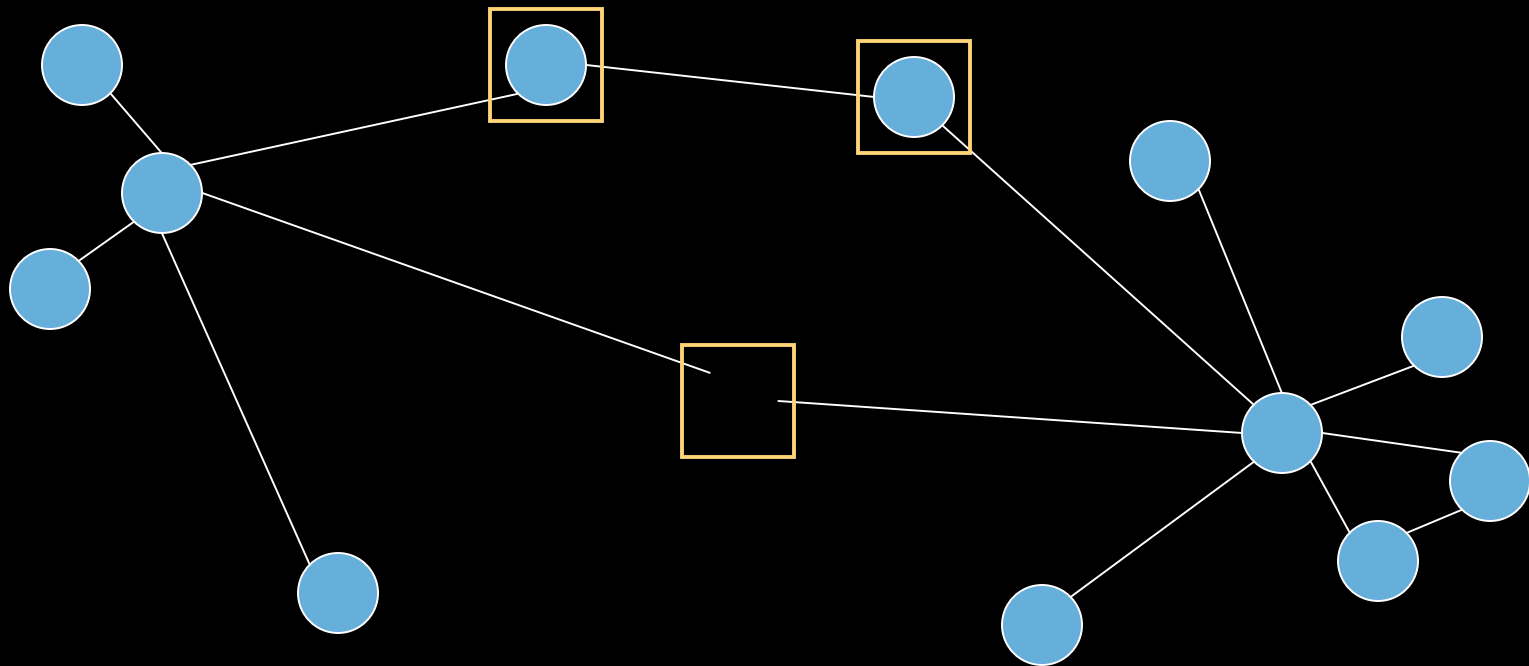
Well Connected Nodes are Obvious Vulnerabilities



Other Critical Nodes May Not Be So Obvious



Fault Tolerance and Resilience Require Nodes to be Able to Substitute for Each Other



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The Global Containerized Shipping System Has Such Vulnerabilities

- **Network characteristics**
 - **Nodes - 242 ports**
 - **Edges - 1783 services between ports**
 - **Characteristic path length - 4.6**
- **Network has megaports that serve as terminal hubs**
 - **Dominated by East Asian ports but include LA/LB**
 - **Most ports are small and have only a few services to regional megaports**
- **Three critical “bridge” ports keep the system connected**
 - **Rotterdam**
 - **Bremerhaven**
 - **Gioia Tauro**
- **Ports are poor substitutes for each other**

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- How do we characterize resilience?
- Through analysis of the supply chain and supporting infrastructure as a network
- How can resilience be improved?
- Through coordinated private and public sector action

There are Limits to the Ability of a Single Firm to Improve Fault Tolerance and Resilience

- **Firms may engage in contingency planning in the Transaction Layer**
 - Backup suppliers
 - Inventory of critical parts
 - Flexible production lines
- **Building resilience into the Logistics Layer is difficult**
 - Local issues often dominate decisionmaking
 - Attention goes to bottlenecks, not to “bridges”
 - Resilience thought to indicate excess capacity
- **Difficult for system to “rewire” after the loss of a key node**

Five Questions for Your Consideration

- **Can firms be motivated to invest in infrastructure that improve the global properties of the transportation system?**
- **As volumes of trade increase and the transportation system nears capacity is the system more sensitive to small disruptions?**
- **Are there operational or regulatory impediments to improving the ability of ports and routes to substitute for one another?**
- **Who bears the responsibility for funding changes to the system that improve resilience?**
- **What lessons can be learned from small disruptions regarding appropriate planning for large disruptions?**

The RAND Supply Chain Policy Center Addresses Critical Issues in Freight Transport

- **Members support independent and objective analysis to improve decisionmaking**
- **Many topics require attention**
 - **Addressing “intermodalism” in the context of transportation policy**
 - **Defining roles for the public and private sectors**
 - **Managing complex institutional settings**
 - **Labor unions**
 - **Rail deregulation**
 - **Protecting the environment**
 - **Ports of Los Angeles and Long Beach**
- **<http://www.rand.org/ise/centers/scpc/>**