Synergies and Vulnerabilities of Supply Chain Networks in a Global Economy

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Fogelman College of Business & Economics
2008 Distinguished Speaker Series
University of Memphis, October 31, 2008

Acknowledgements

Thanks go to Dean Rajiv Grover and the organizers of this Speaker Series.

Thanks to the Memphis Business Community

Outline

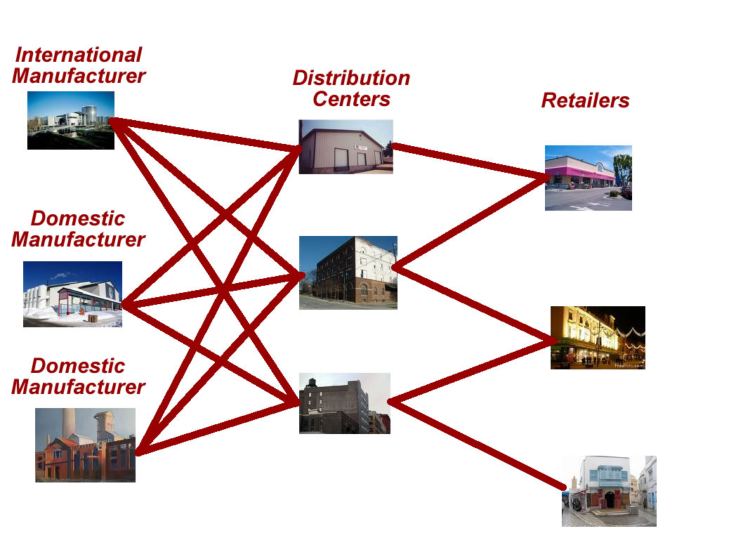
- Today's Supply Chain Networks
- Major Recent Supply Chain Disruptions
- Motivation for Our Research
- Network Vulnerabilities and Supply Chain Networks
- Mergers and Acquisitions and Supply Chain Network Synergies
- Summary and Conclusions

Today's Supply Chain Networks

Supply chain networks are the underpinning skeletons of the business world. These networks, more and more, are global in nature, with products consisting of parts manufactured in different regions of the world, assembled in yet other locations, and then shipped across continents and oceans to retailers and consumers.

Such complex networks consist of manufacturers (and their suppliers), shippers and carriers using various modes of transportation, distribution centers where the products are stored, and, ultimately, sent from to the customers.

Supply chains involve many decision-makers interacting with one another, sometimes competing, and at other times necessarily cooperating.



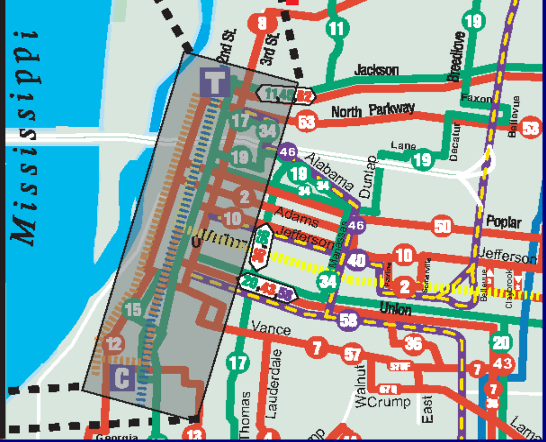
Depiction of a Supply Chain Network

Supply chain networks depend on infrastructure networks for their effective and efficient operations from: manufacturing and logistical networks, to transportation networks, to electric power networks, financial networks, and telecommunication networks, most, notably, the Internet.

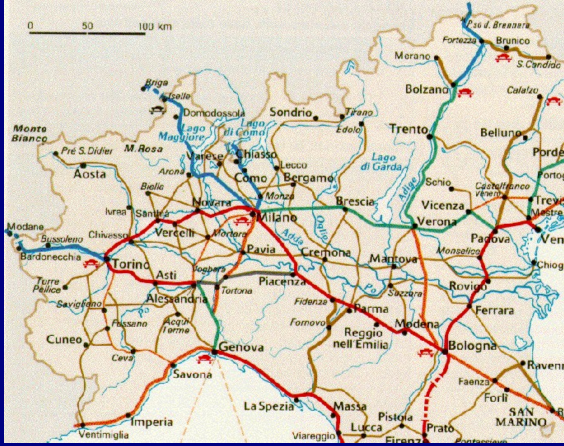
No supply chain, logistics system, or infrastructure system is immune to disruptions and as long as there have been supply chains there have been disruptions.

However, in the past decade there have been vivid high-profile examples of supply chain disruptions and their impacts. Supply chain disruptions and the associated risk are major topics now in theoretical and applied research, as well as in practice, since risk in the context of supply chains may be associated with the production/procurement processes, the transportation/shipment of the goods, and/or the demand markets.

Transportation, Communication, and Energy Networks

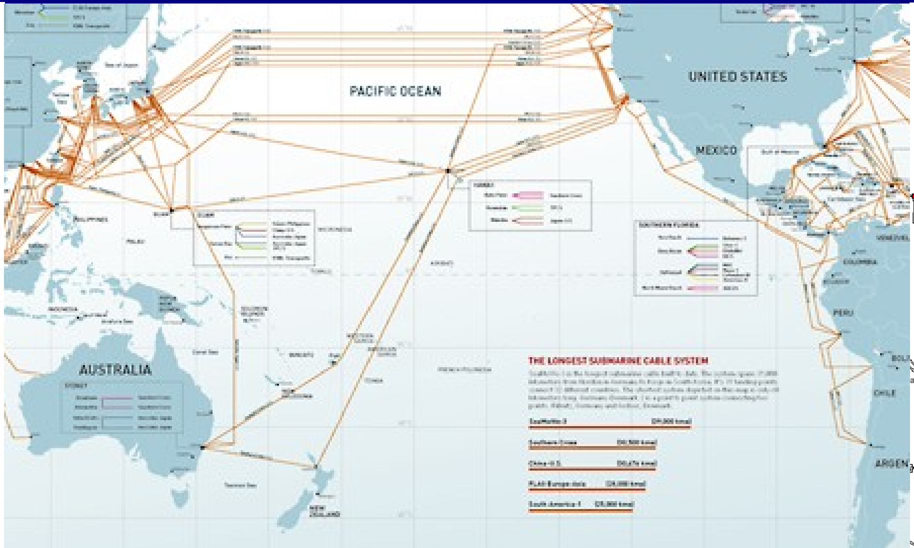


Bus Network

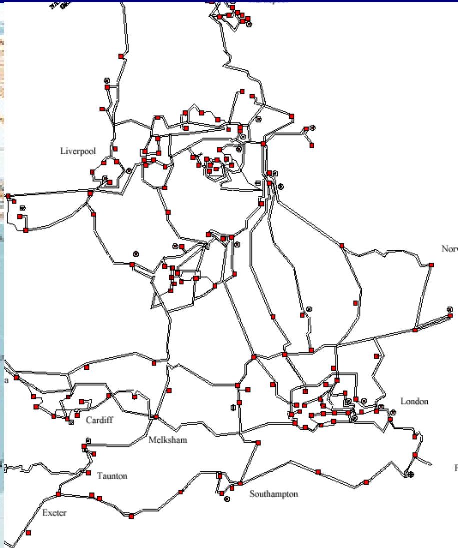


Rail Network

Iridium Satellite Constellation Network



Satellite and Undersea Cable Networks

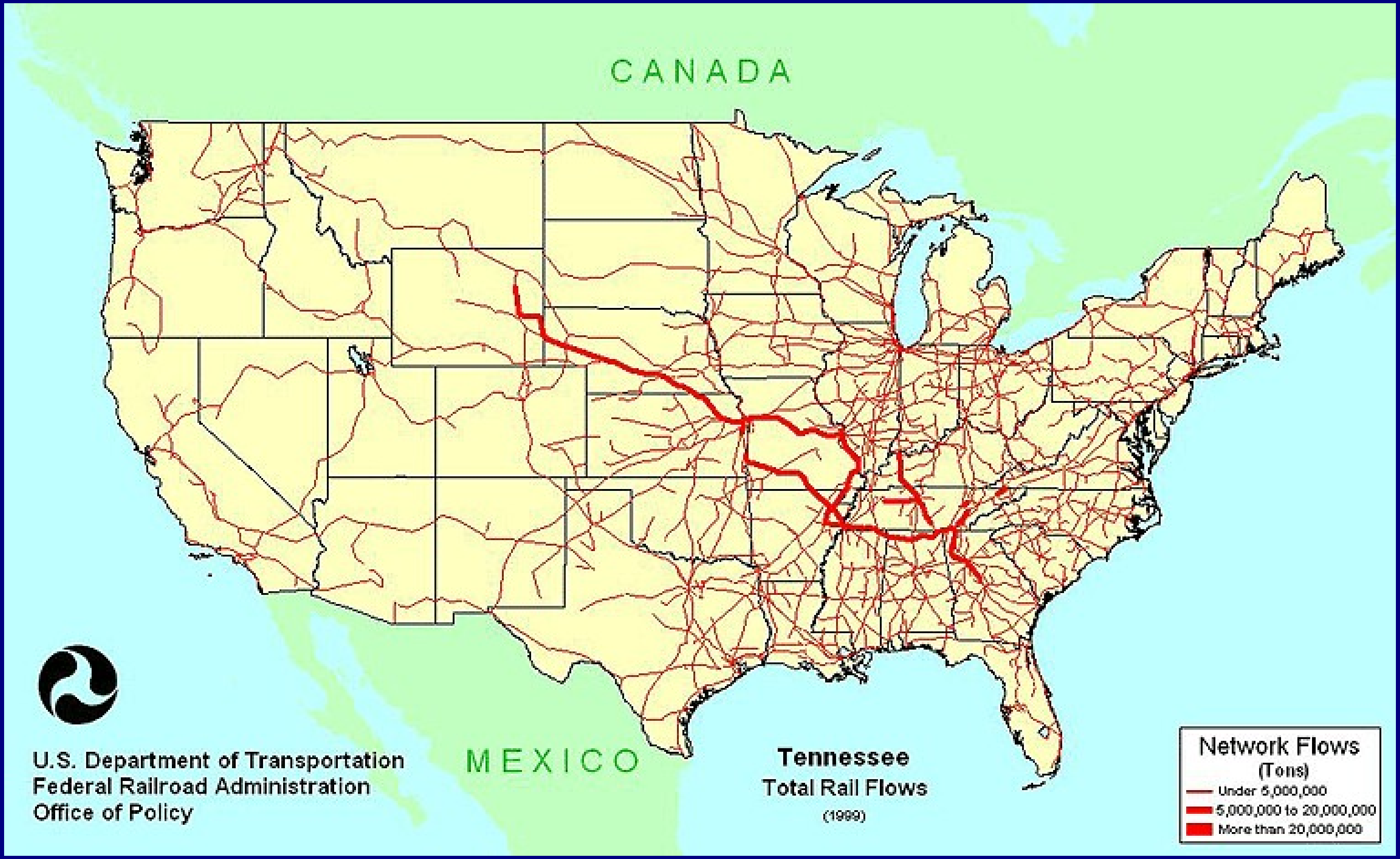


British Electricity Grid

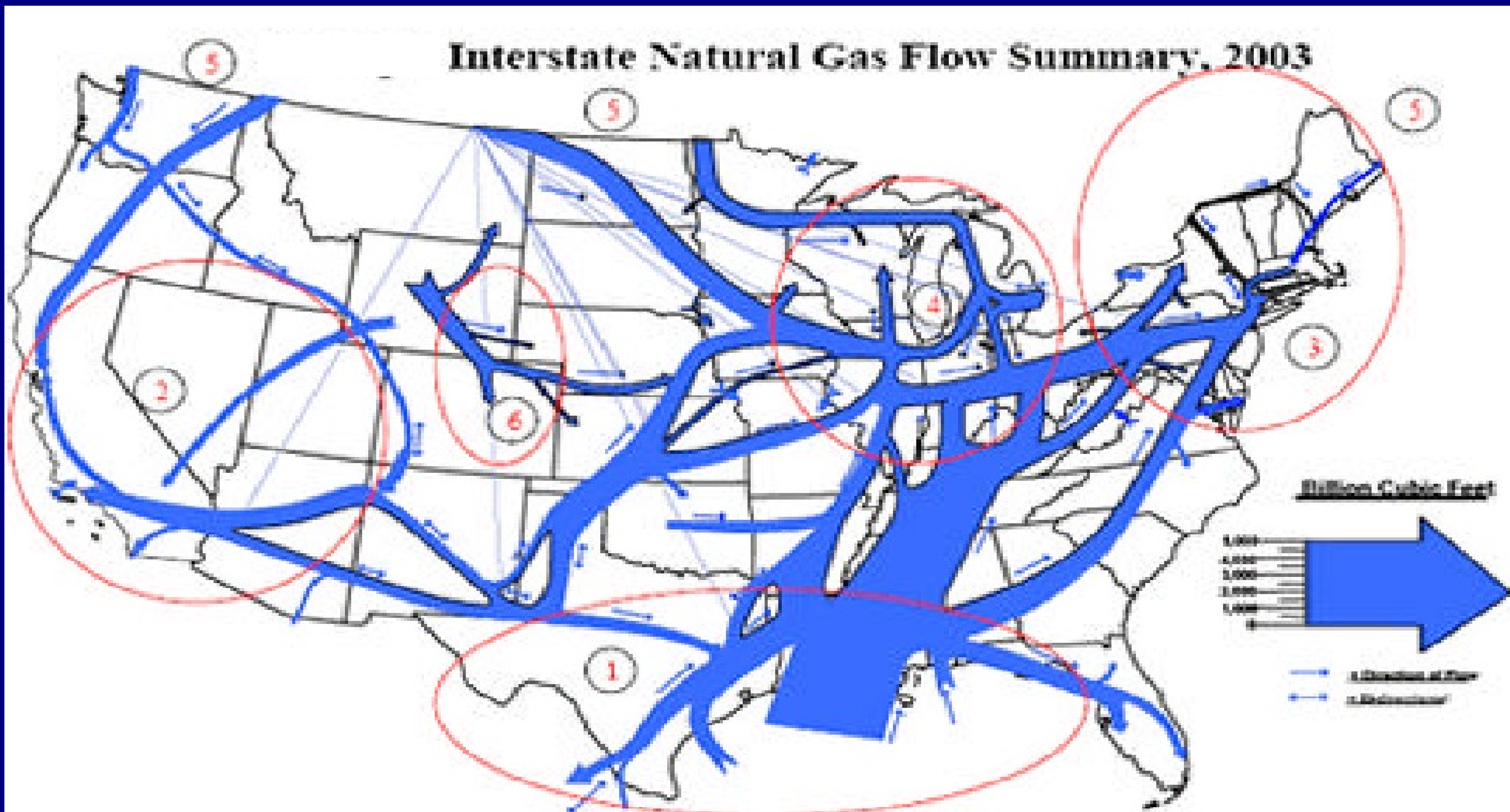
Components of Common Networks

Network System	Nodes	Links	Flows
Transportation	Intersections, Homes, Workplaces, Airports, Railyards	Roads, Airline Routes, Railroad Track	Automobiles, Trains, and Planes,
Manufacturing and logistics	Workstations, Distribution Points	Processing, Shipment	Components, Finished Goods
Communication	Computers, Satellites, Telephone Exchanges	Fiber Optic Cables Radio Links	Voice, Data, Video
Energy	Pumping Stations, Plants	Pipelines, Transmission Lines	Water, Gas, Oil, Electricity

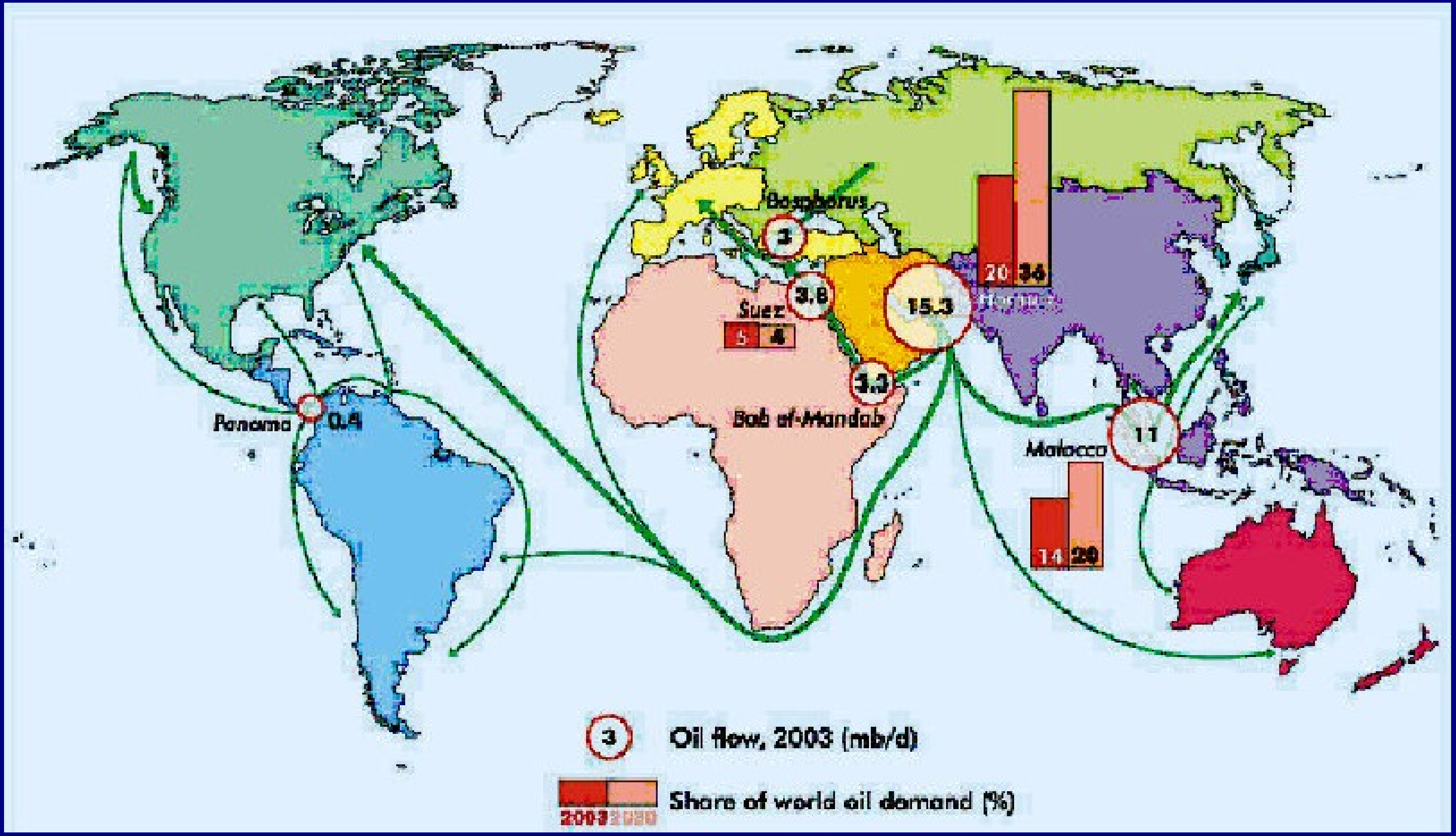
Tennessee Railroad Freight Flows



Natural Gas Pipeline Network in the US



World Oil Trading Network



Moreover, in recent decades, the focus has been on lean supply chains and, although such supply chains may work well when the environment is predictable and steady, they may be very sensitive to disruptions since they lack redundancy and slack in their systems.

Furthermore, firms today may be much less vertically integrated (and, clearly, more global). Decades ago, Ford Motor Company and other automobile manufacturers and even IBM produced their products, essentially in their entirety.

Lynn (2006) has argued that globalization has led to extremely fragile supply chains. Suppliers today may be in parts of the world that are unstable and subject to natural disasters, political instability, and strife.

In fact, Craighead, Blackhurst, Rungtusanatham, and Handfield (2007) have argued that supply chain disruptions and the associated operational and financial risks are the most pressing issue faced by firms in today's competitive global environment.

Notably, the focus of research has been on "demand-side" risk, which is related to fluctuations in the demand for products, as opposed to the "supply-side" risk, which deals with uncertain conditions that affect the production and transportation processes of the supply chain.

Major Recent Supply Chain Disruptions

Several recent major disruptions:

- In March 2000, a lightning bolt struck a Philips Semiconductor plant in Albuquerque, New Mexico, and created a 10-minute fire that resulted in the contamination of millions of computer chips and subsequent delaying of deliveries to its two largest customers: Finland's Nokia and Sweden's Ericsson.
- Ericsson used the Philips plant as its sole source and reported a $400 million loss because it did not receive the chip deliveries in a timely manner whereas Nokia moved quickly to tie up spare capacity at other Philips plants and refitted some of its phones so that it could use chips from other US suppliers and from Japanese suppliers.
- Nokia managed to arrange alternative supplies and, therefore, mitigated the impact of the disruption.
- Ericsson learned a painful lesson from this disaster.

Another Major Supply Chain Disruption

Another major disruption to supply chains:

- The West Coast port lockout in 2002, which resulted in a 10 day shutdown of ports in early October, typically, the busiest month. 42% of the US trade products and 52% of the imported apparel go through these ports, including Los Angeles. The Pacific Maritime Association (PMA) locked out members of the International Longshore and Warehouse Union (ILWU) forcing cargo ships to sit idly in ports from Seattle to San Diego and holding up the loading and unloading of potentially billions of dollars of cargo. Estimated losses were one billion dollars per day.
- Walmart and Costco planned months in advance and Walmart anticipated the lockout and had extra inventory shipped to Hawaii and Alaska.
- Port operations and schedules did not return to normal until 6 months after the strike ended!

Yet Other Major Supply Chain Disruptions

- The impact of Hurricane Katrina, which hit in 2005, with the consequence that 10% - 15% of total U.S. gasoline production was halted, not only raised the oil price in the U.S., but also overseas (see, e. g., Canadian Competition Bureau (2006)). More recently, we saw the impact of Hurricane Gustav where people in the Southeast experienced major gas shortages.

- The world price of coffee rose 22% after Hurricane Mitch struck the Central American republics of Nicaragua, Guatemala, and Honduras, which also affected supply chains worldwide (Fairtrade Foundation (2002)).

As summarized by Sheffi (2005), one of the main characteristics of disruptions in supply networks is "the seemingly unrelated consequences and vulnerabilities stemming from global connectivity."

Indeed, supply chain disruptions may have impacts that propagate not only locally but globally and, hence, a *holistic, system-wide approach* to supply chain network modeling and analysis is essential in order to be able to capture the complex interactions among decision-makers.

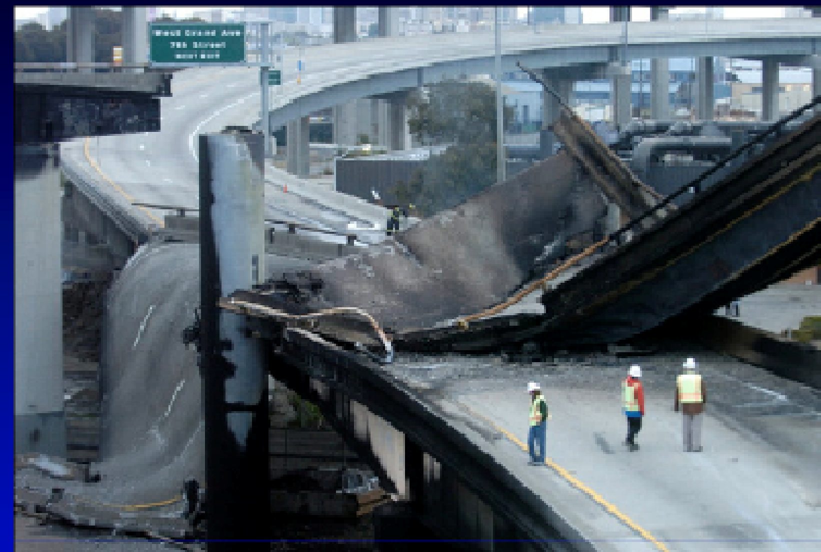
In addition, to demonstrate the dependence of supply chain networks on other infrastructure networks, including the Internet, we highlight the following:

According to Kembel (2000) the cost of downtime (in terms of lost revenue) for several online companies if their computers and/or telecomm networks are down (for one hour of downtime):

- Ebay: $225,000;
- Amazon.com: $180,000;
- Brokerage Company: $6,450,000.

(These costs do not include employee costs nor loss of goodwill.)

Disasters in Transportation Networks



www.salem-news.com

www.boston.com

Disasters in Electric Power Networks

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www.crh.noaa.gov

Disasters in Communication Networks

www.tx.mb21.co.uk

www.w5jgv.com

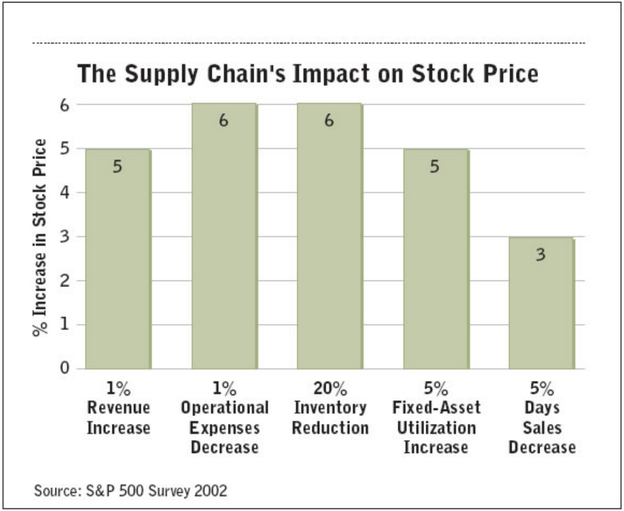
www.wirelessestimator.com

Motivation for Our Research

Hence, the rigorous modeling and analysis of supply chain networks, in the presence of possible disruptions is imperative since disruptions may have lasting major financial consequences.

Hendricks and Singhal (2005) analyzed 800 instances of supply chain disruptions experienced by firms whose stocks are publicly traded. They found that the companies that suffered supply chain disruptions experienced share price returns 33 percent to 40 percent lower than the industry and the general market benchmarks. Furthermore, share price volatility was 13.5 percent higher in these companies in the year following a disruption than in the prior year.

A company that experiences a supply chain disruption can expect to experience significant decreases in sales growth, stock return, and shareholder wealth for two years or more following the incident (Hendricks and Singhal (2003, 2005)). It is evident that only well-prepared companies can effectively cope with supply chain disruptions.



Supply Chain Management Review · March 2005

Wagner and Bode (2007), in turn, designed a survey to empirically study the responses from executives of firms in Germany regarding their opinions as to the factors that impact supply chain vulnerability. The authors found that demand-side risks are related to customer dependence while supply-side risks are associated with supplier dependence, single sourcing, and global sourcing.

Motivation for Our Research

The goal of supply chain risk management is to alleviate the consequences of disruptions and risks or, simply put, to increase the *robustness* of a supply chain. However, there are very few quantitative models for measuring supply chain robustness.

Snyder and Daskin (2005) examined supply chain disruptions in the context of facility location. The objective of their model was to select locations for warehouses and other facilities that minimize the transportation costs to customers and, at the same time, account for possible closures of facilities that would result in re-routing of the product. However, as commented in Snyder and Shen (2006), "Although these are multi-location models, they focus primarily on the local effects of disruptions."

To-date, most supply disruption studies have focused on a local point of view, in the form of a single-supplier problem (see, e. g., Gupta (1996) and Parlar (1997)) or a two-supplier problem (see, e. g., Parlar and Perry (1996)).

Very few studies/papers have examined supply chain risk management in an environment with multiple decision-makers and in the case of uncertain demands (cf. Tomlin (2006)).

We believe that it is imperative to study supply chain modeling and risk management from a holistic point of view and to capture the interactions among the multiple decision-makers in the various supply chain network tiers.

More companies are now using strategies to ensure quick recovery and business continuity following disruptions (Walmart, IBM, etc.)

Of course, in order to study supply chain robustness, an informative and effective performance measure is first required. Beamon (1998, 1999) reviewed the supply chain literature and suggested directions for research on supply chain performance measures, which should include criteria on efficient resource allocation, output maximization, and flexible adaptation to the environmental changes (see also, Lee and Whang (1999), Lambert and Pohlen (2001), and Lai, Ngai, and Cheng (2002)).

We emphasize that different supply performance measures can be devised based on the specific nature of the problem. In any event, the discussion here is not meant to cover all the existing supply chain performance measures. Indeed, we are well aware that it is a daunting task to propose a supply chain performance measure that covers all aspects of supply chains.

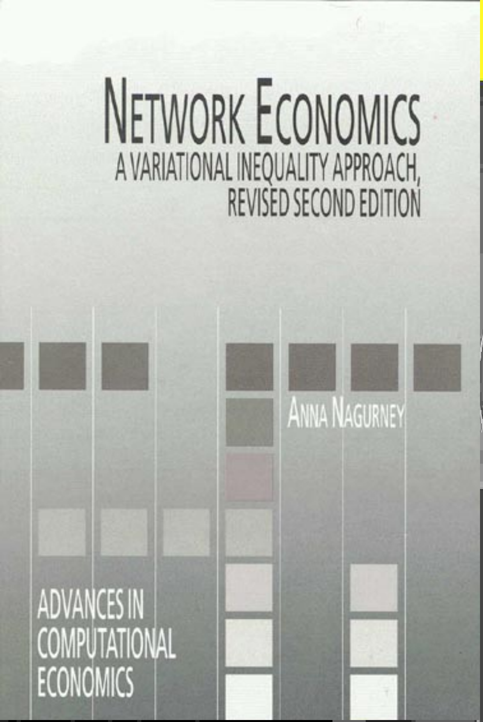
Characteristics of Networks Today Including Supply Chains

- *Large-scale nature* and complexity of network topology;

- *Congestion*; in the US we are experiencing a freight capacity crisis;

- the *interactions among networks* themselves such as in transportation versus telecommunications;

- *Dynamics* and global reach; increasing risk and uncertainty.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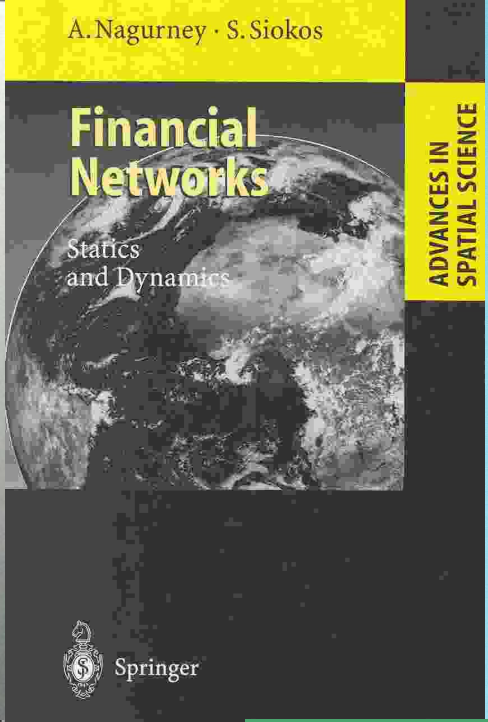
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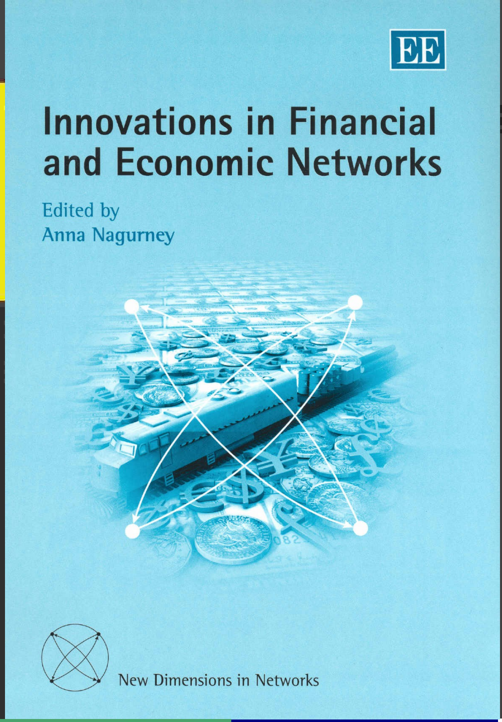
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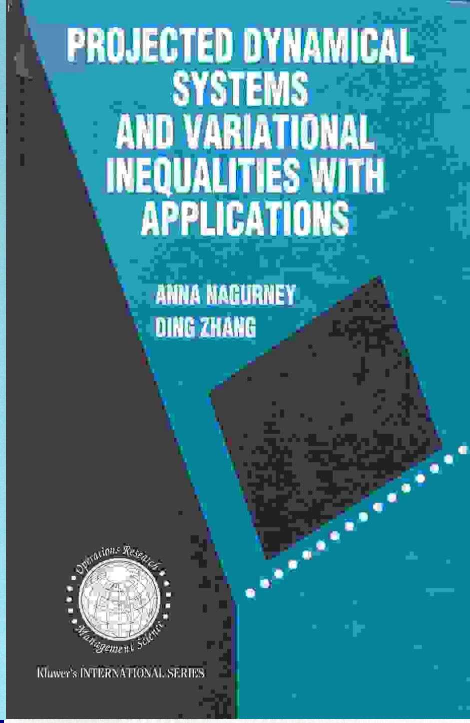
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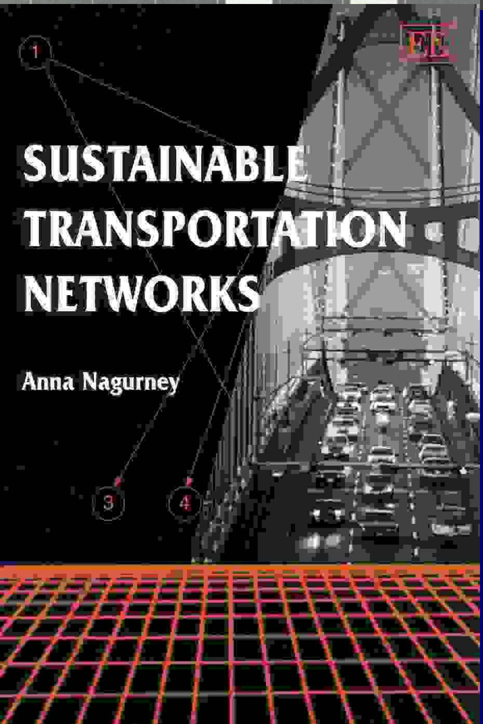
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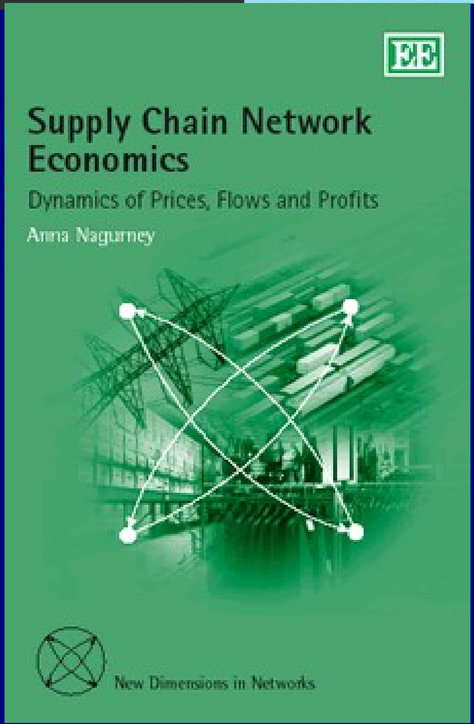
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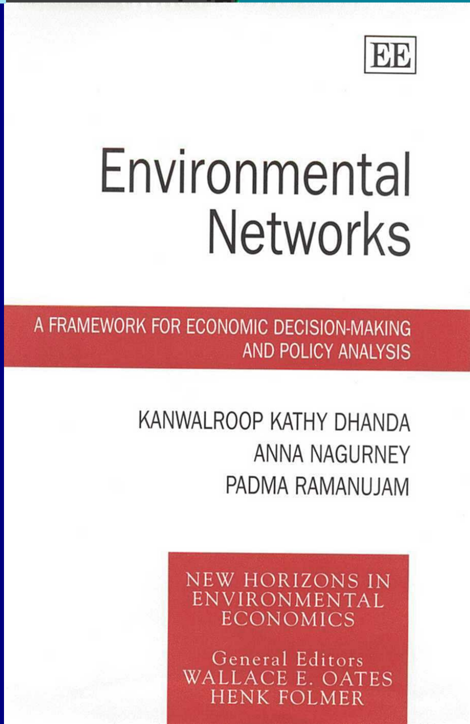
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- *alternative behaviors of the users of the network*

  - System-optimized (S-O) (centralized supply chain) versus

  - user-optimized (U-O) (decentralized supply chain),

which may lead to paradoxical phenomena (Braess Paradox and the Merger Paradox).

Network Equilibrium Problem Derived from Transportation

(U-O Problem)

Network Equilibrium

The network equilibrium conditions are then given by: For each path $p \in P_w$ and every O/D pair w:

$$C_p \begin{cases} = \lambda_w, & \text{if} \quad x_p^* > 0 \\ \geq \lambda_w, & \text{if} \quad x_p^* = 0 \end{cases}$$

where λ_w is an indicator, whose value is not known a priori. These equilibrium conditions state that the user costs on all used paths connecting a given O/D pair will be minimal and equalized.

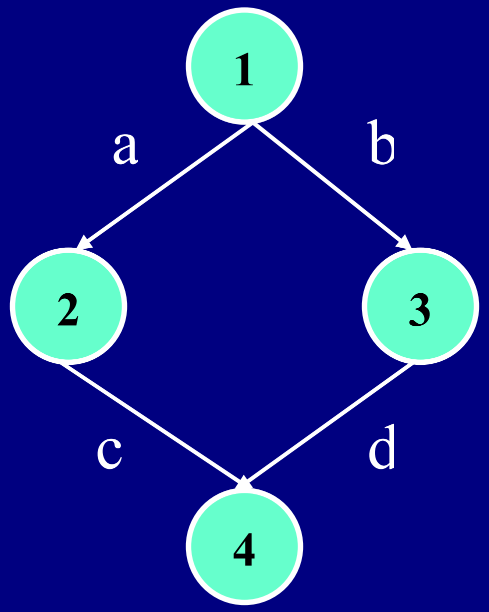
The Braess (1968) Paradox

Assume a network with a single O/D pair (1,4). There are 2 paths available to travelers: **p_1=(a,c)** and **p_2=(b,d).**

For a travel demand of **6,** the equilibrium path flows are $\mathbf{x_{p_1}^*}$ $\mathbf{= x_{p_2}^* = 3}$ and

The equilibrium path travel cost is

$\mathbf{C_{p_1} = C_{p_2} = 83.}$



$c_a(f_a) = 10\ f_a \qquad c_b(f_b) = f_b + 50$

$c_c(f_c) = f_c + 50 \quad c_d(f_d) = 10\ f_d$

Adding a Link Increases Travel Cost for All!

Adding a new link creates a new path **p_3=(a,e,d).**

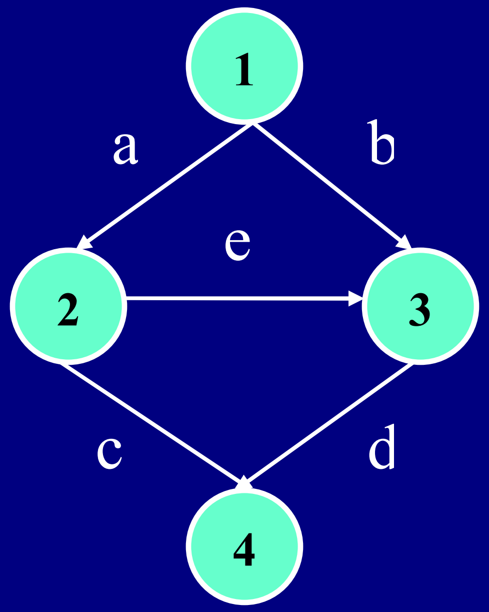
The original flow distribution pattern is no longer an equilibrium pattern, since at this level of flow the cost on path **p_3, C_{p_3}=70.**

The new equilibrium flow pattern network is

$x_{p_1}^* = x_{p_2}^* = x_{p_3}^* = 2$.

The equilibrium path travel costs:

$C_{p_1} = C_{p_2} = C_{p_3} = 92$.



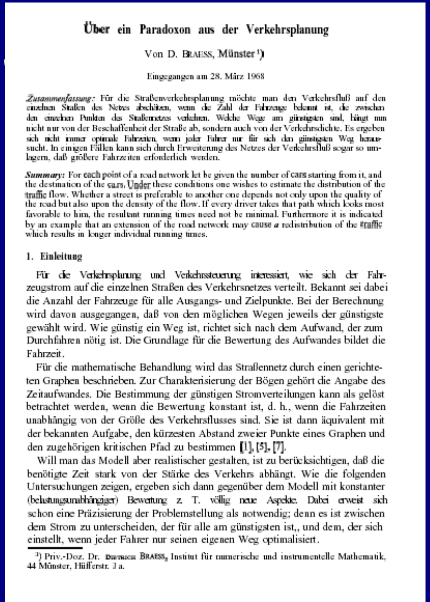
$c_e(f_e) = f_e + 10$

The 1968 Braess article has been translated from German to English and appears as

On a Paradox of Traffic Planning

by Braess, Nagurney, Wakolbinger

in the November 2005 issue of *Transportation*



Über ein Paradoxon aus der Verkehrsplanung

Von D. Braess, Münster [1])

Eingegangen am 28. März 1968

Zusammenfassung: Für die Straßenverkehrsplanung möchte man den Verkehrsfluß auf den einzelnen Straßen des Netzes abschätzen, wenn die Zahl der Fahrzeuge bekannt ist, die zwischen den einzelnen Punkten des Straßennetzes verkehren. Welche Wege am günstigsten sind, hängt nun nicht nur von der Beschaffenheit der Straße ab, sondern auch von der Verkehrsdichte. Es ergeben sich nicht immer optimale Fahrzeiten, wenn jeder Fahrer nur für sich den günstigsten Weg heraussucht. In einigen Fällen kann sich durch Erweiterung des Netzes der Verkehrsfluß sogar so umlagern, daß größere Fahrzeiten erforderlich werden.

Summary: For each point of a road network let be given the number of cars starting from it, and the destination of the cars. Under these conditions one wishes to estimate the distribution of the traffic flow. Whether a street is preferable to another one depends not only upon the quality of the road but also upon the density of the flow. If every driver takes that path which looks most favorable to him, the resultant running times need not be minimal. Furthermore it is indicated by an example that an extension of the road network may cause a redistribution of the traffic which results in longer individual running times.

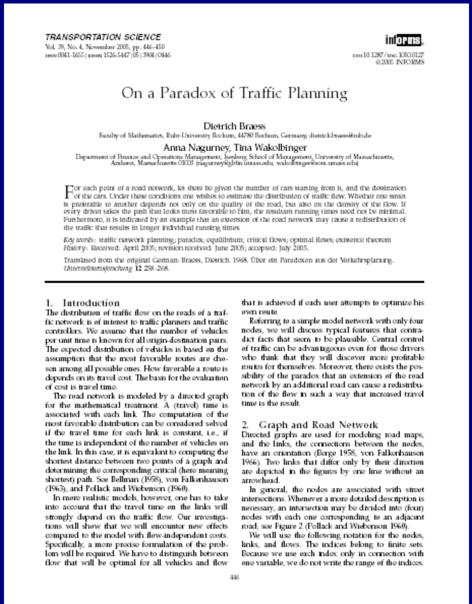
1. Einleitung

Für die Verkehrsplanung und Verkehrssteuerung interessiert, wie sich der Fahrzeugstrom auf die einzelnen Straßen des Verkehrsnetzes verteilt. Bekannt sei dabei die Anzahl der Fahrzeuge für alle Ausgangs- und Zielpunkte. Bei der Berechnung wird davon ausgegangen, daß von den möglichen Wegen jeweils der günstigste gewählt wird. Wie günstig ein Weg ist, richtet sich nach dem Aufwand, der zum Durchfahren nötig ist. Die Grundlage für die Bewertung des Aufwandes bildet die Fahrzeit.

Für die mathematische Behandlung wird das Straßennetz durch einen gerichteten Graphen beschrieben. Zur Charakterisierung der Bögen gehört die Angabe des Zeitaufwandes. Die Bestimmung der günstigen Stromverteilungen kann als gelöst betrachtet werden, wenn die Bewertung konstant ist, d. h., wenn die Fahrzeiten unabhängig von der Größe des Verkehrsflusses sind. Sie ist dann äquivalent mit der bekannten Aufgabe, den kürzesten Abstand zweier Punkte eines Graphen und den zugehörigen kritischen Pfad zu bestimmen [1], [5], [7].

Will man das Modell aber realistischer gestalten, ist zu berücksichtigen, daß die benötigte Zeit stark von der Stärke des Verkehrs abhängt. Wie die folgenden Untersuchungen zeigen, ergeben sich dann gegenüber dem Modell mit konstanter (belastungsunabhängiger) Bewertung z. T. völlig neue Aspekte. Dabei erweist sich schon eine Präzisierung der Problemstellung als notwendig; denn es ist zwischen dem Strom zu unterscheiden, der für alle am günstigsten ist,, und dem, der sich einstellt, wenn jeder Fahrer nur seinen eigenen Weg optimalisiert.

[1]) Priv.-Doz. Dr. Dietrich Braess, Institut für numerische und instrumentelle Mathematik, 44 Münster, Hüfferstr. 3 a.



TRANSPORTATION SCIENCE
Vol. 39, No. 4, November 2005, pp. 446–450
ISSN 0041-1655 | EISSN 1526-5447 | 05 | 3904 | 0446

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DOI 10.1287/trsc.1050.0127

On a Paradox of Traffic Planning

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For each point of a road network, let there be given the number of cars starting from it, and the destination of the cars. Under these conditions one wishes to estimate the distribution of traffic flow. Whether one street is preferable to another depends not only on the quality of the road, but also on the density of the flow. If every driver takes the path that looks most favorable to him, the resultant running times need not be minimal. Furthermore, it is indicated by an example that an extension of the road network may cause a redistribution of the traffic that results in longer individual running times.

Key words: traffic network planning; paradox; equilibrium; critical flows; optimal flows; existence theorem
History: Received: April 2005; revision received: June 2005; accepted: July 2005.

Translated from the original German: Braess, Dietrich. 1968. Über ein Paradoxon aus der Verkehrsplanung. *Unternehmensforschung* **12** 258–268.

1. Introduction

The distribution of traffic flow on the roads of a traffic network is of interest to traffic planners and traffic controllers. We assume that the number of vehicles per unit time is known for all origin-destination pairs. The expected distribution of vehicles is based on the assumption that the most favorable routes are chosen among all possible ones. How favorable a route is depends on its travel cost. The basis for the evaluation of cost is travel time.

The road network is modeled by a directed graph for the mathematical treatment. A (travel) time is associated with each link. The computation of the most favorable distribution can be considered solved if the travel time for each link is constant, i.e., if the time is independent of the number of vehicles on the link. In this case, it is equivalent to computing the shortest distance between two points of a graph and determining the corresponding critical (here meaning shortest) path. See Bellman (1958), von Falkenhausen (1963), and Pollack and Wiebenson (1960).

In more realistic models, however, one has to take into account that the travel time on the links will strongly depend on the traffic flow. Our investigations will show that we will encounter new effects compared to the model with flow-independent costs. Specifically, a more precise formulation of the problem will be required. We have to distinguish between flow that will be optimal for all vehicles and flow that is achieved if each user attempts to optimize his own route.

Referring to a simple model network with only four nodes, we will discuss typical features that contradict facts that seem to be plausible. Central control of traffic can be advantageous even for those drivers who think that they will discover more profitable routes for themselves. Moreover, there exists the possibility of the paradox that an extension of the road network by an additional road can cause a redistribution of the flow in such a way that increased travel time is the result.

2. Graph and Road Network

Directed graphs are used for modeling road maps, and the links, the connections between the nodes, have an orientation (Berge 1958, von Falkenhausen 1966). Two links that differ only by their direction are depicted in the figures by one line without an arrowhead.

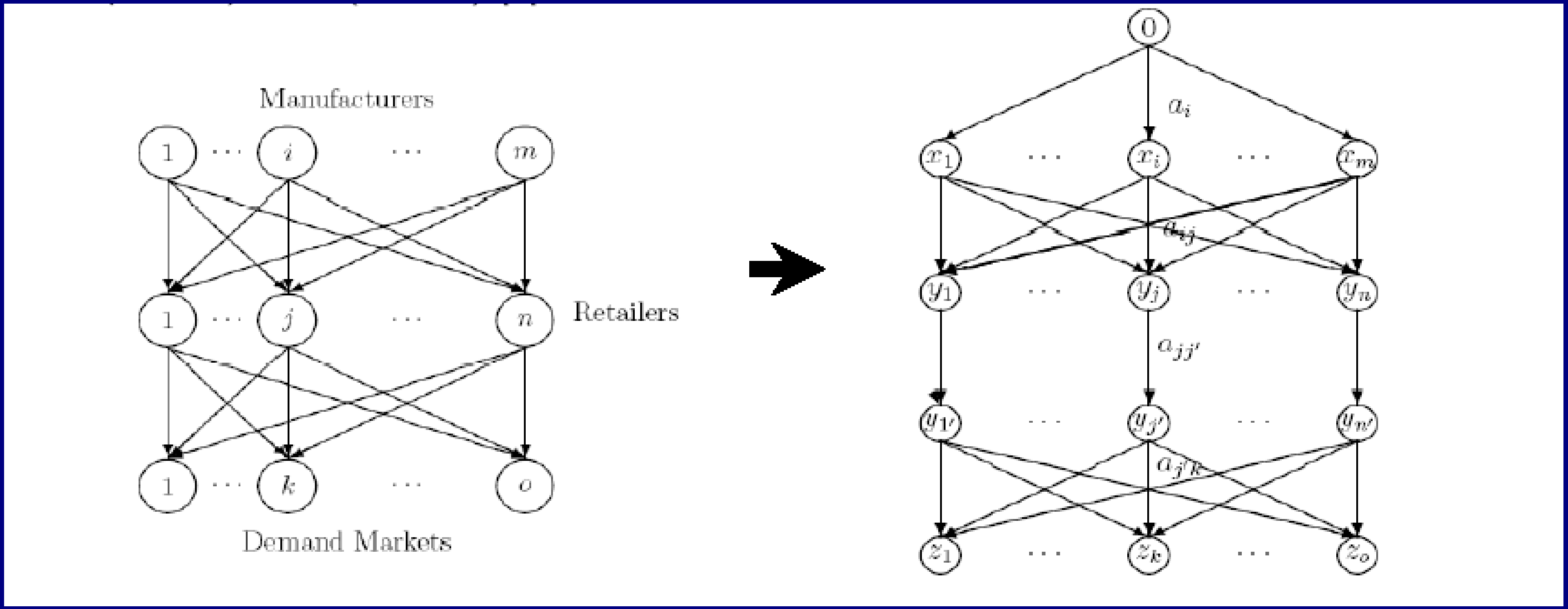
In general, the nodes are associated with street intersections. Whenever a more detailed description is necessary, an intersection may be divided into (four) nodes with each one corresponding to an adjacent road; see Figure 2 (Pollack and Wiebenson 1960).

We will use the following notation for the nodes, links, and flows. The indices belong to finite sets. Because we use each index only in connection with one variable, we do not write the range of the indices.

The NE Paradigm is the Unifying Paradigm:

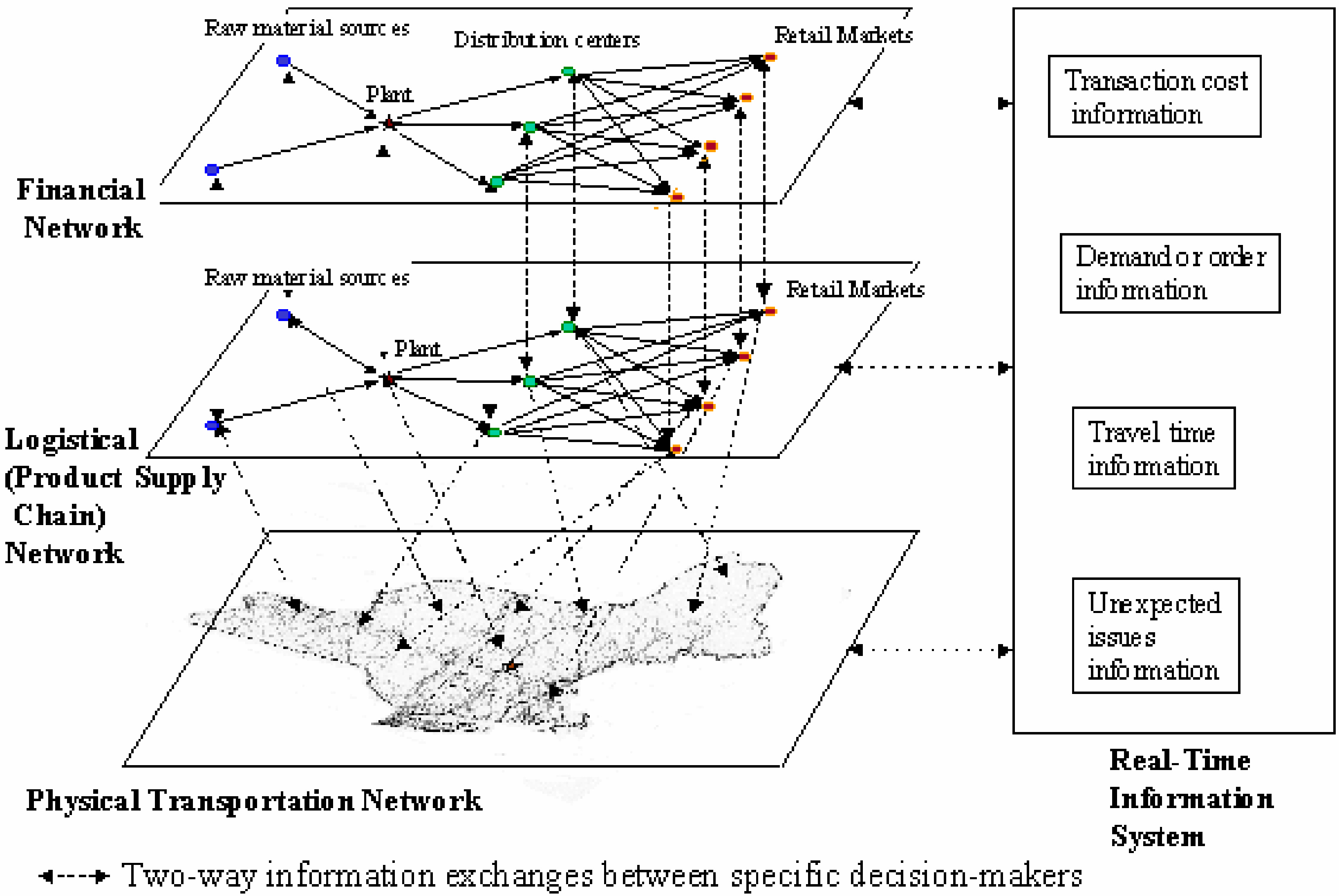
- Transportation Networks
- The Internet
- Financial Networks
- Decentralized Supply Chains.

The Equivalence of Decentralized Supply Chains and Transportation Networks



Nagurney, *Transportation Research E* (2006).

Supply Chain -Transportation Supernetwork Representation



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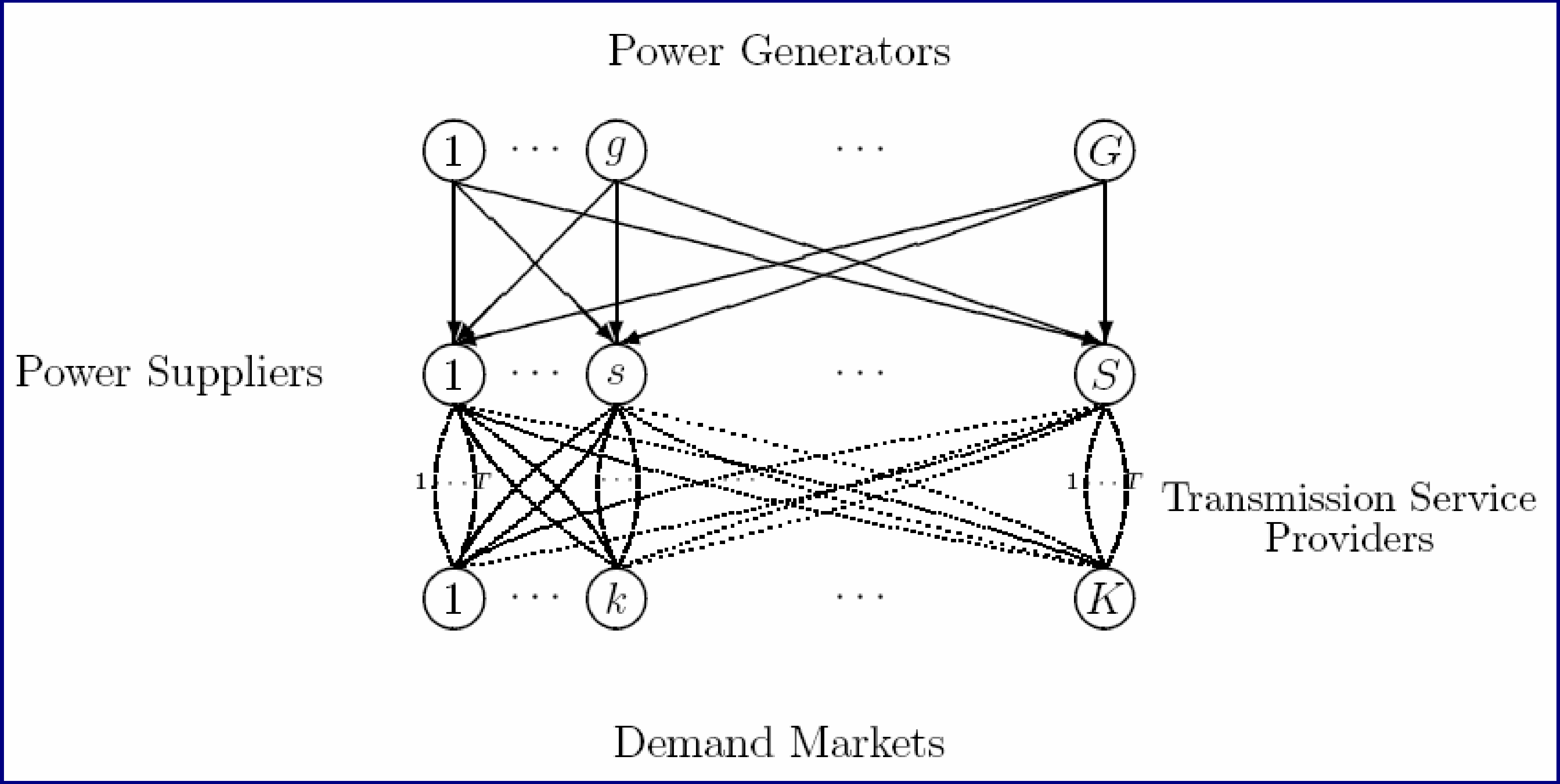
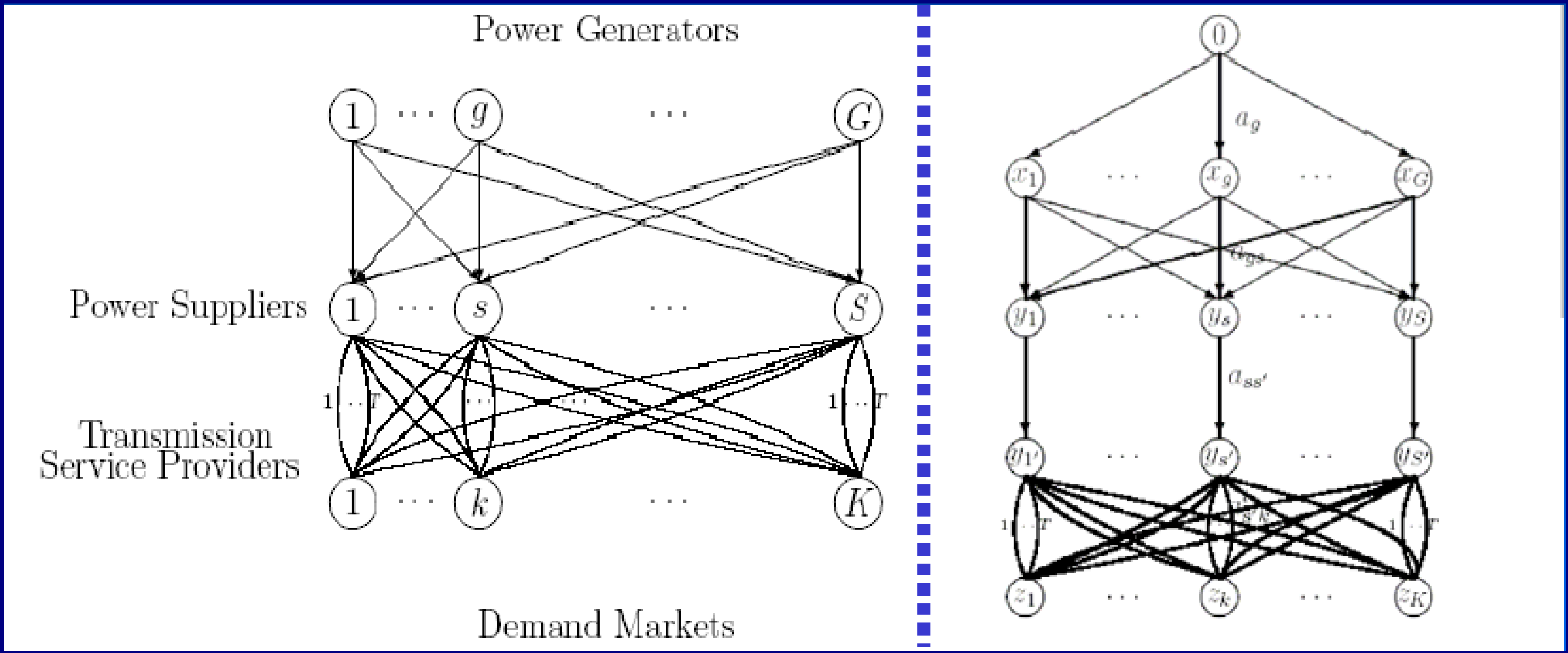
Electric Power Supply Chains

The Electric Power Supply Chain Network



Nagurney and Matsypura, *Proceedings of the CCCT* (2004).

The Transportation Network Equilibrium Reformulation of Electric Power Supply Chain Networks

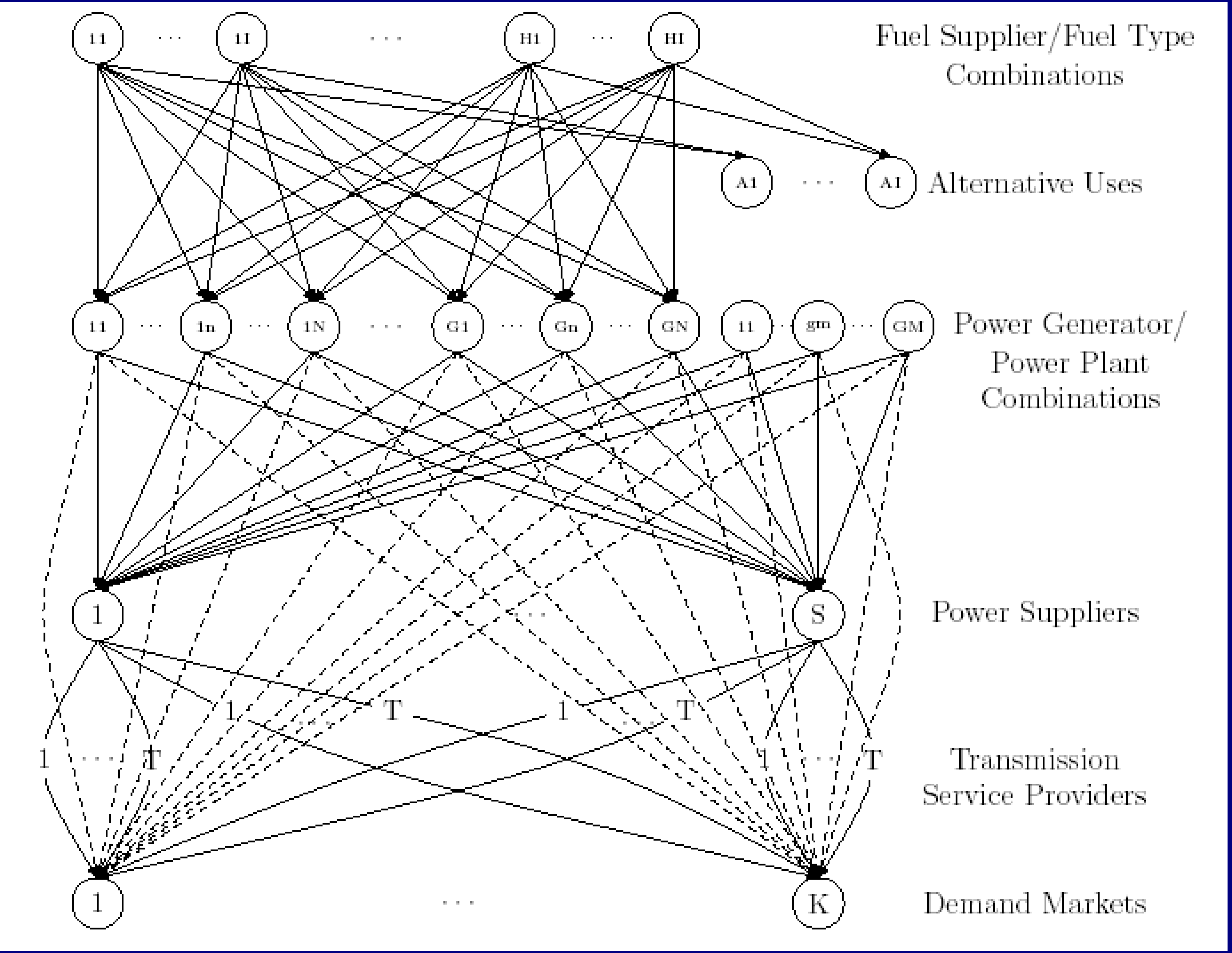


Electric Power Supply Network

Transportation Chain Network

Nagurney, Liu, Cojocaru, and Daniele, *Transportation Research E* (2007).

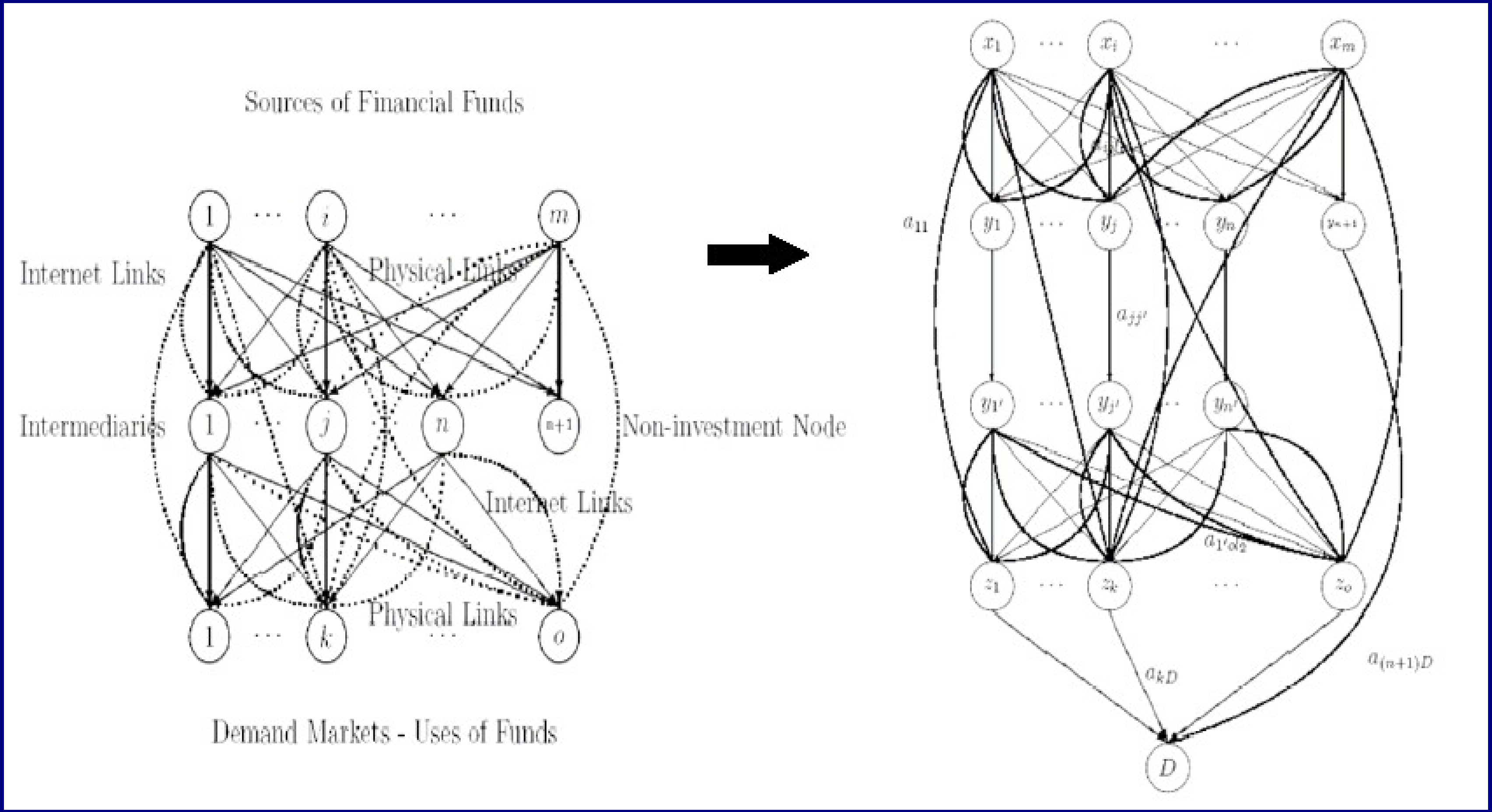
Electric Power Supply Chain Network with Fuel Suppliers



Matsypura, Nagurney, and Liu, *International Journal of Emerging Power Systems* (2007).

In 1952, Copeland wondered whether money flows like water or electricity.

The Transportation Network Equilibrium Reformulation of the Financial Network Equilibrium Model with Intermediation



Liu and Nagurney, *Computational Management Science* (2007).

We have shown that *money* as well as *electricity* flow like *transportation* and have answered questions posed fifty years ago by Copeland and by Beckmann, McGuire, and Winsten!

Additional disasters that have demonstrated the importance and the vulnerability of network systems.

Examples:

- 9/11 Terrorist Attacks, September 11, 2001;
- The biggest blackout in North America, August 14, 2003;
- Two significant power outages in September 2003 -- one in the UK and the other in Italy and Switzerland;
- Hurricane Katrina, August 23, 2005;
- The Minneapolis I35 Bridge Collapse, August 1, 2007
- The severance of the Mediterranean cable in 2008.

Our Research on Network Efficiency, Vulnerability, and Robustness

A Network Efficiency Measure for Congested Networks, Nagurney and Qiang, *Europhysics Letters,* **79**, August (2007).

A Transportation Network Efficiency Measure that Captures Flows, Behavior, and Costs with Applications to Network Component Importance Identification and Vulnerability, Nagurney and Qiang, *Proceedings of the POMS 18th Annual Conference,* Dallas, Texas (2007).

A Network Efficiency Measure with Application to Critical Infrastructure Networks, Nagurney and Qiang, *Journal of Global Optimization* (2008).

Robustness of Transportation Networks Subject to Degradable Links, Nagurney and Qiang, *Europhysics Letters,* **80**, December (2007).

A Unified Network Performance Measure with Importance Identification and the Ranking of Network Components, Qiang and Nagurney, *Optimization Letters,* **2** (2008).

A New Network Performance/Efficiency Measure with Applications to Infrastructure Networks including Supply Chains

The Nagurney and Qiang (N-Q) Network Efficiency Measure

The network performance/efficiency measure $\mathcal{E}(G,d)$, for a given network topology G and fixed demand vector d, is defined as

$$\mathcal{E}(G,d) = \frac{\sum_{w \in W} \frac{d_w}{\lambda_w}}{n_W},$$

where n_w is the number of O/D pairs in the network and λ_w is the equilibrium disutility for O/D pair w.

Nagurney and Qiang, *Europhysics Letters,* **79** (2007).

Importance of a Network Component

Definition: Importance of a Network Component

The importance, *I(g),* of a network component *gεG* is measured by the relative network efficiency drop after *g* is removed from the network:

$$I(g) = \frac{\triangle \mathcal{E}}{\mathcal{E}} = \frac{\mathcal{E}(G,d) - \mathcal{E}(G-g,d)}{\mathcal{E}(G,d)},$$

where *G-g* is the resulting network after component g is removed.

The Approach to Study the Importance of Network Components

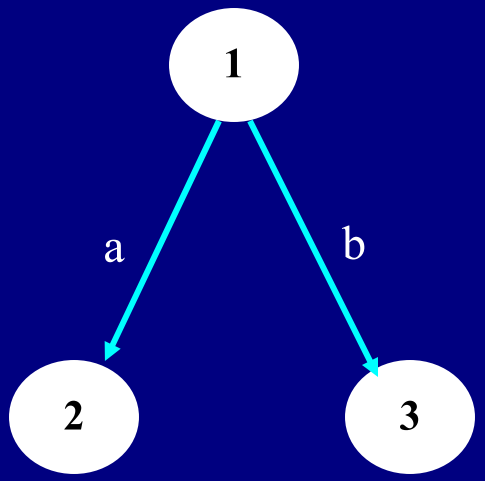
The elimination of a link is treated in the N-Q network efficiency measure by removing that link while the removal of a node is managed by removing the links entering and exiting that node.

In the case that the removal results in no path connecting an O/D pair, we simply assign the demand for that O/D pair to an abstract path with a cost of infinity. Hence, our measure is well-defined even in the case of disconnected networks.

The measure generalizes the Latora and Marchiori network measure for complex networks.

Example 1

Assume a network with two O/D pairs:
$\boldsymbol{w_1}$=(1,2) and $\boldsymbol{w_2}$=(1,3) with demands:
$\boldsymbol{d_{w_1}}$=100 and $\boldsymbol{d_{w_2}}$=20.



$c_a(f_a)=0.01f_a+19$
$c_b(f_b)=0.05f_b+19$

The paths are:

for $\boldsymbol{w_1}$, $\boldsymbol{p_1=a}$; for $\boldsymbol{w_2}$, $\boldsymbol{p_2=b}$.

The equilibrium path flows are:
$\boldsymbol{x_{p_1}^*=}$ 100, $\boldsymbol{x_{p_2}^*=}$20.

The equilibrium path travel costs are:
$\boldsymbol{C_{p_1}=C_{p_2}=}$20.

Importance and Ranking of Links and Nodes

Link	Importance Value from Our Measure	Importance Ranking from Our Measure
a	0.8333	1
b	0.1667	2

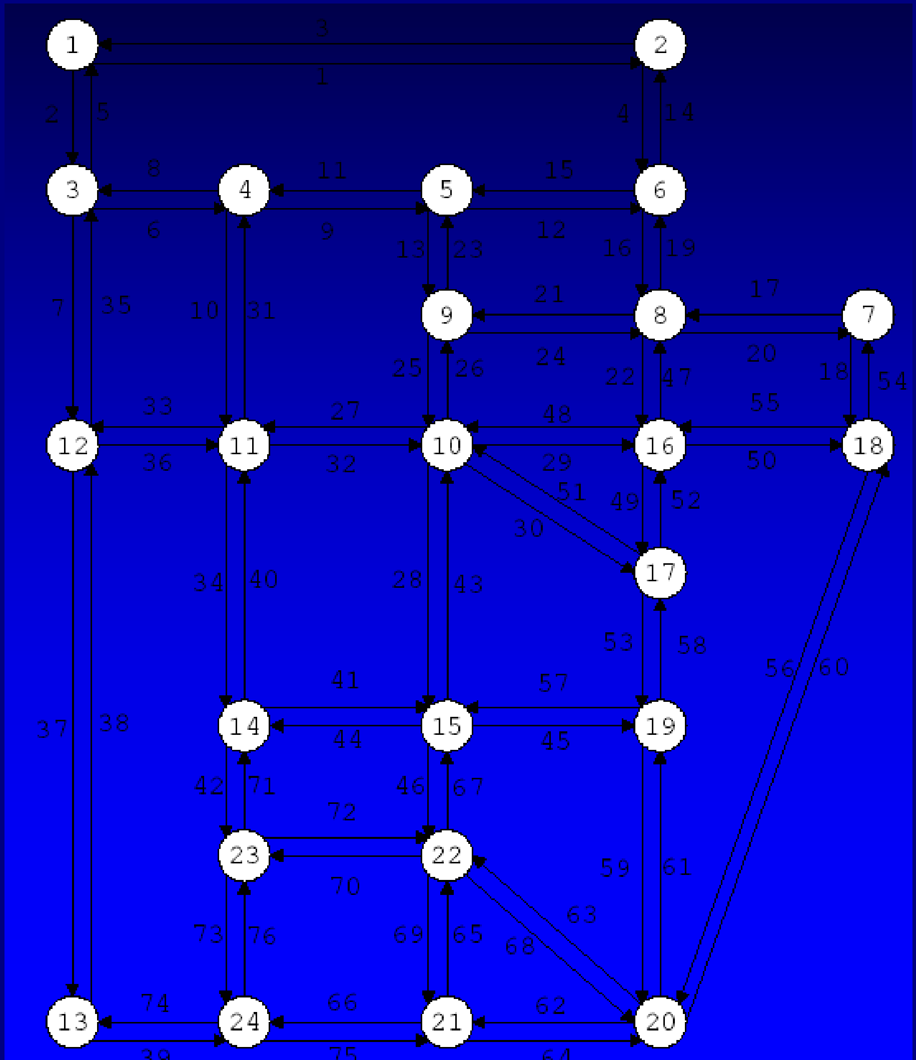
Node	Importance Value from Our Measure	Importance Ranking from Our Measure
1	1	1
2	0.8333	2
3	0.1667	3

Example - Sioux Falls Network

The network data are from LeBlanc, Morlok, and Pierskalla (1975).

The network has 528 O/D pairs, 24 nodes, and 76 links.

The user link cost functions are of Bureau of Public Roads (BPR) form.



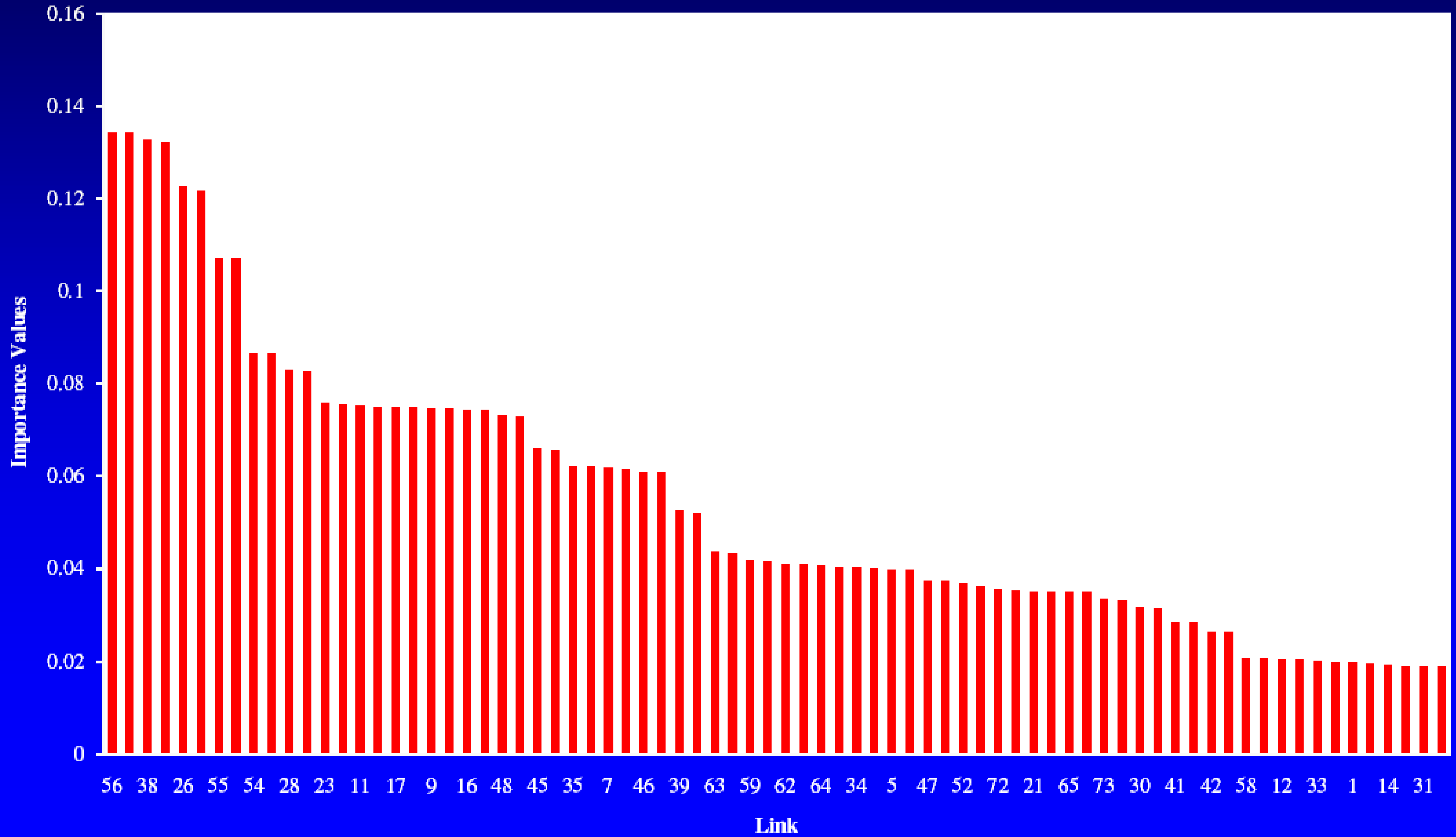
BPR Link Cost Functions

The Bureau of Public Roads (BPR) link cost functional form is:

$$c_a(f_a) = t_a^0 \left[1 + k\left(\frac{f_a}{u_a}\right)^{\beta} \right] \qquad \forall a \in L$$

where *k* and *β* are greater than zero and the *u's* are the practical capacities on the links.

Example - Sioux Falls Network Link Importance Rankings



The Advantages of the N-Q Network Efficiency Measure

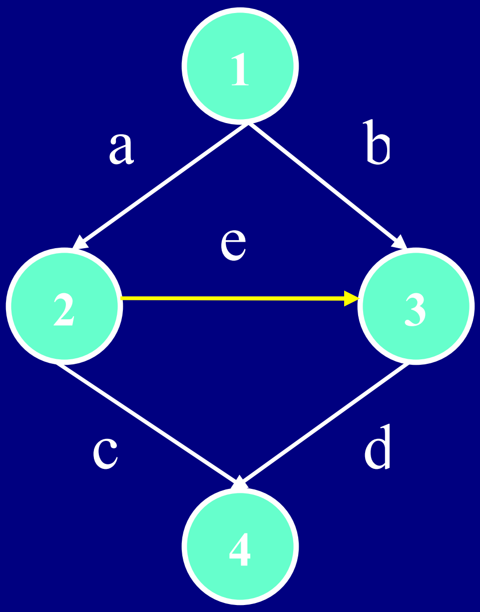
- The measure captures demands, flows, costs, and behavior of users, in addition to network topology;
- The resulting importance definition of network components is applicable and well-defined even in the case of disconnected networks;
- It can be used to identify the importance (and ranking) of either nodes, or links, or both; and
- It can be applied to assess the efficiency/performance of a wide range of network systems.
- It is applicable also to elastic demand networks (Qiang and Nagurney, *Optimization Letters* (2008)).
- It has been extended to dynamic networks (Nagurney and Qiang, *Netnomics*, in press).

The focus of the robustness of networks (and complex networks) has been on the impact of different network measures when facing the removal of nodes on networks.

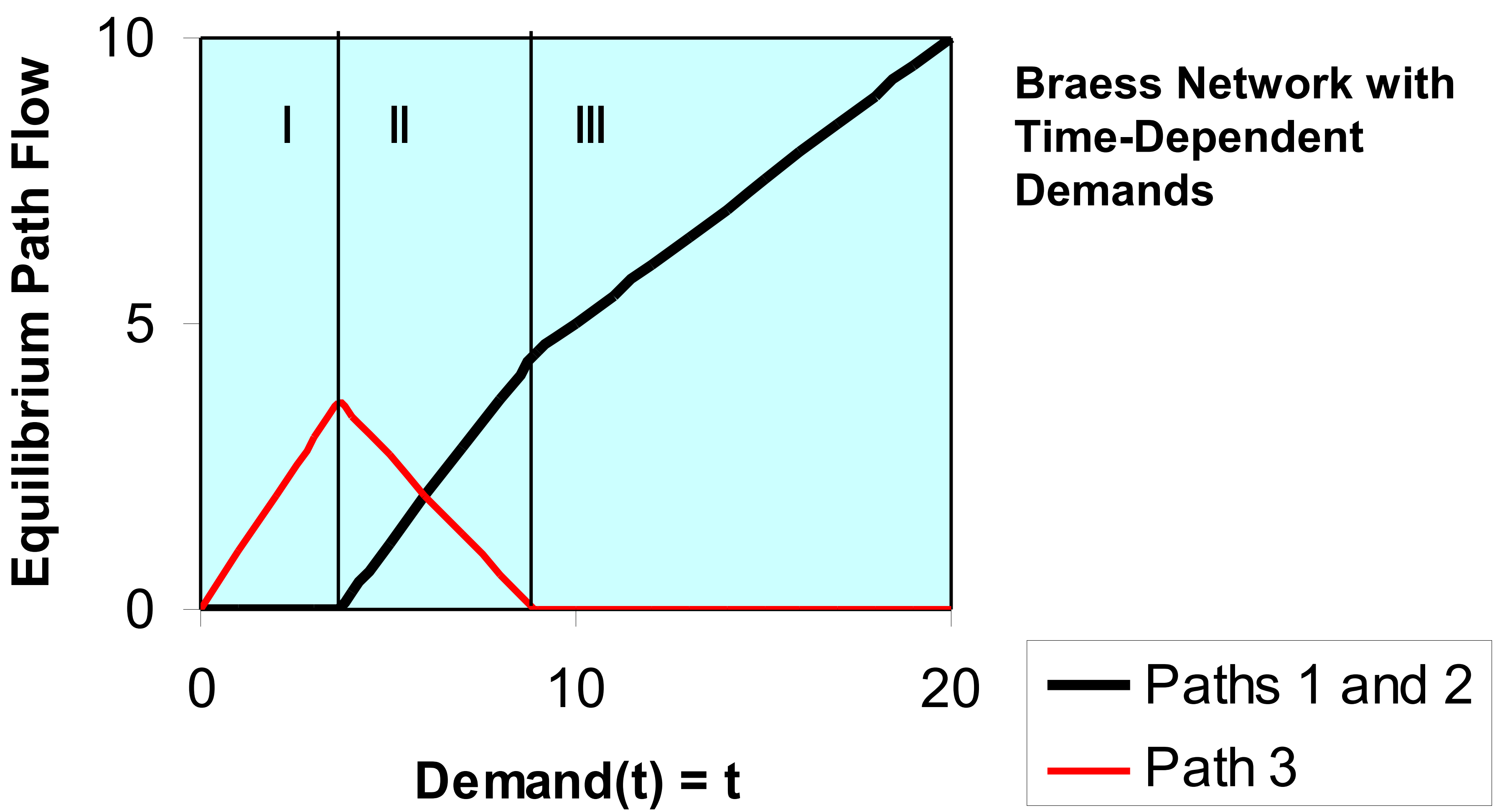
We focus on the *degradation of links through reductions in their capacities* and the effects on the induced costs in the presence of known demands and different functional forms for the links.

The Time-Dependent (Demand-Varying) Braess Paradox and Evolutionary Variational Inequalities

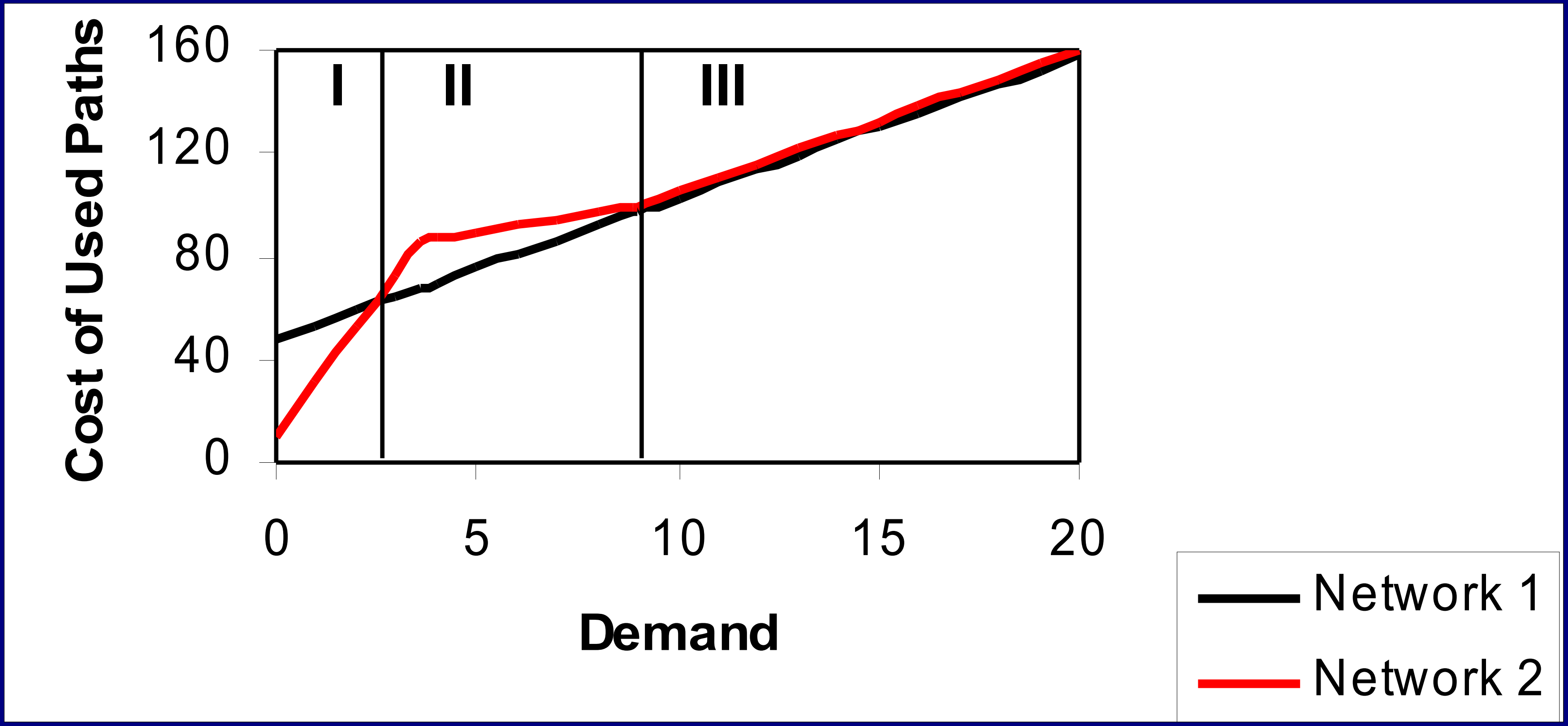
Recall the Braess Network
where we add the link e.



The Solution of an Evolutionary (Time-Dependent) Variational Inequality for the Braess Network with Added Link (Path)



In Demand Regime I, only the new path is used.
In Demand Regime II, the Addition of a New Link (Path) Makes Everyone Worse Off!
In Demand Regime III, only the original paths are used.



Network 1 is the Original Braess Network - Network 2 has the added link.

The new link is NEVER used after a certain demand is reached even if the demand approaches infinity.

Hence, in general, except for a limited range of demand, building the new link is a complete waste!

In the paper:

"Modeling of Supply Chain Risk Under Disruptions with Performance Measurement and Robustness Analysis," invited for the volume **Managing Supply Chain Risk and Vulnerability: Tools and Methods for Supply Chain Decision Makers**, Wu and Blackhurst, editors, Springer

we have extended the performance measure of Nagurney and Qiang to handle disruptions in supply chains under risk and uncertainty.

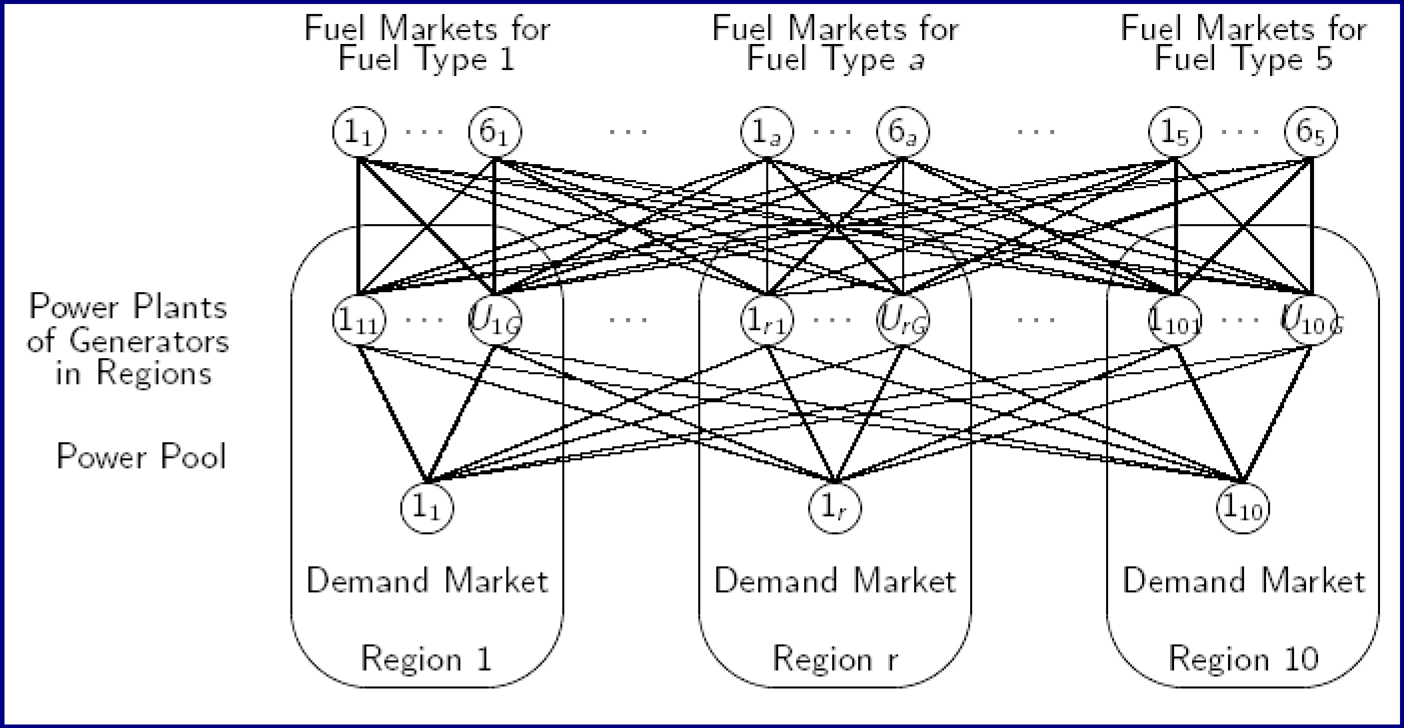
Where Are We Now?

An Integrated Electric Power Supply Chain and Fuel Market Network Framework: Theoretical Modeling with Empirical Analysis for New England, Liu and Nagurney (2007).

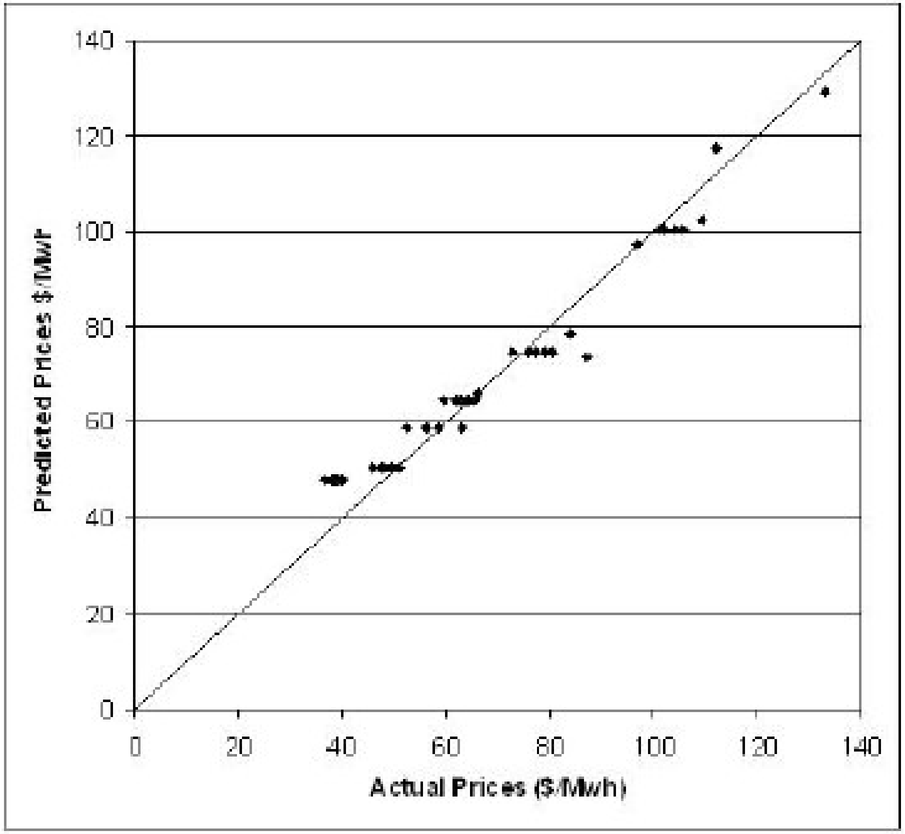
Empirical Case Study

- New England electric power market and fuel markets
- 82 generators who own and operate 573 power plants
- 5 types of fuels: natural gas, residual fuel oil, distillate fuel oil, jet fuel, and coal
- Ten regions (R=10): 1. Maine, 2. New Hampshire, 3. Vermont, 4. Connecticut(excluding Southwest Connecticut), 5. Southwest Connecticut(excluding Norwalk-Stamford area), 6. Norwalk-Stamford area, 7. Rhode Island, 8. Southeast Massachusetts, 9. West and Central Massachusetts, 10. Boston/Northeast Massachusetts
- Hourly demand/price data of July 2006 ($24 \times 31 = 744$ scenarios)
- 6 blocks (L1 = 94 hours, and Lw = 130 hours; w = 2, ..., 6)

The New England Electric Power Supply Chain Network with Fuel Suppliers



Predicted Prices vs. Actual Prices ($/Mwh)



Mergers and Acquisitions and Supply Chain Network Synergies

- Today, supply chains are more extended and complex than ever before. At the same time, the current competitive economic environment requires that firms operate efficiently, which has spurred research to determine how to utilize supply chains more effectively.
- There is also a pronounced amount of merger activity. According to Thomson Financial, in the first nine months of 2007 alone, worldwide merger activity hit $3.6 trillion, surpassing the total from all of 2006 combined.
- Notable examples: KMart and Sears in the retail industry in 2004 and Federated and May in 2005, Coors and Molson in the beverage industry in 2005, and the recently proposed merger between Anheuser Busch and InBev.

kmart Sears


Coors LIGHT
MOLSON CANADIAN


Federated
DEPARTMENT STORES, INC.
MAY

According to Kusstatscher and Cooper (2005) there were five major waves of of Merger & Acquisition (M &A) activity:

The First Wave: 1898-1902: an increase in horizontal mergers that resulted in many US industrial groups;

The Second Wave: 1926-1939: mainly public utilities;

The Third Wave: 1969-1969: *diversification* was the driving force;

The Fourth Wave: 1983-1986: the goal was efficiency;

The Fifth Wave: 1997 until the early years of the 21st century: *globalization* was the motto.

In 1998, M&As reached $2.1 trillion worldwide; in 1999, the activity exceeded $3.3 trillion, and in 2000, almost $3.5 was reached.

- A survey of 600 executives involved in their companies' mergers and acquisitions (M&A) conducted by Accenture and the Economist Unit (see Byrne (2007)) found that less than half (45%) achieved expected cost-saving synergies.

- Langabeer and Seifert (2003) determined a direct correlation between how effectively supply chains of merged firms are integrated and how successful the merger is. They concluded, based on the empirical findings of Langabeer (2003), who analyzed hundreds of mergers over the preceding decade, that

Improving Supply Chain Integration between Merging Companies is the Key to Improving the Likelihood of Post-Merger Success!

Mergers and Acquisitions and Supply Chain Network Synergies

Recently, we introduced a system-optimization perspective for supply chains in which firms are engaed in multiple activities of production, storage, and distribution to the demand markets and proposed a cost synergy measure associated with evaluating proposed mergers:

- Nagurney, A. (2008a) "A System-Optimization Perspective for Supply Chain Network Integration: The Horizontal Merger Case," *Transportation Research E*, in press.

In that paper, the merger of two firms was modeled and the demands for the product at the markets, which were distinct for each firm prior to the merger, were assumed to be fixed.

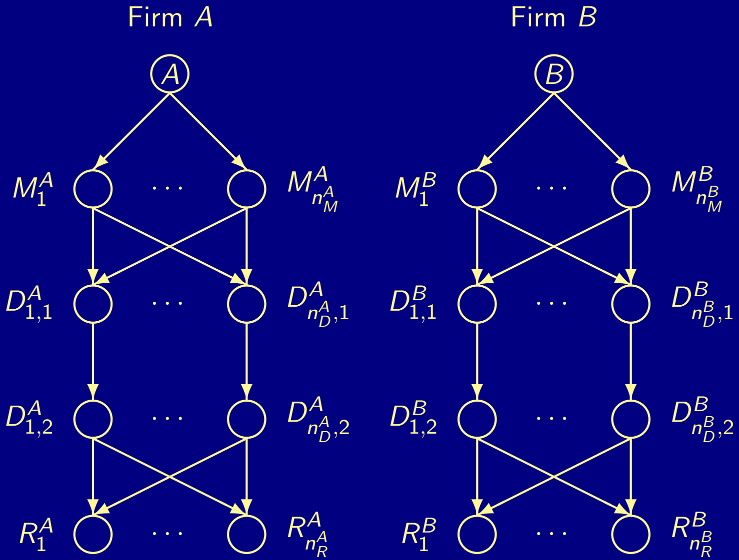


Figure 1: Case 0: Firms A and B Prior to Horizontal Merger (Nagurney (2008a))

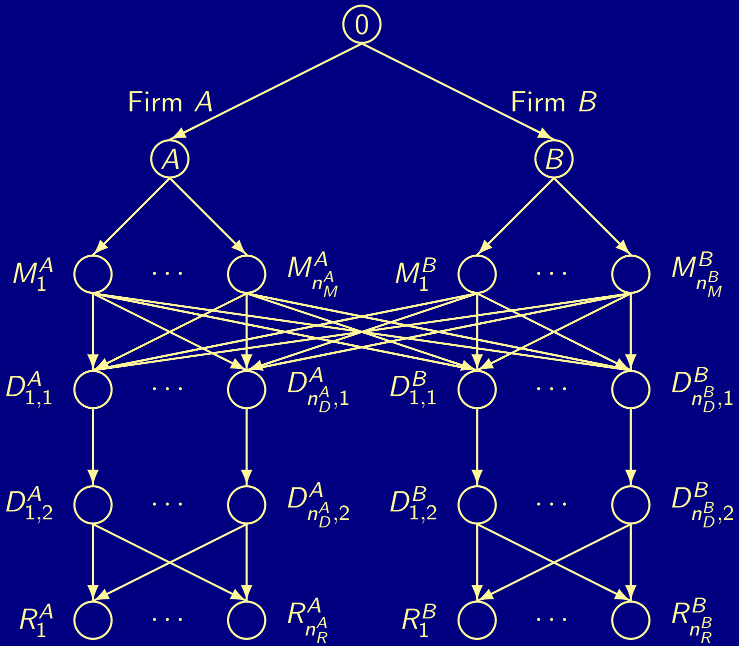


Figure 2: Case 1: Firms A and B Merge (Nagurney (2008a))

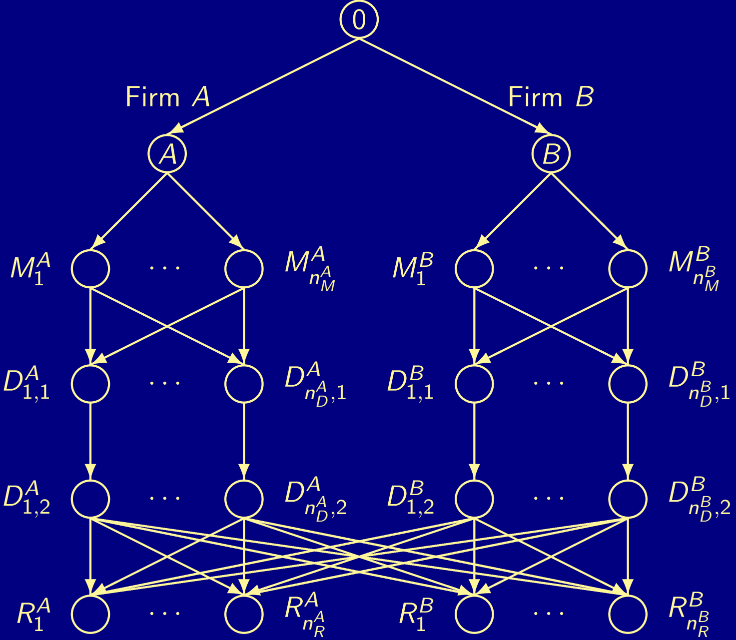


Figure 3: Case 2: Firms A and B Merge (Nagurney (2008a))

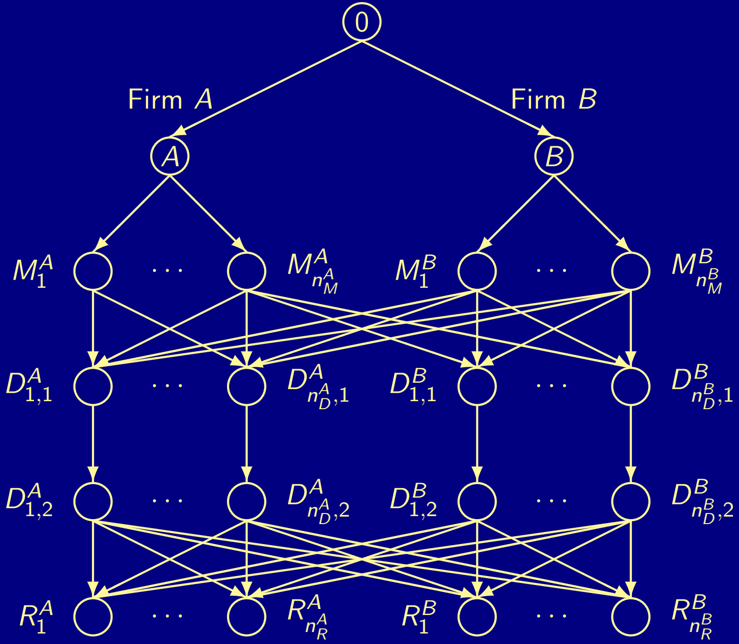


Figure 4: Case 3: Firms A and B Merge (Nagurney (2008a))

Synergy Measure

The measure that we utilized in Nagurney (2008a) to capture the gains, if any, associated with a horizontal merger Case i; $i = 1, 2, 3$ is as follows:

$$\mathcal{S}^i = \left[\frac{TC^0 - TC^i}{TC^0} \right] \times 100\%,$$

where TC^i is the total cost associated with the value of the objective function $\sum_{a \in L^i} \hat{c}_a(f_a)$ for $i = 0, 1, 2, 3$ evaluated at the optimal solution for Case i. Note that $\mathcal{S}^i$; $i = 1, 2, 3$ may also be interpreted as *synergy*.

The Supply Chain Network Oligopoly Model (Nagurney (2008b))

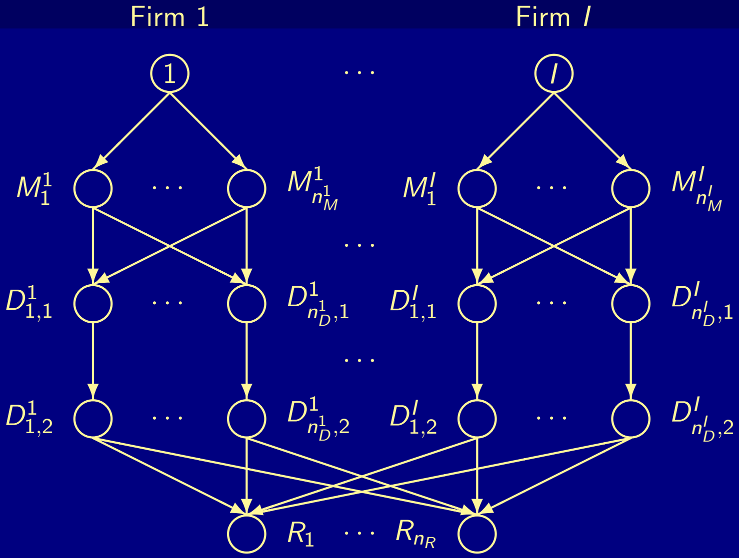


Figure 5: Supply Chain Network Structure of the Oligopoly

Mergers Through Coalition Formation

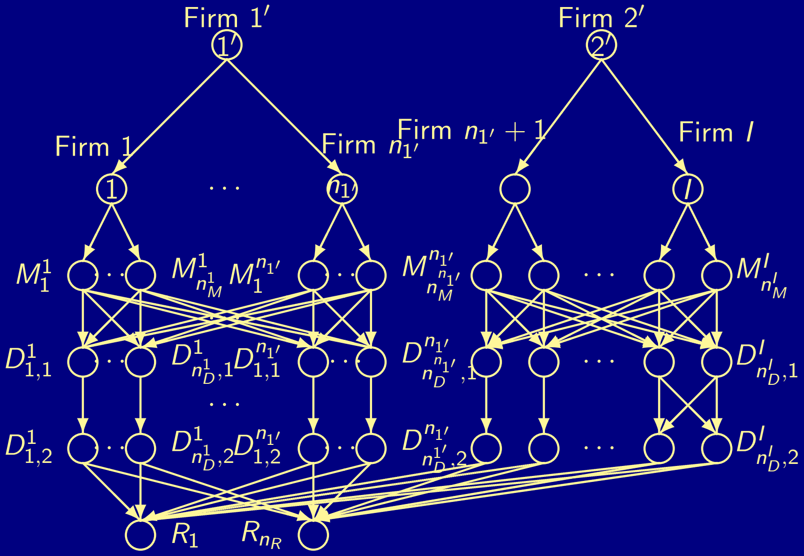


Figure 6: Mergers of the First $n_{1'}$ Firms and the Next $n_{2'}$ Firms

This framework can also be applied to teaming of humanitarian organizations in the case of humanitarian logistics operations.

http://hlogistics.som.umass.edu

Summary and Conclusions

In this talk we have demonstrated the richness of network concepts for quantifying synergies as well as vulnerabilities associated with supply chain networks in the global economy.

The need for performance metrics as well as analytics has never been more profound nor more feasible.

By focusing on interdisciplinary research and practice we can better identify which nodes and links in supply chain networks truly matter and whether or not to participate in any merger based on potential and predetermined synergies.

Thank You!

For more information, see http://supernet.som.umass.edu