Grand Challenges and Opportunities in Supply Chain Networks: From Analysis to Design

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- Background and Motivation
- Representation of Supply Chains as Networks
- Why User Behavior Must be Captured in Network Design
- Supply Chain Network Theory
- Methodology – The Variational Inequality Problem
- Variational Inequalities and Optimization Theory
- Variational Inequalities and Game Theory
- A Full Model and Application to Sustainable Fashion Supply Chains
- Other Issues That Have Been Explored Using Supply Chain Network Theory
- Summary, Conclusions, and Suggestions for Future Research

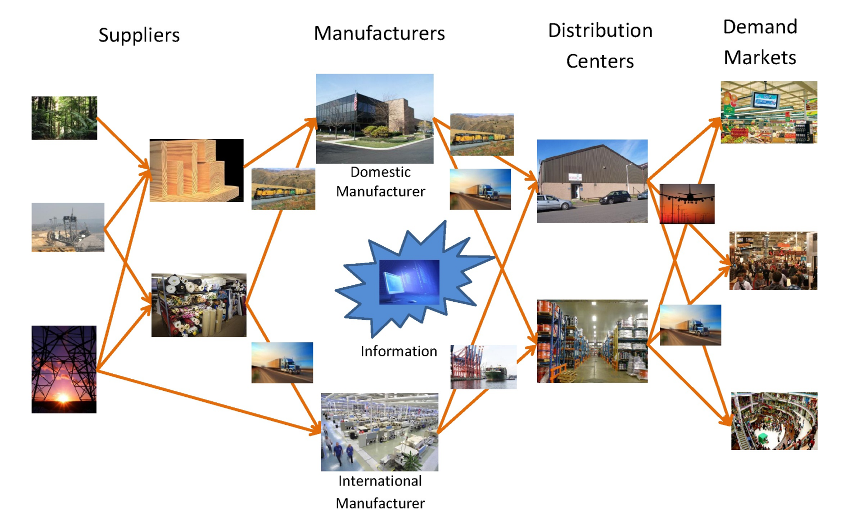
Background and Motivation

Supply chains are the *critical infrastructure and backbones* for the production, distribution, and consumption of goods as well as services in our globalized *Network Economy*.

Supply chains, in their most fundamental realization, *consist of manufacturers and suppliers, distributors, retailers, and consumers at the demand markets*.

Today, supply chains may span thousands of miles across the globe, involve numerous suppliers, retailers, and consumers, and be underpinned by multimodal transportation and telecommunication networks.

A General Supply Chain

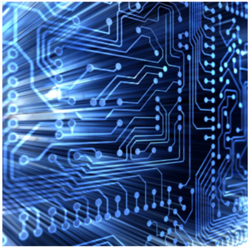


Examples of Supply Chains

- food and food products
- high tech products
- automotive
- energy (oil, electric power, etc.)
- clothing and toys
- humanitarian relief
- healthcare supply chains
- supply chains in nature.

Food Supply Chains

High Tech Products



Automotive Supply Chains

Energy Supply Chains

Healthcare Supply Chains

Supply Chains in Nature

Supply chains may be characterized by *decentralized decision-making* associated with the different economic agents or by *centralized* decision-making.

Supply chains are, in fact, *Complex Network Systems*.

Hence, *any formalism that seeks to model supply chains and to provide quantifiable insights and measures must be a system-wide one and network-based.*

Indeed, such crucial issues as the stability and resiliency of supply chains, as well as their adaptability and responsiveness to events in *a global environment of increasing risk and uncertainty* can only be rigorously examined from the view of supply chains as network systems.

Characteristics of Supply Chains and Networks Today

- *large-scale nature* and complexity of network topology;
- *congestion*, which leads to nonlinearities;
- *alternative behavior of users of the networks*, which may lead to paradoxical phenomena;
- *possibly conflicting criteria associated with optimization*;
- *interactions among the underlying networks themselves*, such as the Internet with electric power networks, financial networks, and transportation and logistical networks;
- recognition of *their fragility and vulnerability*;
- policies surrounding networks today may have major impacts not only economically, but also *socially, politically, and security-wise*.

Representation of Supply Chains as Networks

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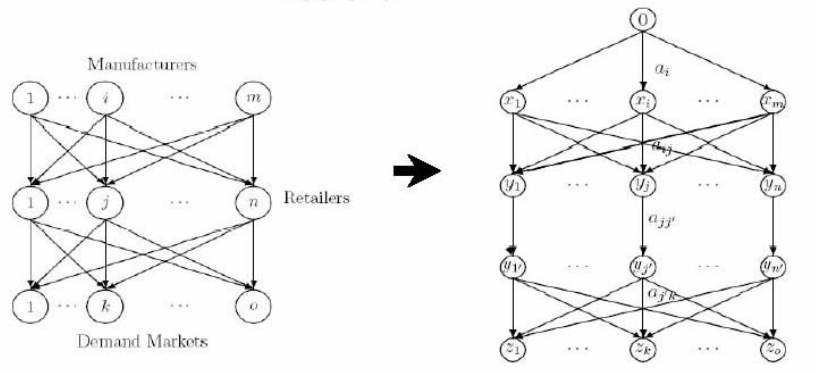
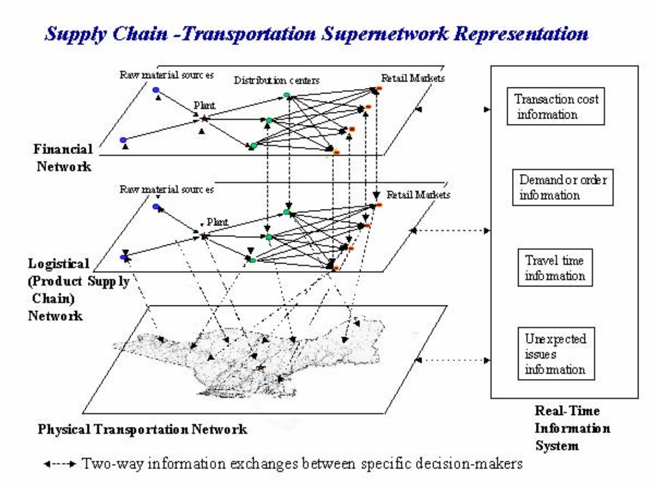
• build powerful extensions using the graphical/network conceptualization.

Representation of Supply Chains as Networks



The equivalence between supply chains and transportation networks established in Nagurney, *Transportation Research E* **42** (2006), 293-316.

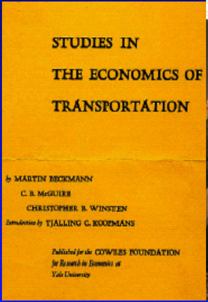
Representation of Supply Chains as Networks



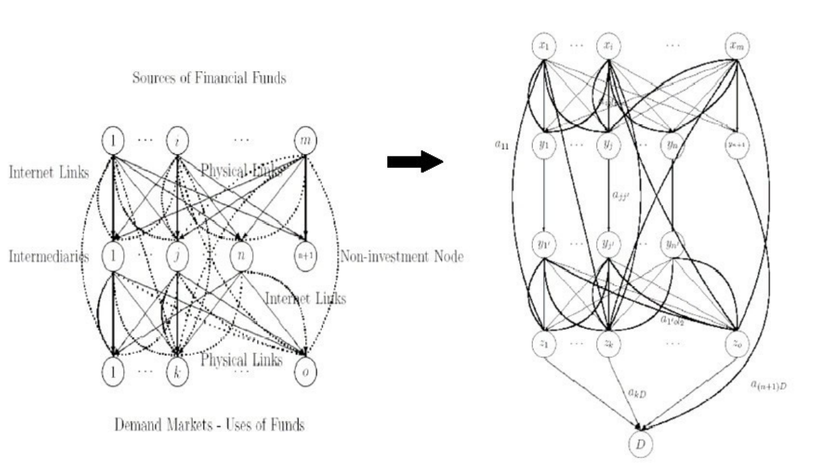
Multilevel supply chain established by Nagurney, Ke, Cruz, Hancock, and Southworth in *Environment & Planning B* **29** (2002), 795-818.

In 1952, Copeland in his book, *A Study of Moneyflows in the United States*, NBER, NY, asked whether money flows lie water or electricity?

In 1956, Beckmann, McGuire, and Winsten in their classic book, *Studies in the Economics of Transportation*, Yale University Press, hypothesized that electric power generation and distribution networks could be transformed into transportation network equilibrium problems.

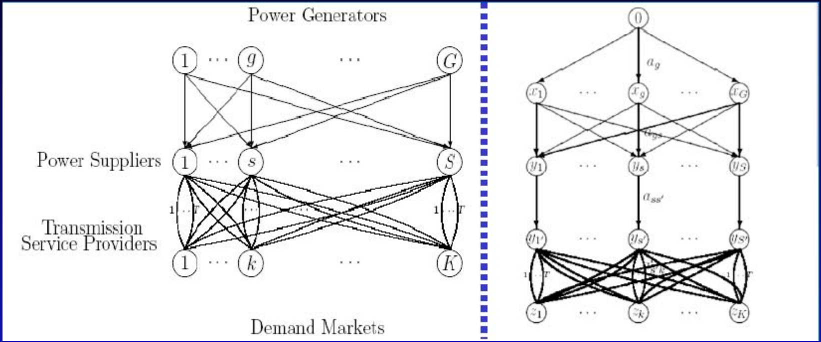


Transportation Network Equilibrium Reformulation of the Financial Network Equilibrium Model with Intermediation



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

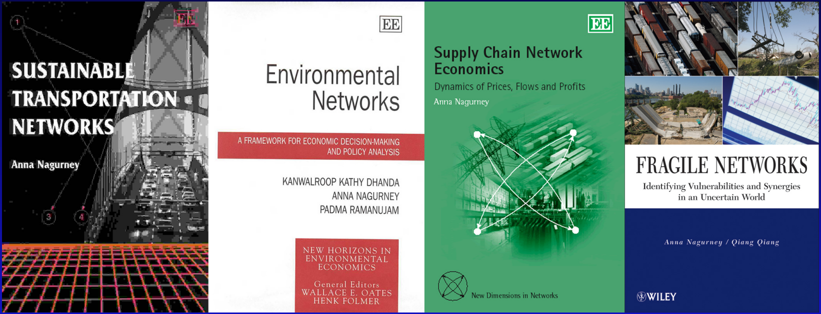
Representation of Supply Chains as Networks



The transportation network equilibrium reformulation of electric power supply chain networks by Nagurney, Liu, Cojocaru, and Daniele, *Transportation Research E* **43** (2007), 624-646.

Hence, we have shown that both electricity as well as money flow like transportation flows.

Our Approach to Supply Chain Network Analysis and Design



Why User Behavior Must be Captured in Network Design

Supply Chain Network Design Must Capture the Behavior of Users

Behavior on Congested Networks

Decision-makers select their cost-minimizing routes.

		User-Optimized
Decentralized	Selfish	U–O
vs. ⇔	vs. ⇔	vs.
Centralized	Unselfish	S–O
		System-Optimized

Flows are routed so as to minimize the total cost to society.

Two fundamental principles of travel behavior, due to Wardrop (1952), with terms coined by Dafermos and Sparrow (1969).

User-optimized (U-O) (network equilibrium) Problem – each user determines his/her cost minimizing route of travel between an origin/destination, until an equilibrium is reached, in which no user can decrease his/her cost of travel by unilateral action (in the sense of Nash).

System-optimized (S-O) Problem – users are allocated among the routes so as to minimize the total cost in the system, where the total cost is equal to the sum over all the links of the link's user cost times its flow.

The U-O problems, under certain simplifying assumptions, possesses optimization reformulations. But now we can handle cost asymmetries, multiple modes of transport, and different classes of travelers, without such assumptions.

We Can State These Conditions Mathematically!

The U-O and S-O Conditions

Definition: U-O or Network Equilibrium – Fixed Demands

A path flow pattern x^*, with nonnegative path flows and O/D pair demand satisfaction, is said to be U-O or in equilibrium, if the following condition holds for each O/D pair $w \in W$ and each path $p \in P_w$:

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

Definition: S-O Conditions

A path flow pattern x with nonnegative path flows and O/D pair demand satisfaction, is said to be S-O, if for each O/D pair $w \in W$ and each path $p \in P_w$:

$$\hat{C}'_p(x) \begin{cases} = \mu_w, & \text{if} \quad x_p > 0, \\ \geq \mu_w, & \text{if} \quad x_p = 0, \end{cases}$$

where $\hat{C}'_p(x) = \sum_{a \in \mathcal{L}} \frac{\partial \hat{c}_a(f_a)}{\partial f_a} \delta_{ap}$, and μ_w is a Lagrange multiplier.

The importance of behavior will now be illustrated through a famous example known as the Braess paradox which demonstrates what can happen under *U-O* as opposed to *S-O* behavior.

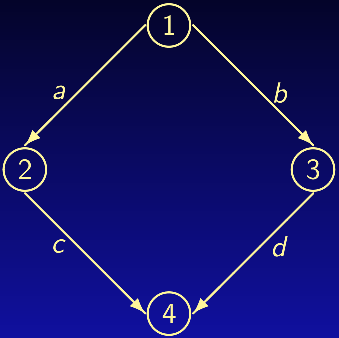
Although the paradox was presented in the context of transportation networks, it is relevant to other network systems in which decision-makers act in a noncooperative (competitive) manner.

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 $x^*_{p_1} = x^*_{p_2} = 3$ and

The equilibrium path travel cost is
$C_{p_1} = C_{p_2} = 83.$



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

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

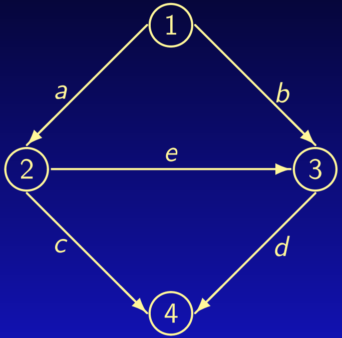
Adding a Link Increases Travel Cost for All!

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



$c_e(f_e) = f_e + 10$

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

"On a Paradox of Traffic Planning,"

D. Braess, A. Nagurney, and T. Wakolbinger (2005) Transportation Science **39**, 446-450.

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.

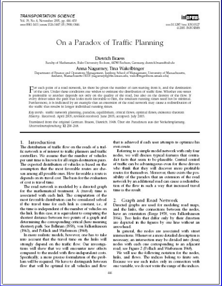
1. Einleitung

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.



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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.

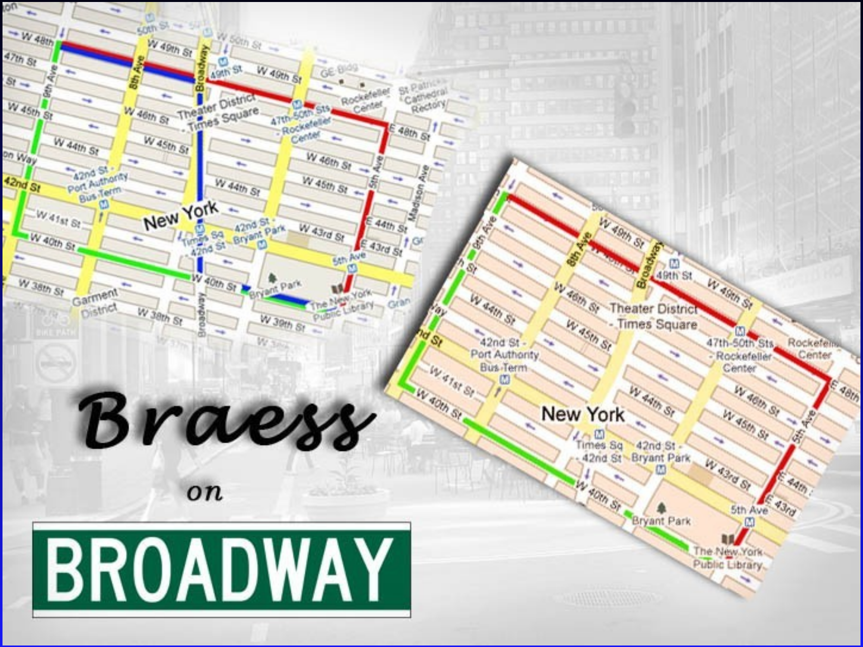
1. Introduction

The Braess Paradox Around the World

1969 - Stuttgart, Germany - The traffic worsened until a newly built road was closed.

1990 - Earth Day - New York City - 42^{nd} Street was closed and traffic flow improved.

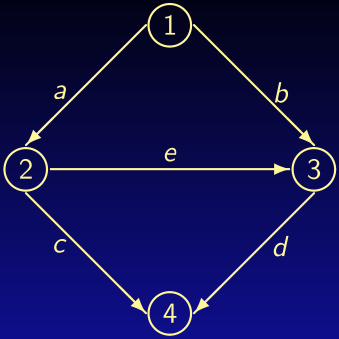
2002 - Seoul, Korea - A 6 lane road built over the Cheonggyecheon River that carried 160,000 cars per day and was perpetually jammed was torn down to improve traffic flow.


Braess
on
BROADWAY
New York
Theater District - Times Square
W 49th St
W 46th St
W 45th St
W 44th St
W 43rd St
W 41st St
W 40th St
W 38th St
8th Ave
5th Ave
Broadway
Bryant Park
The New York Public Library
42nd St - Port Authority Bus Term
Times Sq - 42nd St
42nd St - Bryant Park
47th-50th Sts - Rockefeller Center
Garment District

Interview on Broadway for *America Revealed* on March 15, 2011

Under S-O behavior, the total cost in the network is minimized, and the new route p_3, under the same demand, would not be used.

The Braess paradox never occurs in S-O networks.



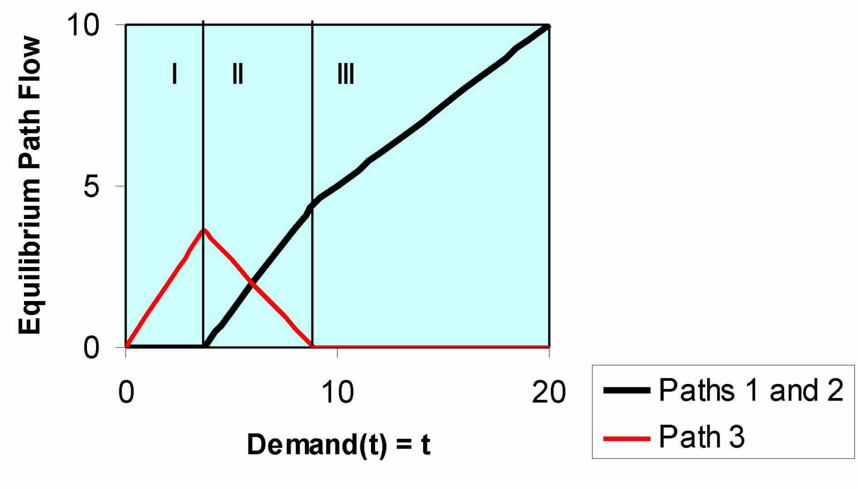
Recall the Braess network with the added link e.

What happens as the demand increases?

For Networks with Time-Dependent Demands

We Use Evolutionary Variational Inequalities

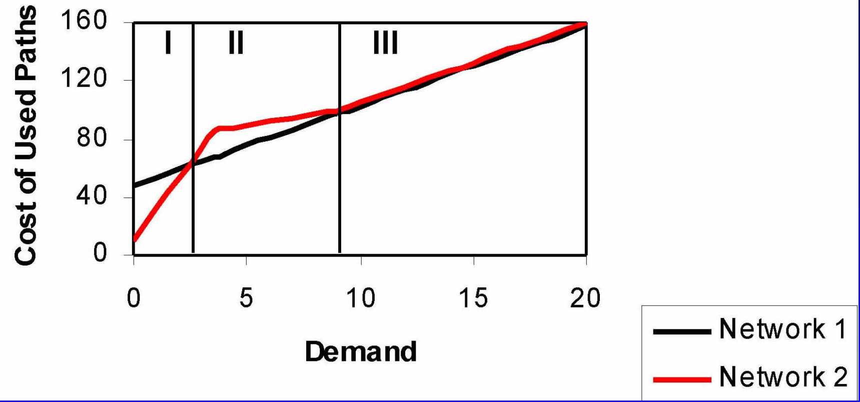
The U-O Solution of the Braess Network with Added Link (Path) and Time-Varying Demands Solved as an *Evolutionary Variational Inequality* (Nagurney, Daniele, and Parkes, *Computational Management Science* (2007)).



In Demand Regime I, Only the New Path is Used.

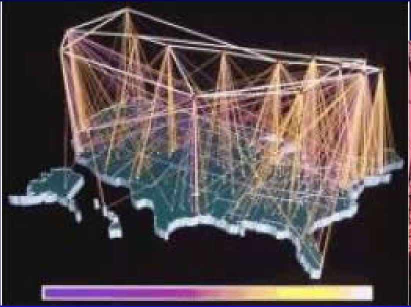
In Demand Regime II, the travel demand lies in the range [2.58, 8.89], and *the Addition of a New Link (Path) Makes Everyone Worse Off*!

In Demand Regime III, when the travel demand exceeds 8.89, *Only the Original Paths are Used!*



The new path is never used, under U-O behavior, when the demand exceeds 8.89, even out to infinity!

Other Networks that Behave like Traffic Networks



The Internet and electric power networks

Supply Chain Network Theory

Supply Chain Network Theory

Supply chain network theory is an integrated theory that includes:

- *network theory* – in order to identify the structure of the supply chain and relationships
- *optimization theory* – in order to capture the decision-maker's criteria in the form of objective functions, the decision variables that they control, and the underlying recourse constraints, and
- *game theory* – so that cooperation, if appropriate, as well as the reality of competition can be modeled.

For full background, see the book: Anna Nagurney, *Supply Chain Network Economics: Dynamics of Prices, Flows, and Profits*, Edward Elgar Publishing, Cheltenham, England (2006).
The fundamental methodology that we utilize for the integration is that of *Variational Inequality Theory*.

Methodology - The Variational Inequality Problem

Methodology - The Variational Inequality Problem

We utilize the theory of variational inequalities for the formulation, analysis, and solution of both centralized and decentralized supply chin network problems.

Definition: The Variational Inequality Problem

The finite-dimensional variational inequality problem, $\mathrm{VI}(F, \mathcal{K})$*, is to determine a vector* $X^* \in \mathcal{K}$*, such that:*

$$\langle F(X^*), X - X^* \rangle \geq 0, \quad \forall X \in \mathcal{K},$$

where F *is a given continuous function from* $\mathcal{K}$ *to* R^N*,* $\mathcal{K}$ *is a given closed convex set, and* $\langle \cdot, \cdot \rangle$ *denotes the inner product in* R^N*.*

Methodology - The Variational Inequality Problem

The vector X consists of the decision variables – typically, the flows (products, prices, etc.).

$\mathcal{K}$ is the feasible set representing how the decision variables are constrained – for example, the flows may have to be nonnegative; budget constraints may have to be satisfied; similarly, quality and/or time constraints.

The function F that enters the variational inequality represents functions that capture the bahvior in the form of the functions such as costs, profits, risk, etc.

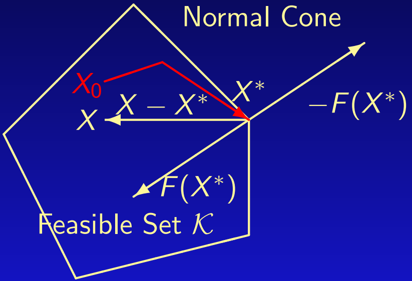
The variational inequality problem contains, as special cases, such mathematical programming problems as:

- systems of equations,
- optimization problems,
- complementarity problems,
- game theory problems, operating under Nash equilibrium,
- and is related to the fixed point problem.

Hence, it is a natural methodology for a spectrum of supply chain network problems from centralized to decentralized ones as well as to design problems.

Geometric Interpretation of VI($F, \mathcal{K}$) and a Projected Dynamical System (Dupuis and Nagurney, Nagurney and Zhang)

In particular, $F(X^*)$ is "orthogonal" to the feasible set $\mathcal{K}$ at the point X^*.



Associated with a VI is a Projected Dynamical System, which provides a natural underlying dynamics associated with travel (and other) behavior to the equilibrium.

To model the *dynamic behavior of complex networks*, including supply chains, we utilize *projected dynamical systems* (PDSs) advanced by Dupuis and Nagurney (1993) in *Annals of Operations Research* and by Nagurney and Zhang (1996) in our book *Projected Dynamical Systems and Variational Inequalities with Applications*.

Such nonclassical dynamical systems are now being used in

evolutionary games (Sandholm (2005, 2011)),

ecological predator-prey networks (Nagurney and Nagurney (2011a, b)), and

even *neuroscience* (Girard et al. (2008)).

Variational Inequalities and Optimization Theory

Variational Inequalities and Optimization Theory

Optimization problems, including constrained and unconstrained, can be formulated as variational inequality problems (see Nagurney (1999)). The relationship between variational inequalities and optimization problems is as follows.

Proposition

Let X^* be a solution to the optimization problem:

$$\text{Minimize} \quad f(X)$$

subject to:

$$X \in \mathcal{K},$$

where f is continuously differentiable and $\mathcal{K}$ is closed and convex. Then X^* is a solution of the variational inequality problem: determine $X^* \in \mathcal{K}$, such that

$$\langle \nabla f(X^*), X - X^* \rangle \geq 0, \quad \forall X \in \mathcal{K},$$

where $\nabla f(X)$ is the gradient vector of f with respect to X.

Variational Inequalities and Optimization Theory

Proposition

If $f(X)$ is a convex function and X^* is a solution to $\mathrm{VI}(\nabla f, \mathcal{K})$, then X^* is a solution to the optimization problem:

$$\textit{Minimize} \quad f(X)$$

subject to:

$$X \in \mathcal{K}.$$

In the case that the feasible set $\mathcal{K} = R^n$, then the unconstrained optimization problem is also a variational inequality problem.

The variational inequality problem can be reformulated as an optimization problem under certain symmetry conditions. The definitions of positive semidefiniteness, positive definiteness, and strongly positive definiteness are presented next, followed by stating the above relationship in a theorem.

Optimization and Supply Chain Networks

The types of optimization problems that are of relevance to supply chain networks, include:

- the minimization of costs,
- the maximization of profits,
- the minimization of risk, the minimization of pollution emissions,
- the minimization of delay,
- or a combination thereof, subject to the constraints being met.

Variational Inequalities and Game Theory

The Nobel laureate John Nash (1950, 1951) developed noncooperative game theory, involving multiple players, each of whom acts in his/her own interest.

In particular, consider a game with m players, each player i having a strategy vector $X_i = \{X_{i1}, ..., X_{in}\}$ selected from a closed, convex set $\mathcal{K}^i \subset R^n$. Each player i seeks to maximize his/her own utility function, U_i: $\mathcal{K} \rightarrow R$, where $\mathcal{K} = \mathcal{K}^1 \times \mathcal{K}^2 \times \ldots \times \mathcal{K}^m \subset R^{mn}$.

The utility of player i, U_i, depends not only on his/her own strategy vector, X_i, but also on the strategy vectors of all the other players, $(X_1, \ldots, X_{i-1}, X_{i+1}, \ldots, X_m)$.

An equilibrium is achieved if no one can increase his/her utility by unilaterally altering the value of its strategy vector. The formal definition of Nash equilibrium is:

Definition: Nash Equilibrium

A Nash equilibrium is a strategy vector

$$X^* = (X_1^*, \ldots, X_m^*) \in \mathcal{K},$$

such that

$$U_i(X_i^*, \hat{X}_i^*) \geq U_i(X_i, \hat{X}_i^*), \quad \forall X_i \in \mathcal{K}^i, \forall i,$$

where $\hat{X}_i^* = (X_1^*, \ldots, X_{i-1}^*, X_{i+1}^*, \ldots, X_m^*)$.

In other words, under Nash equilibrium, no unilateral deviation in strategy by any single player is profitable for that player.

Variational Inequalities and Game Theory

Given continuously differentiable and concave utility functions, U_i, $\forall i$, the Nash equilibrium problem can be formulated as a variational inequality problem defined on $\mathcal{K}$ (cf. Hartman and Stampacchia (1966), Gabay and Moulin (1980), and Nagurney (1999)).

Theorem: Variational Inequality Formulation of Nash Equilibrium

Under the assumption that each utility function U_i is continuously differentiable and concave, X^* is a Nash equilibrium if and only if $X^* \in \mathcal{K}$ is a solution of the variational inequality

$$\langle F(X^*), X - X^* \rangle \geq 0, \quad X \in \mathcal{K},$$

where $F(X) \equiv (-\nabla_{X_1} U_1(X), \ldots, -\nabla_{X_m} U_m(X))$ and $\nabla_{X_i} U_i(X) = (\frac{\partial U_i(X)}{\partial X_{i1}}, \ldots, \frac{\partial U_i(X)}{\partial X_{in}})$.

Game Theory and Supply Chain Networks

In game theory models of supply chain networks, each decision-maker (such as a firm) has his/her own objective function and constraints.

In the case of oligopolies, for example, the objective functions could be profits and the strategic variables the product flows.

Examples of oligopolies are:

- airlines
- freight carriers
- automobile manufacturers
- oil companies
- beer / beverage companies
- wireless communications
- fast fashion brands
- certain financial institutions.

Supply Chain Networks – Optimization Models

Blood Supply Chains for the Red Cross

A. Nagurney, A. Masoumi, and M. Yu, "Supply Chain Network Operations Management of a Blood Banking System with Cost and Risk Minimization," *Computational Management Science* **9(2)** (2012), pp 205-231.

Blood Supply Chains for the Red Cross

- Over 39,000 donations are needed everyday in the United States, and the blood supply is frequently reported to be just 2 days away from running out (American Red Cross (2010)).
- Hospitals with as many days of surgical delays due to blood shortage as 120 a year have been observed (Whitaker et al. (2007)).
- The national estimate for the number of units blood products outdated by blood centers and hospitals was 1,276,000 out of 15,688,000 units (Whitaker et al. (2007)).

The American Red Cross is the major supplier of blood products to hospitals and medical centers satisfying over 45% of the demand for blood components nationally (Walker (2010)).

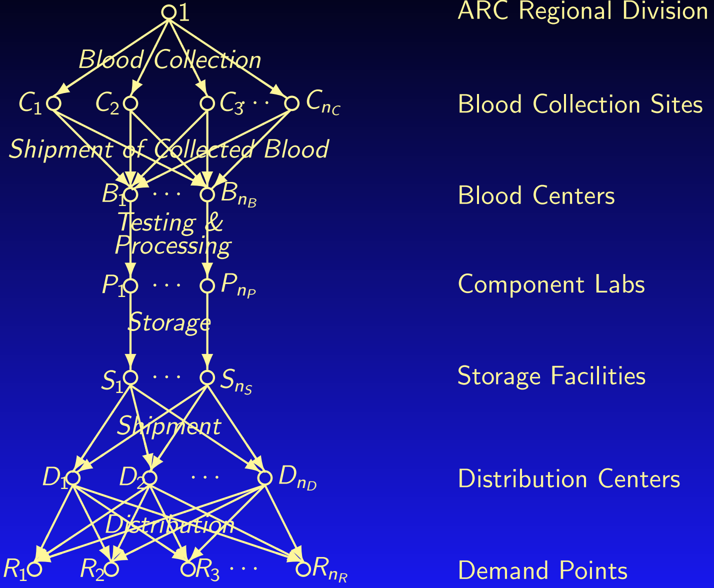
American Red Cross
Together, we can save a life

Background and Motivation

The hospital cost of a unit of red blood cells in the US had a 6.4% increase from 2005 to 2007.

In the US, this criticality has become more of an issue in the Northeastern and Southwestern states since this cost is meaningfully higher compared to that of the Southeastern and Central states.

Supply Chain Network Topology for a Regionalized Blood Bank



Blood Supply Chains for the Red Cross

We developed a supply chain network optimization model for the management of the procurement, testing and processing, and distribution of a perishable product – that of human blood.

Novel features of the model include:

- It captures *perishability of this life-saving product* through the use of arc multipliers;
- It contains *discarding costs* associated with waste/disposal;
- It handles *uncertainty* associated with demand points;
- It assesses *costs associated with shortages/surpluses at the demand points*, and
- It quantifies the *supply-side risk* associated with procurement.

Medical Nuclear Supply Chains

Medical nuclear supply chains are essential supply chains in healthcare and provide the conduits for products used in nuclear medical imaging, which is routinely utilized by physicians for diagnostic analysis for both cancer and cardiac problems.

Such supply chains have unique features and characteristics due to the products' time-sensitivity, along with their hazardous nature.

Salient Features:

- complexity
- economic aspects
- underlying physics of radioactive decay
- importance of considering both waste management and risk management.

Medical Nuclear Supply Chains

We developed a medical nuclear supply chain network design model which captures the decay of the radioisotope molybdenum.

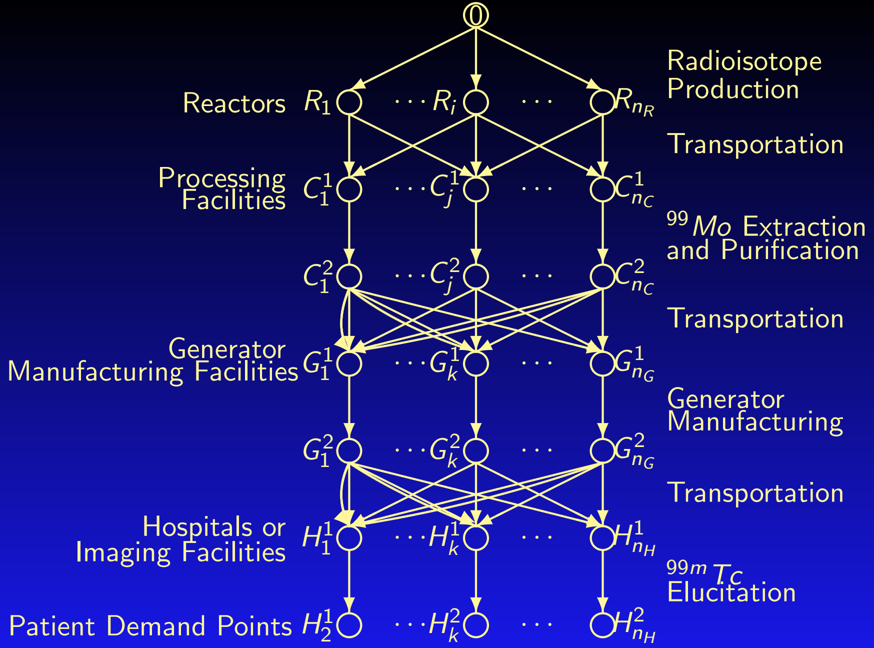


Figure 1: The Medical Nuclear Supply Chain Network Topology

Supply Chain Networks – Game Theory Models

Electric Power Supply Chains

We developed *an empirical, large-scale electric supply chain network equilibrium model*, formulated it as a VI problem, and were able to solve it by *exploiting the connection between electric power supply chain networks and transportation networks* using our proof of a hypothesis posed in the classic book, *Studies in the Economics of Transportation*, by Beckmann, McGuire, and Winsten (1956).

The paper, "An Integrated Electric Power Supply Chain and Fuel Market Network Framework: Theoretical Modeling with Empirical Analysis for New England," by Zugang Liu and Anna Nagurney was published in *Naval Research Logistics* **56** (2009), pp 600-624.

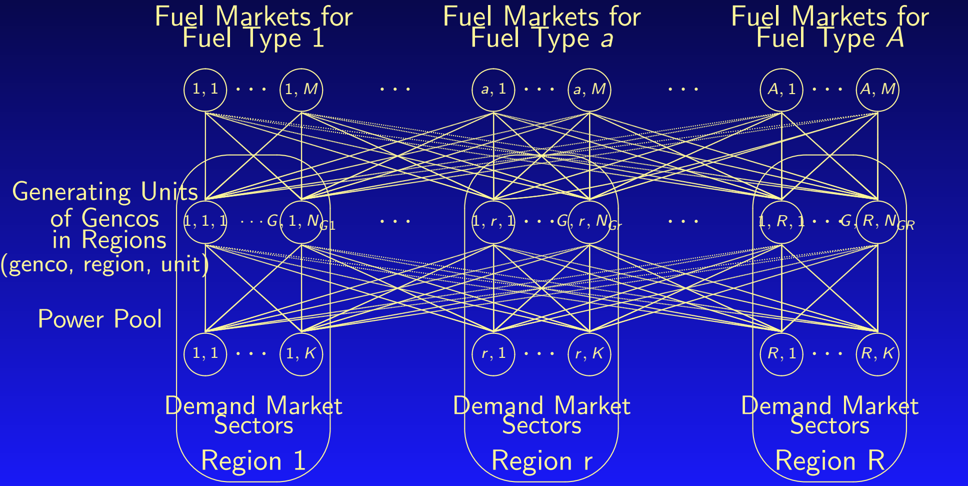
An Empirical Example of an Electric Power Supply Chain for New England

There are 82 generating companies who own and operate 573 generating units. We considered 5 types of fuels: natural gas, residual fuel oil, distillate fuel oil, jet fuel, and coal. The whole area was divided into 10 regions:

1. Maine,
2. New Hampshire,
3. Vermont,
4. Connecticut (excluding Southwest Connecticut),
5. Southwestern Connecticut (excluding the Norwalk-Stamford area),
6. Norwalk-Stamford area,
7. Rhode Island,
8. Southeastern Massachusetts,
9. Western and Central Massachusetts,
10. Boston/Northeast Massachusetts.

Graphic of New England

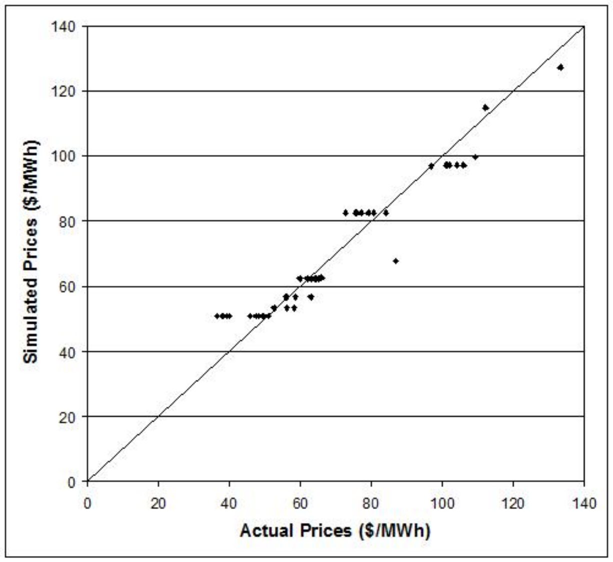
The Electric Power Supply Chain Network with Fuel Supply Markets



We tested the model on the data of July 2006 which included $24 \times 31 = 744$ hourly demand/price scenarios. We sorted the scenarios based on the total hourly demand, and constructed the load duration curve. We divided the duration curve into 6 blocks ($L_1 = 94$ hours, and $L_w = 130$ hours; $w = 2, \ldots, 6$) and calculated the average regional demands and the average weighted regional prices for each block.

The empirical model had on the order of $20,000$ *variables.*

Actual Prices Vs. Simulated Prices ($/Mwh)



Food Supply Chains

Food is something anyone can elate to.

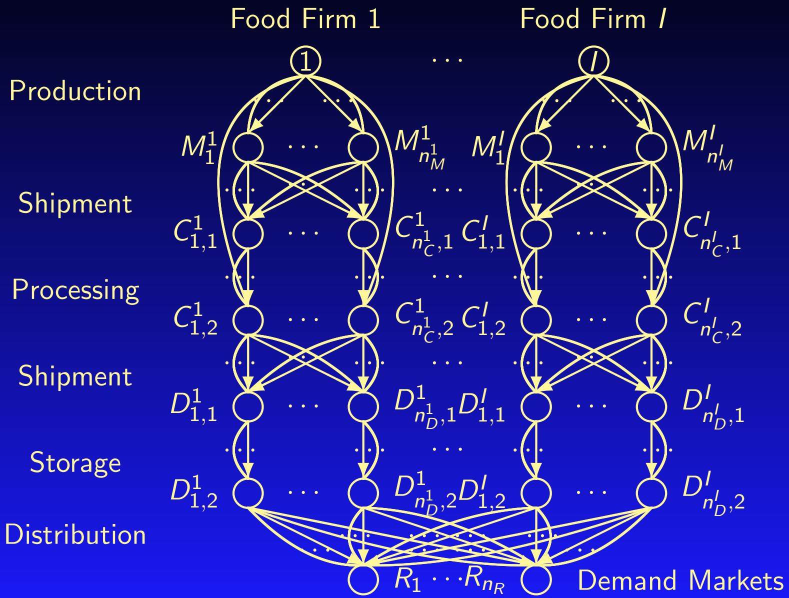
Fresh Produce Food Supply Chains

We developed a fresh produce supply chain network oligopoly model that

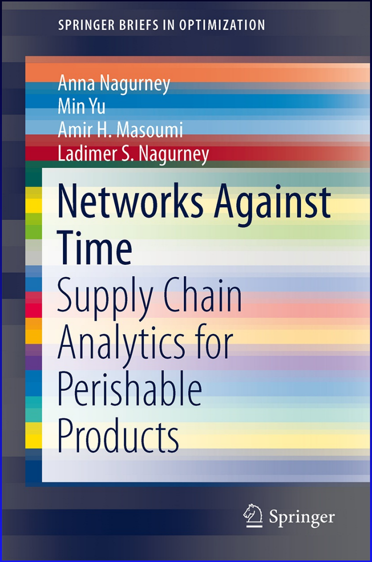
1. captures the deterioration of fresh food along the entire supply chain from a network perspective;
2. handles the exponential time decay through the introduction of arc multipliers;
3. formulates oligopolistic competition with product differentiation;
4. includes the disposal of the spoiled food products, along with the associated costs;
5. allows for the assessment of alternative technologies involved in each supply chain activity.

Reference: "Competitive Food Supply Chain Networks with Application to Fresh Produce," Min Yu and Anna Nagurney, *European Journal of Operational Research* **224(2)**, (2013), pp 273-282.

Fresh Produce Food Supply Chains



A variety of perishable product supply chain models, computational procedures, and applications can be found in our new book:



A Full Model
and
Application to Sustainable Fashion Supply Chains

This part of the lecture is based on the paper:

Anna Nagurney and Min Yu (2012), “Sustainable Fashion Supply Chain Management Under Oligopolistic Competition and Brand Differentiation,” *International Journal of Production Economics* **135**, Special Issue on Green Manufacturing and Distribution in the Fashion and Apparel Industries, pp 532-540.

Outline – A Full Model and Application to Sustainable Fashion Supply Chains

- Background and Motivation
- An Overview of the Relevant Literature
- The Sustainable Fashion Supply Chain Network Oligopoly Model
- The Algorithm
- Case Study with Managerial Insights
- Summary and Conclusions

Background and Motivation

The fashion and apparel industry is facing vast challenges in terms of the environmental impacts.

Background and Motivation

Organizations such as the Natural Resources Defense Council (NRDC) are now increasingly emphasizing that this industry's reduction of its environmental impacts will require that brands and retailers reexamine their supply chains way back to the inputs into their production processes and take more responsibility even for the fabric utilized (cf. Tucker (2010)).

Background and Motivation

- According to the Natural Resources Defense Council (NRDC), textile manufacturing pollutes as much as 200 tons of water per ton of fabric.

- In China, a textile factory may also burn about 7 tons of carbon emitting coal per ton of fabric produced (see Tucker (2010)).

Background and Motivation

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- Polyester is a man-made fiber whose demand from the fashion industry has doubled in the past 15 years. Its manufacture requires petroleum and releases emissions into the air and the water (see Claudio (2007)).

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- The production of cotton accounts for a quarter of all the pesticides used in the United States, which is the largest exporter of cotton in the world (see Claudio (2007)).

Background and Motivation

In the last three decades, there has been a migration of clothing manufacturers from developed to developing countries.

- Whereas in 1992 about 49% of all retail apparel sold in the United States was actually made there, by 1999 the proportion had fallen to just 12% (Rabon (2001)).
- Between 1990 and 2000, the value of apparel imports to the US increased from $25 billion to $64 billion.

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- Between 1990 and 2000, the value of apparel imports to the US increased from \$25 billion to \$64 billion.

Lower production cost is not the only reason for the globalization of apparel manufacturing. Some firms may be taking advantage of a looser environmental regulatory system and/or lower environmental impact awareness in developing nations (see Allwood et al. (2006)).

Xintang, the 'Jeans Capital' of the World

Background and Motivation

Given its global dimensions, it is crucial to realize the seriousness of emissions generated along the entire supply chains associated with the fashion and apparel industry, include emissions generated in the transportation and distribution of the products across oceans and vast tracts of land.

The demand to minimize the environmental pollution is coming not only from **consumers** but, more recently, even from **fashion firms** that wish to enhance or to maintain a positive brand identity (see, e.g., Claudio (2007), Glausiusz (2008), Rosenbloom (2010), Tucker (2010), and Zeller Jr. (2011)).

Background and Motivation

H&M has identified that 51% of its carbon imprint in 2009 was due to transportation. In order to reduce the associated emissions, it began more direct shipments that avoided intermediate warehouses, decreased the volumes shipped by ocean and air by 40% and increased the volume of products shipped by rail, resulting in an over 700 ton decrease in the amount of carbon dioxide emitted. (H&M (2010)).

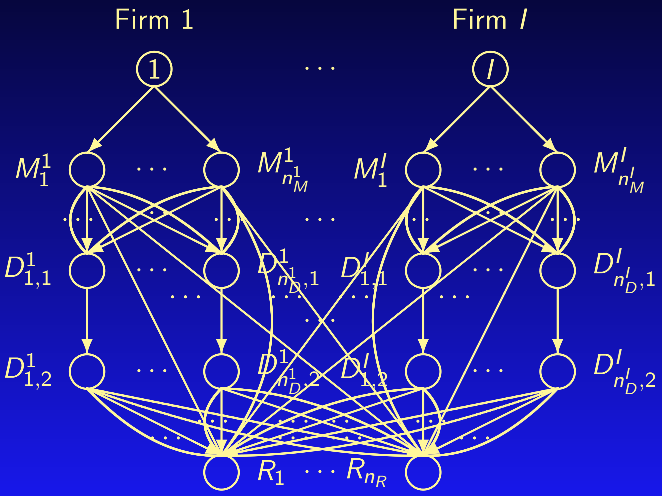
Relevant Literature

- Sustainable Supply Chains
  - Yeung et al. (2008) claimed that social compliance is one of the influentials of operational performance in the clothing manufacturing industry, especially for imported fashion products.
  - Beamon (1999), Sarkis (2003), Corbett and Kleindorfer (2003), Nagurney and Toyasaki (2003, 2005), Sheu, Chou, and Hu (2005), Kleindorfer, Singhal, and van Wassenhove (2005), Nagurney, Liu, and Woolley (2007), Linton, Klassen, and Jayaraman (2007), Piplani, Pujawan, and Ray (2008), Nagurney and Nagurney (2010), and Nagurney and Woolley (2010)
  - Wu et al. (2006), Nagurney, Liu, and Woolley (2006), and Chaabane, Ramudhin, and Paquet (2010)

The Sustainable Fashion Supply Chain Network Oligopoly Model

We consider a finite number of I fashion firms, with a typical firm denoted by i, who are involved in the production, storage, and distribution of a fashion product and who compete noncooperatively in an oligopolistic manner. Each firm corresponds to an individual brand representing the product that it produces.

The Fashion Supply Chain Network Topology of the Oligopoly



Demands, Path Flows, and Link Flows

Let d_{ik} denote the demand for fashion firm i's product at demand market k. The products of all these fashion firms are not homogeneous but are differentiated by *brand*.

Let x_p denote the nonnegative flow on path p joining (origin) node i; $i = 1, \ldots, I$ with a (destination) demand market node. Let f_a denote the flow on link a.

The Conservation of Flow Equations

$$\sum_{p \in P_k^i} x_p = d_{ik}, \quad k = 1, \ldots, n_R; \; i = 1, \ldots, I. \tag{1}$$

$$f_a = \sum_{p \in P} x_p \delta_{ap}, \quad \forall a \in L. \tag{2}$$

The demand price of fashion firm i's product at demand market R_k is denoted by ρ_{ik} and the demand price functions are assumed to be continuous, continuously differentiable and monotone decreasing.

$$\rho_{ik} = \rho_{ik}(d), \quad k = 1, \ldots, n_R; \ i = 1, \ldots, I. \tag{3}$$

The total operational cost on a link is assumed to be a function of the product flows on all the links, that is,

$$\hat{c}_a = \hat{c}_a(f), \quad \forall a \in L. \tag{4}$$

The total cost on each link is assumed to be convex and is continuously differentiable.
The profit function π_i of firm i; $i = 1, \ldots, I$, is:

$$\pi_i = \sum_{k=1}^{n_R} \rho_{ik}(d) \sum_{p \in P_k^i} x_p - \sum_{a \in L^i} \hat{c}_a(f). \tag{5}$$

The emission-generation function associated with link a, denoted by $\hat{e}_a$, is assumed to be a function of the product flow on that link, that is,

$$\hat{e}_a = \hat{e}_a(f_a), \quad \forall a \in L. \tag{6}$$

These functions are assumed to be convex and continuously differentiable.

Each fashion firm aims to minimize the total amount of emissions generated in the manufacture, storage, and shipment of its product.

$$\text{Minimize} \quad \sum_{a \in L^i} \hat{e}_a(f_a). \tag{7}$$

The Sustainable Fashion Supply Chain Network Oligopoly Model

The multicriteria decision-making problem faced by fashion firm i; $i = 1, \ldots, I$, is:

$$U_i = \sum_{k=1}^{n_R} \rho_{ik}(d) \sum_{p \in P_k^i} x_p - \sum_{a \in L^i} \hat{c}_a(f) - \omega_i \sum_{a \in L^i} \hat{e}_a(f_a), \qquad (8)$$

where the term ω_i is assumed to be the price that firm i would be willing to pay for each unit of emission on each of its links, representing the environmental concern of firm i.

In view of (1)-(8),

$$U = U(X), \qquad (9)$$

where U is the I-dimensional vector of all the firms' utilities.

Definition: Supply Chain Network Cournot-Nash Equilibrium

A path flow pattern $X^* \in K = \prod_{i=1}^{I} K_i$ *is said to constitute a supply chain network Cournot-Nash equilibrium if for each firm* i; $i = 1, \ldots, I$:

$$U_i(X_i^*, \hat{X}_i^*) \geq U_i(X_i, \hat{X}_i^*), \quad \forall X_i \in K_i, \tag{10}$$

where
$\hat{X}_i^* \equiv (X_1^*, \ldots, X_{i-1}^*, X_{i+1}^*, \ldots, X_I^*)$ *and* $K_i \equiv \{X_i | X_i \in R_+^{n_{P^i}}\}$.

Theorem: Variational Inequality Formulation

Assume that for each fashion firm i; $i = 1, \ldots, I$, the utility function $U_i(X)$ is concave with respect to the variables in X_i, and is continuously differentiable. Then $X^* \in K$ is a sustainable fashion supply chain network Cournot-Nash equilibrium if and only if it satisfies the variational inequality:

$$-\sum_{i=1}^{I} \langle \nabla_{X_i} U_i(X^*), X_i - X_i^* \rangle \geq 0, \quad \forall X \in K, \tag{11}$$

where $\langle \cdot, \cdot \rangle$ denotes the inner product in the corresponding Euclidean space and $\nabla_{X_i} U_i(X)$ denotes the gradient of $U_i(X)$ with respect to X_i.

Variational Inequality Formulation in Path Flows

The solution of variational inequality (11) is equivalent to the solution of the variational inequality: determine $x^* \in K^1$ satisfying:

$$\sum_{i=1}^{I}\sum_{k=1}^{n_R}\sum_{p\in P_k^i}\left[\frac{\partial \hat{C}_p(x^*)}{\partial x_p}+\omega_i\frac{\partial \hat{E}_p(x^*)}{\partial x_p}-\rho_{ik}(x^*)-\sum_{l=1}^{n_R}\frac{\partial \rho_{il}(x^*)}{\partial d_{ik}}\sum_{p\in P_l^i}x_p^*\right]$$

$$\times[x_p-x_p^*]\geq 0,\ \forall x\in K^1, \qquad (12)$$

where $K^1 \equiv \{x|x\in R_+^{n_P}\}$, $\frac{\partial \hat{C}_p(x)}{\partial x_p}\equiv \sum_{b\in L^i}\sum_{a\in L^i}\frac{\partial \hat{c}_b(f)}{\partial f_a}\delta_{ap}$ *and* $\frac{\partial \hat{E}_p(x)}{\partial x_p}\equiv \sum_{a\in L^i}\frac{\partial \hat{e}_a(f_a)}{\partial f_a}\delta_{ap}$.

Variational Inequality Formulation in Link Flows

In addition, (12) can be re-expressed in terms of link flows as: determine the vector of equilibrium link flows and the vector of equilibrium demands $(f^*, d^*) \in K^2$*, such that:*

$$\sum_{i=1}^{I} \sum_{a \in L^i} \left[\sum_{b \in L^i} \frac{\partial \hat{c}_b(f^*)}{\partial f_a} + \omega_i \frac{\partial \hat{e}_a(f_a^*)}{\partial f_a} \right] \times [f_a - f_a^*]$$

$$+ \sum_{i=1}^{I} \sum_{k=1}^{n_R} \left[-\rho_{ik}(d^*) - \sum_{l=1}^{n_R} \frac{\partial \rho_{il}(d^*)}{\partial d_{ik}} d_{il}^* \right] \times [d_{ik} - d_{ik}^*] \geq 0, \quad \forall (f, d) \in K^2, \tag{13}$$

where $K^2 \equiv \{(f, d) | \exists x \geq 0,$ *and* (1) *and* (2) *hold*$\}$.

Theorem: Existence

There exists at least one Nash Equilibrium, equivalently, at least one solution to variational inequality (12) (equivalently, (13)), since in the light of the demand price functions (3), there exists a $b > 0$*, such that variational inequality*

$$\langle F(X^b), X - X^b \rangle \geq 0, \quad \forall X \in \mathcal{K}_b, \tag{14}$$

admits a solution in $\mathcal{K}_b \equiv \{x | 0 \leq x \leq b\}$ *with*

$$x^b \leq b. \tag{15}$$

Theorem: Uniqueness

Variational inequality (13) admits at least one solution. Moreover, if the function $F(X)$ of variational inequality (13), is strictly monotone on $\mathcal{K} \equiv K^2$, that is,

$$\langle (F(X^1) - F(X^2)), X^1 - X^2 \rangle > 0, \quad \forall X^1, X^2 \in \mathcal{K}, \; X^1 \neq X^2. \quad (16)$$

then the solution to variational inequality (13) is unique, that is, the equilibrium link flow pattern and the equilibrium demand pattern are unique.

The Algorithm – The Euler Method

At an iteration τ of the Euler method (see Dupuis and Nagurney (1993) and Nagurney and Zhang (1996)) one computes:

$$X^{\tau+1} = P_{\mathcal{K}}(X^{\tau} - a_{\tau}F(X^{\tau})), \tag{17}$$

where $P_{\mathcal{K}}$ is the projection on the feasible set $\mathcal{K}$ and F is the function that enters the variational inequality problem: determine $X^* \in \mathcal{K}$ such that

$$\langle F(X^*), X - X^* \rangle \geq 0, \quad \forall X \in \mathcal{K}, \tag{18}$$

where $\langle \cdot, \cdot \rangle$ is the inner product in n-dimensional Euclidean space, $X \in R^n$, and $F(X)$ is an n-dimensional function from $\mathcal{K}$ to R^n, with $F(X)$ being continuous.

The sequence $\{a_{\tau}\}$ must satisfy: $\sum_{\tau=0}^{\infty} a_{\tau} = \infty$, $a_{\tau} > 0$, $a_{\tau} \rightarrow 0$, as $\tau \rightarrow \infty$.

Explicit Formulae for the Euler Method Applied to the Sustainable Fashion Supply Chain Network Oligopoly Variational Inequality (12)

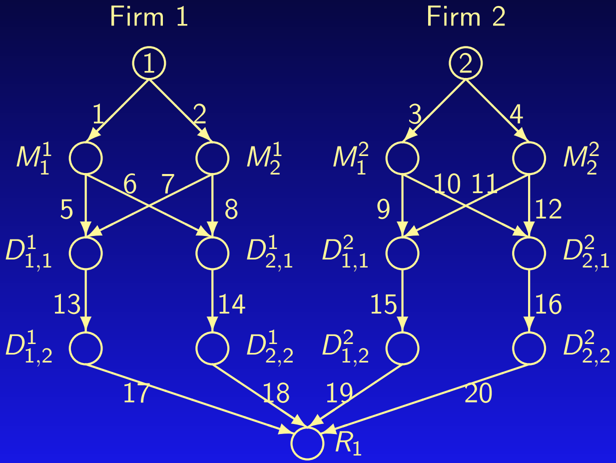
$$x_p^{\tau+1} = \max\{0, x_p^{\tau} + a_{\tau}(\rho_{ik}(x^{\tau}) + \sum_{l=1}^{n_R} \frac{\partial \rho_{il}(x^{\tau})}{\partial d_{ik}} \sum_{p \in P_l^i} x_p^{\tau}$$

$$- \frac{\partial \hat{C}_p(x^{\tau})}{\partial x_p} - \omega_i \frac{\partial \hat{E}_p(x^{\tau})}{\partial x_p})\}, \quad \forall p \in P_k^i, \forall k, \forall i. \qquad (19)$$

Case Study

There are two fashion firms, Firm 1 and Firm 2, each of which is involved in the production, storage, and distribution of a single fashion product, which is differentiated by its brand. Each firm has, at its disposal, two manufacturing plants, two distribution centers, and serves a single demand market. The manufacturing plants M_1^1 and M_1^2 are located in the United States, whereas the manufacturing plants M_2^1 and M_2^2 are located off-shore with lower operational costs. However, the demand market is in the United States as are the distribution centers.

The Fashion Supply Chain Network Topology for the Case Study



Problem Set 1

Fashion Firm 1 cares about the emissions that it generates much more than Firm 2 does, which is indicated by the respective values of ω_1 and ω_2, where $\omega_1 = 5$ and $\omega_2 = 1$. In addition, Firm 1 utilizes more advanced technologies in its supply chain activities in order to lower the emissions that it generates, but at relatively higher costs.

Total Cost and Total Emission Functions

Link a	$\hat{c}_a(f)$	$\hat{e}_a(f_a)$
1	$10f_1^2 + 10f_1$	$.05f_1^2 + .5f_1$
2	$f_2^2 + 7f_2$	$.1f_2^2 + .8f_2$
3	$10f_3^2 + 7f_3$	$.1f_3^2 + f_3$
4	$f_4^2 + 5f_4$	$.15f_4^2 + 1.2f_4$
5	$f_5^2 + 4f_5$	$.08f_5^2 + f_5$
6	$f_6^2 + 6f_6$	$.1f_6^2 + f_6$
7	$2f_7^2 + 30f_7$	$.15f_7^2 + 1.2f_7$
8	$2f_8^2 + 20f_8$	$.15f_8^2 + f_8$
9	$f_9^2 + 3f_9$	$.25f_9^2 + f_9$
10	$f_{10}^2 + 4f_{10}$	$.25f_{10}^2 + 2f_{10}$
11	$1.5f_{11}^2 + 30f_{11}$	$.4f_{11}^2 + 1.5f_{11}$
12	$1.5f_{12}^2 + 20f_{12}$	$.45f_{12}^2 + f_{12}$
13	$f_{13}^2 + 3f_{13}$	$.01f_{13}^2 + .1f_{13}$
14	$f_{14}^2 + 2f_{14}$	$.01f_{14}^2 + .15f_{14}$
15	$f_{15}^2 + 1.8f_{15}$	$.05f_{15}^2 + .3f_{15}$
16	$f_{16}^2 + 1.5f_{16}$	$.08f_{16}^2 + .5f_{16}$
17	$2f_{17}^2 + f_{17}$	$.08f_{17}^2 + f_{17}$
18	$f_{18}^2 + 4f_{18}$	$.1f_{18}^2 + .8f_{18}$
19	$f_{19}^2 + 5f_{19}$	$.3f_{19}^2 + 1.2f_{19}$
20	$1.5f_{20}^2 + f_{20}$	$.35f_{20}^2 + 1.2f_{20}$

Example 1

$$\rho_{11}(d) = -d_{11} - .2d_{21} + 300, \quad \rho_{21}(d) = -2d_{21} - .5d_{11} + 300.$$

Example 2

$$\rho_{21}(d) = -3d_{21} - .5d_{11} + 300.$$

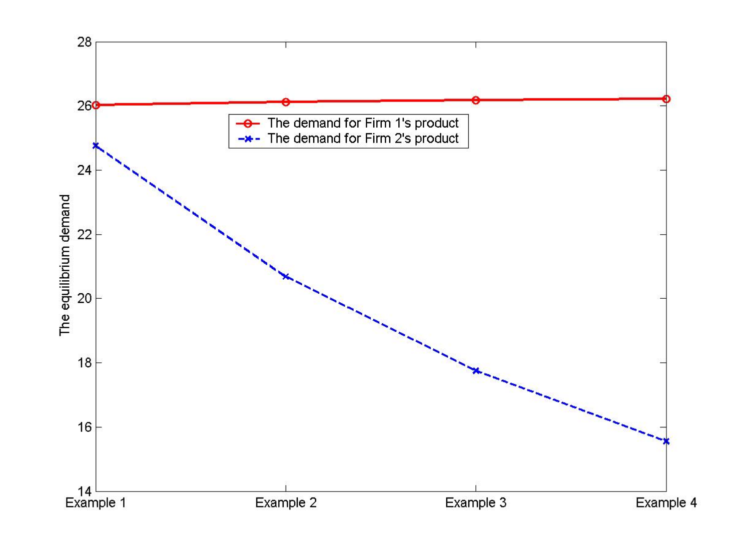
Example 3

$$\rho_{21}(d) = -4d_{21} - .5d_{11} + 300.$$

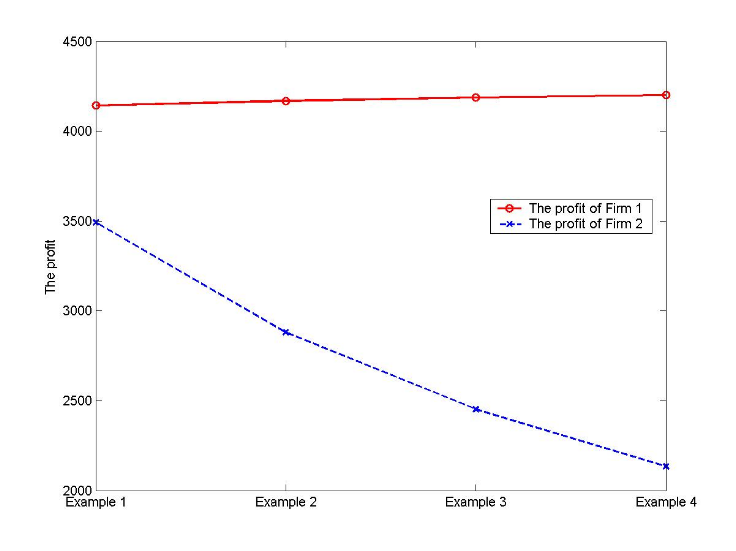
Example 4

$$\rho_{21}(d) = -5d_{21} - .5d_{11} + 300.$$

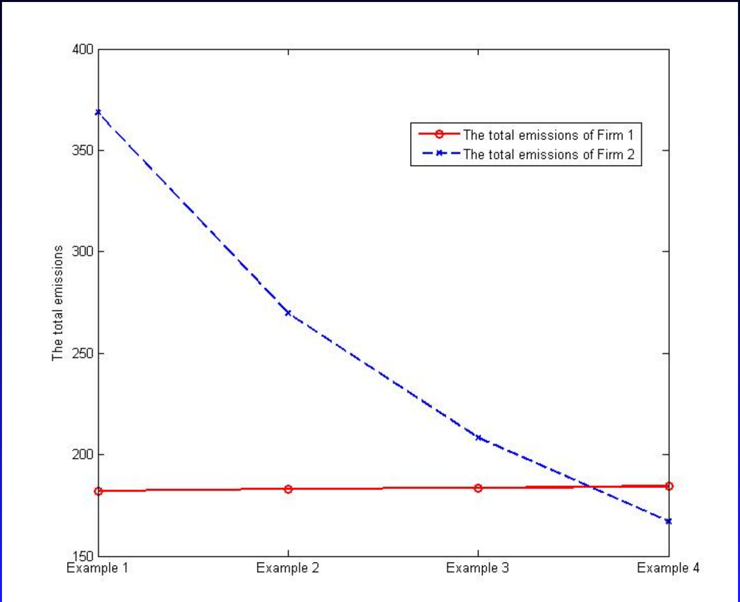
The Equilibrium Demands as ρ_{21} Varies



The Equilibrium Profits as ρ_{21} Varies



The Equilibrium Total Emissions as ρ_{21} Varies

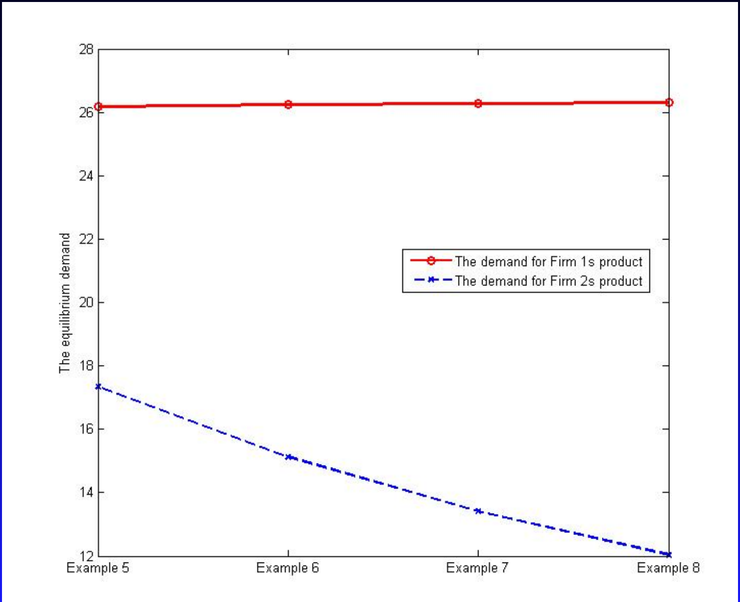


Problem Set 2

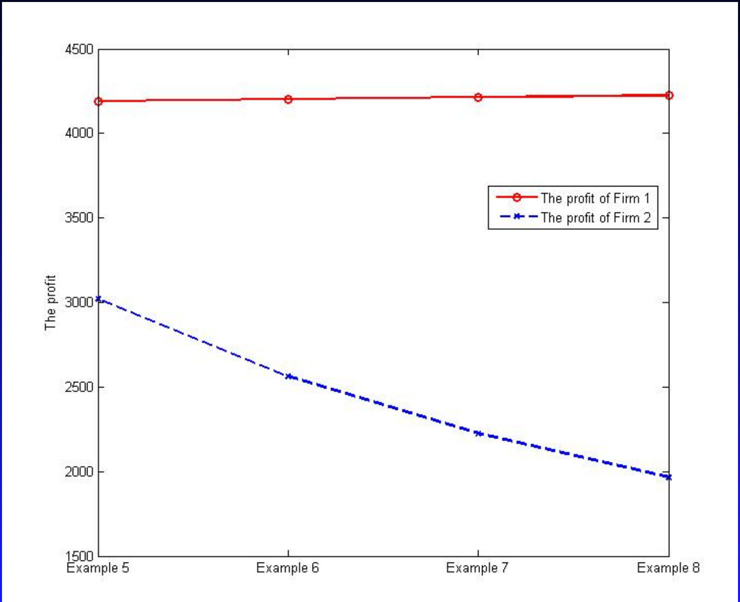
Firm 2 was now more environmentally conscious and raised ω_2 from 1 to 5. Hence, in this set of examples, Firm 1 and Firm 2 both had their ω weights equal to 5. Examples 5 through 8 had their data identical to the data in Examples 1 through 4, respectively, except for the larger value of ω_2.

The weights, the ω_is, may also be interpreted as *taxes* in that a governmental authority may impose a tax associated with carbon emissions, for example, that each firm must pay.

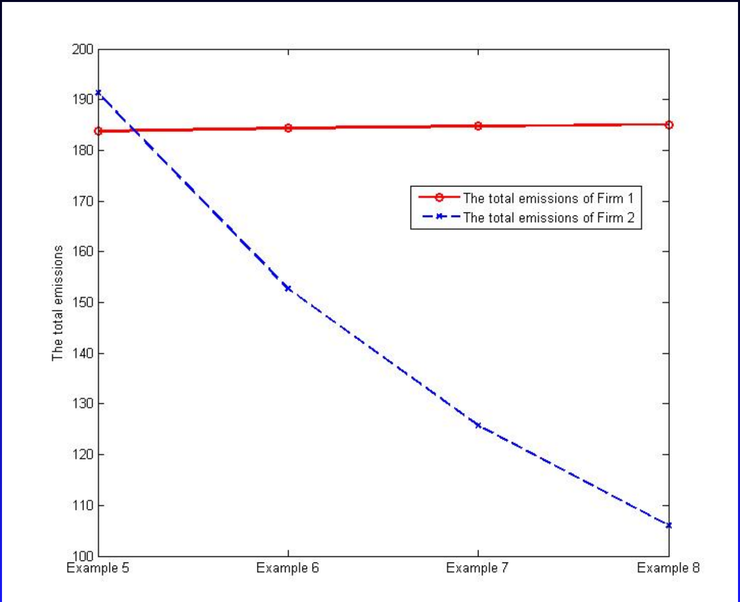
The Equilibrium Demands as ρ_{21} Varies



The Equilibrium Profits as ρ_{21} Varies



The Equilibrium Total Emissions as ρ_{21} Varies



We varied both the total cost functions and the total emission functions of Firm 2. Example 9

$$\hat{c}_3(f) = 10f_3^2 + 10f_3, \quad \hat{c}_4(f) = f_4^2 + 7f_4,$$

$$\hat{e}_3(f_3) = .05f_3^2 + .5f_3, \quad \hat{e}_4(f_4) = .1f_4^2 + .8f_4.$$

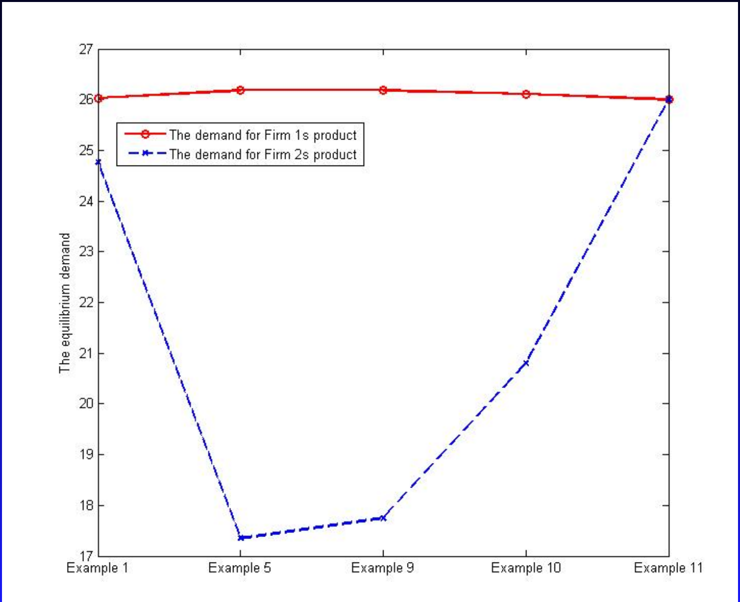
Example 10 Fashion Firm 2 made even a greater effort to lower its emissions, not only focusing on its manufacturing processes, but also on all other supply chain activities.
Example 11 Firm 1 and 2 were *identical*.

$$\rho_{11}(d) = -d_{11} - .2d_{21} + 300, \quad \rho_{21}(d) = -d_{21} - .2d_{11} + 300.$$

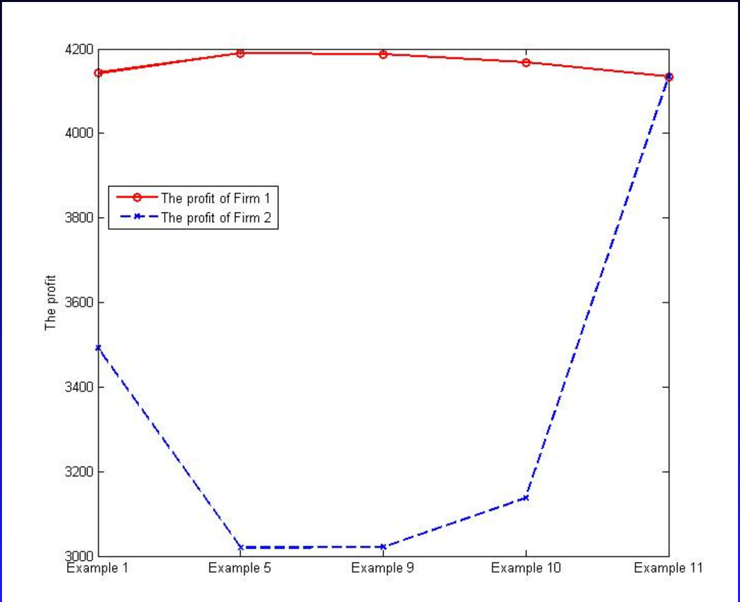
Total Cost and Total Emission Functions for Example 10

Link a	$\hat{c}_a(f)$	$\hat{e}_a(f_a)$
1	$10f_1^2 + 10f_1$	$.05f_1^2 + .5f_1$
2	$f_2^2 + 7f_2$	$.1f_2^2 + .8f_2$
3	$10f_3^2 + 10f_3$	$.05f_3^2 + .5f_3$
4	$f_4^2 + 7f_4$	$.1f_4^2 + .8f_4$
5	$f_5^2 + 4f_5$	$.08f_5^2 + f_5$
6	$f_6^2 + 6f_6$	$.1f_6^2 + f_6$
7	$2f_7^2 + 30f_7$	$.15f_7^2 + 1.2f_7$
8	$2f_8^2 + 20f_8$	$.15f_8^2 + f_8$
9	$f_9^2 + 4f_9$	$.08f_9^2 + f_9$
10	$f_{10}^2 + 6f_{10}$	$.1f_{10}^2 + f_{10}$
11	$2f_{11}^2 + 30f_{11}$	$.15f_{11}^2 + 1.2f_{11}$
12	$2f_{12}^2 + 20f_{12}$	$.15f_{12}^2 + f_{12}$
13	$f_{13}^2 + 3f_{13}$	$.01f_{13}^2 + .1f_{13}$
14	$f_{14}^2 + 2f_{14}$	$.01f_{14}^2 + .15f_{14}$
15	$f_{15}^2 + 3f_{15}$	$.01f_{15}^2 + .1f_{15}$
16	$f_{16}^2 + 2f_{16}$	$.01f_{16}^2 + .15f_{16}$
17	$2f_{17}^2 + f_{17}$	$.08f_{17}^2 + f_{17}$
18	$f_{18}^2 + 4f_{18}$	$.1f_{18}^2 + .8f_{18}$
19	$2f_{19}^2 + f_{19}$	$.08f_{19}^2 + f_{19}$
20	$f_{20}^2 + 4f_{20}$	$.1f_{20}^2 + .8f_{20}$

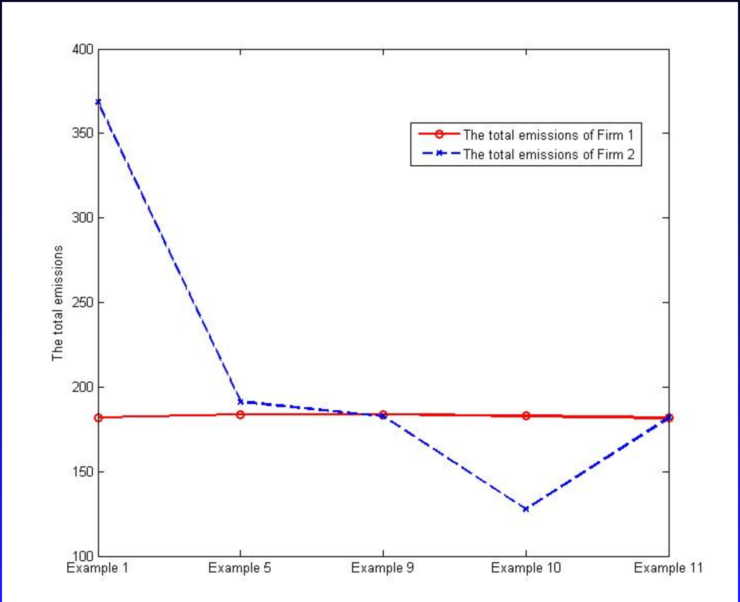
Comparison of the Equilibrium Demands



Comparison of the Equilibrium Profits



Comparison of the Equilibrium Total Emissions



Case Study

- Consumers' environmental consciousness can be a valuable incentive to spur fashion companies to reexamine their supply chains so as to reduce their environmental pollution, which can, in turn, help such companies to obtain competitive advantages and increased profits.
- The development of a positive image for a firm in terms of its environmental consciousness and concern may also be an effective marketing strategy for fashion firms.

Other Issues That Have Been Explored Using Supply Chain Network Theory

Outline – Other Issues that Have Been Explored Using Supply Chain Network Theory

- Mergers & Acquisitions
- Integration of Social Networks with Supply Chains and with Financial Networks
- Supply Chain Networks for Rescue, Recovery and Reconstruction in Disasters
- The Nagurney-Qiang (N-Q) Network Efficiency / Performance Measure
- Design of Supply Chains for Critical Needs Products
- Summary, Conclusions, and Suggestions for Future Research

Mergers & Acquisitions

Merger & Acquisition Activity

M&As totaled over $2 trillion in 2009, down 32% from full-year 2008 and down 53% from the record high in 2007, according to data from Thomson Reuters.

Mergers announced in October 2010 include Bain Capital / Gymboree, at $1.789 billion and Dynamex / Greenbriar Equity Group ($207 million).

Some of the most visible recent mergers have occurred in the airline industry with Delta and Northwest completing their merger in October 2008 and United and Continental closing on the formation of United Continental Holdings Oct. 1, 2010.

Merger & Acquisition Activity

Global 2010 M&A activity is estimated to rise as much as 35% from 2009 figures (Sanford C. Bernstein research firm).

Successful mergers can add tremendous value; however, the failure rate is estimated to be between 74% and 83% (Devero (2004)).

It is worthwhile to develop tools to better predict the associated strategic gains, which include, among others, cost savings (Eccles, Lanes, and Wilson (1999)).

Mergers and Acquisitions and Network Synergies

A successful merger depends on the ability to measure the anticipated synergy of the proposed merger (cf. Chang (1988)) .

- A. Nagurney, “A System-Optimization Perspective for Supply Chain Network Integration: The Horizontal Merger Case,” *Transportation Research E* (2009) **45**, pp 1-15.

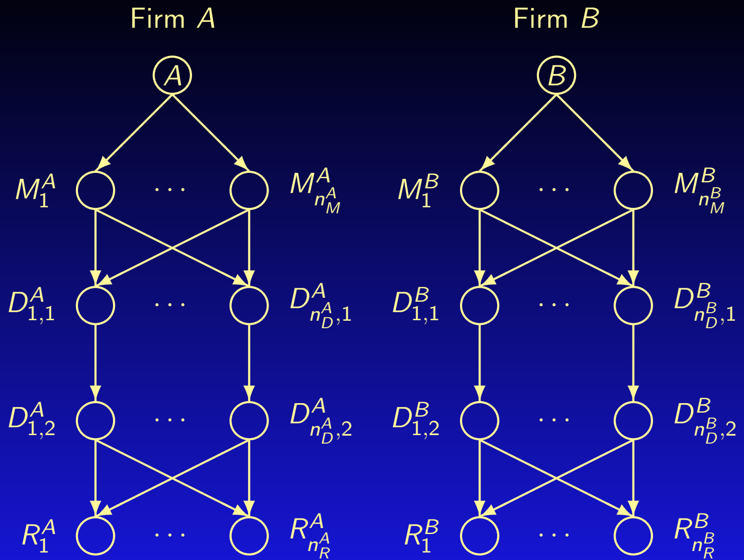


Figure 3: Case 0: Firms A and B Prior to Horizontal Merger

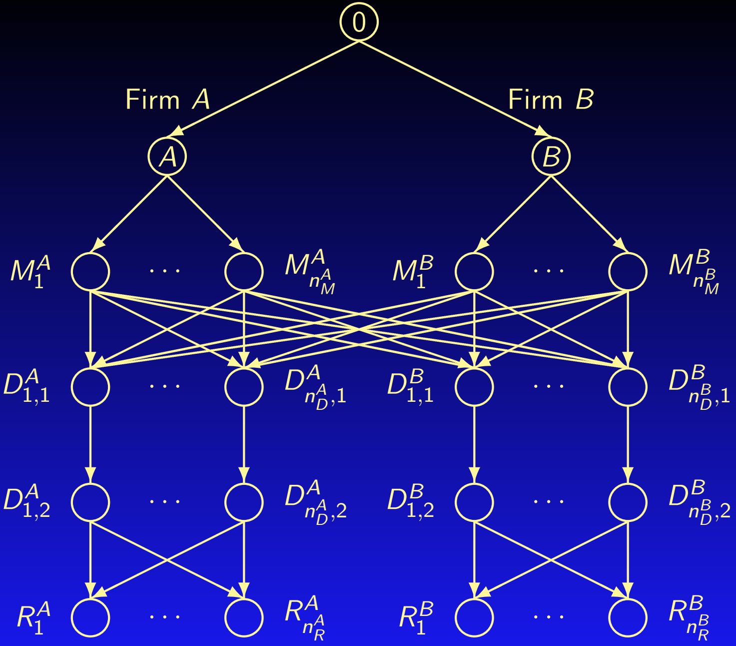


Figure 4: Case 1: Firms A and B Merge

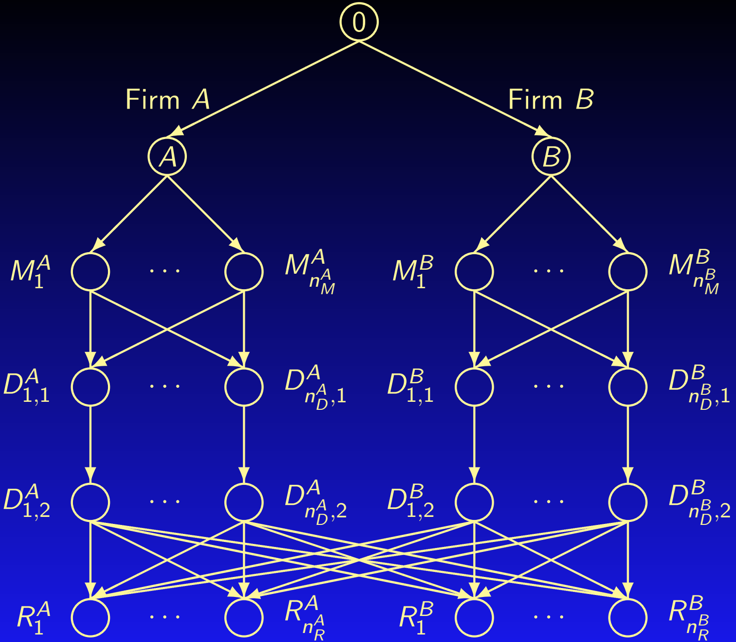


Figure 5: Case 2: Firms A and B Merge

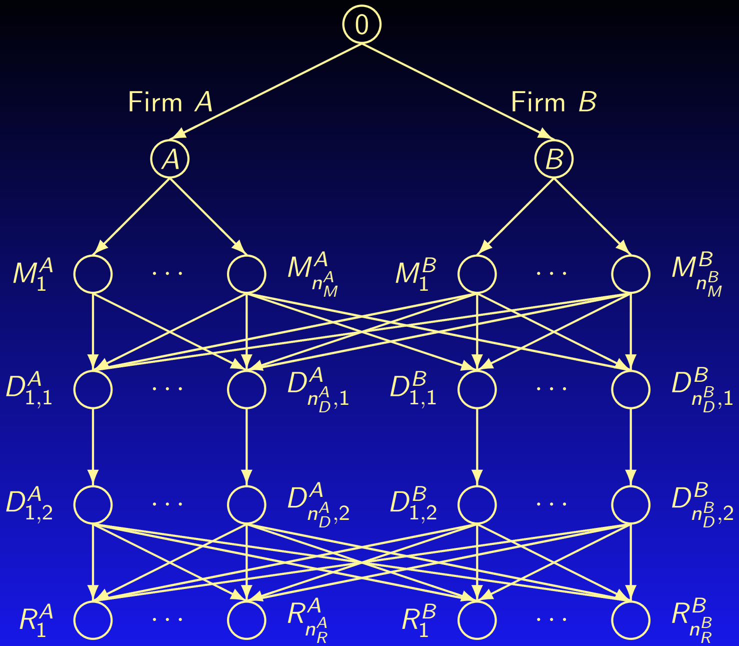


Figure 6: Case 3: Firms A and B Merge

Synergy Measure

The measure that we utilized in Nagurney (2009) 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*.

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

Bellagio Conference on Humanitarian Logistics

See: http://hlogistics.isenberg.umass.edu/

The Supply Chain Network Oligopoly Model

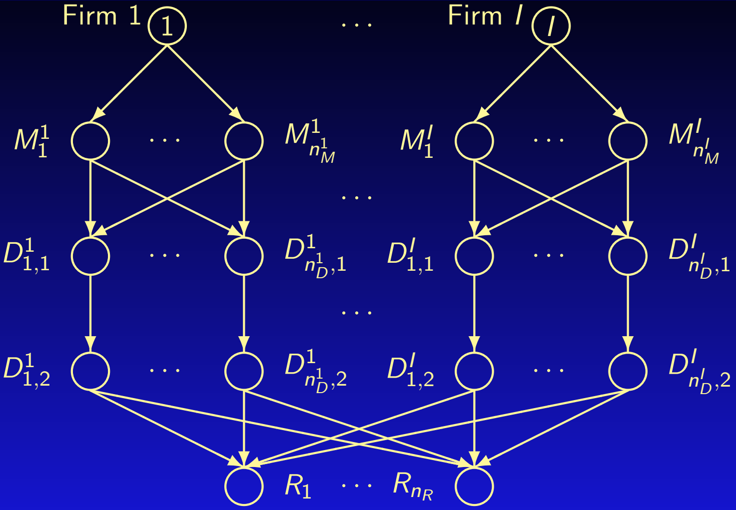


Figure 7: Supply Chain Network Structure of the Oligopoly

Nagurney *Computational Management Science* (2010) **7**, pp 377-401.

Mergers Through Coalition Formation

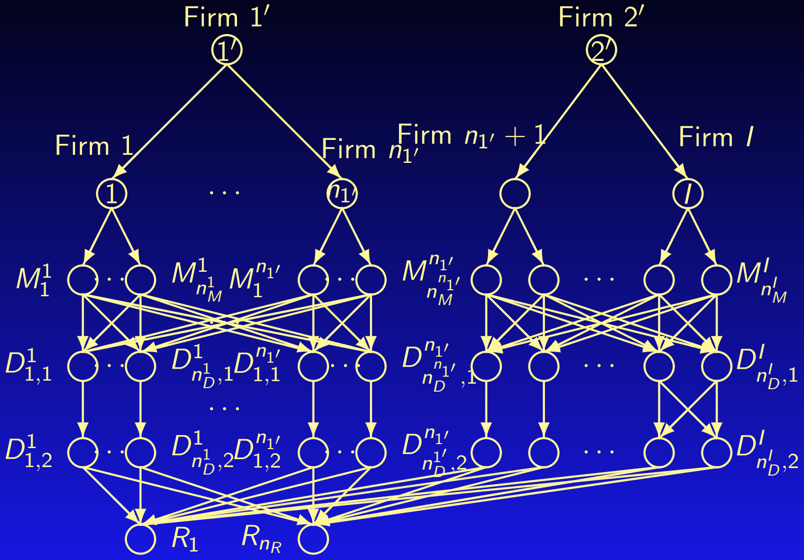


Figure 8: Mergers of the First $n_{1'}$ Firms and the Next $n_{2'}$ Firms

Integration of Social Networks
with
Supply Chains and with Financial Networks

Integration of Social Networks with Supply Chains and with Financial Networks

Two References:

A. Nagurney, T. Wakolbinger, and L. Zhao (2006) "The Evolution and Emergence of Integrated Social and Financial Networks with Electronic Transactions: A Dynamic Supernetwork Theory for the Modeling, Analysis, and Computation of Financial Flows and Relationship Levels," *Computational Economics* **27**, pp 353-393.

J. M. Cruz, A. Nagurney, and T. Wakolbinger (2006) "Financial Engineering of the Integration of Global Supply Chain Networks and Social Networks with Risk Management," *Naval Research Logistics* **53**, pp 674-696.

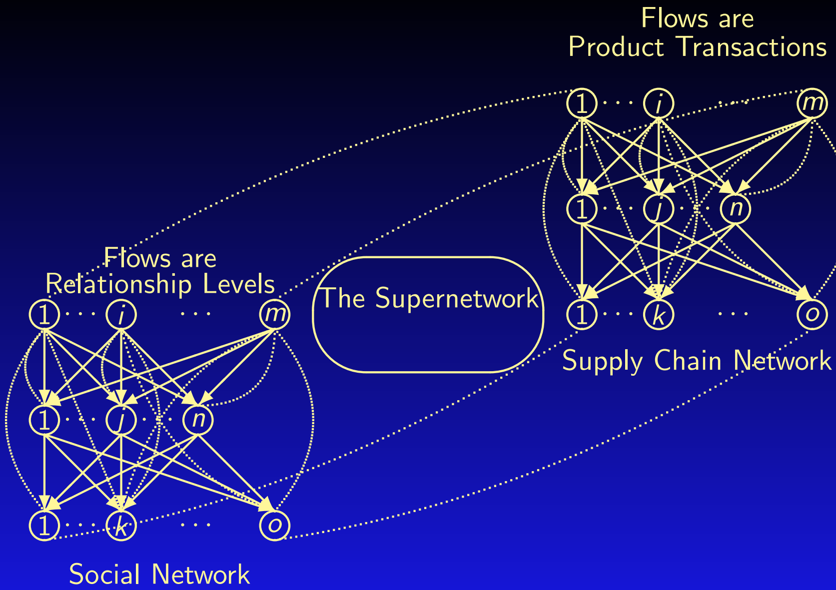


Figure 9: The Multilevel Supernetwork Structure of the Integrated Supply Chain / Social Network System

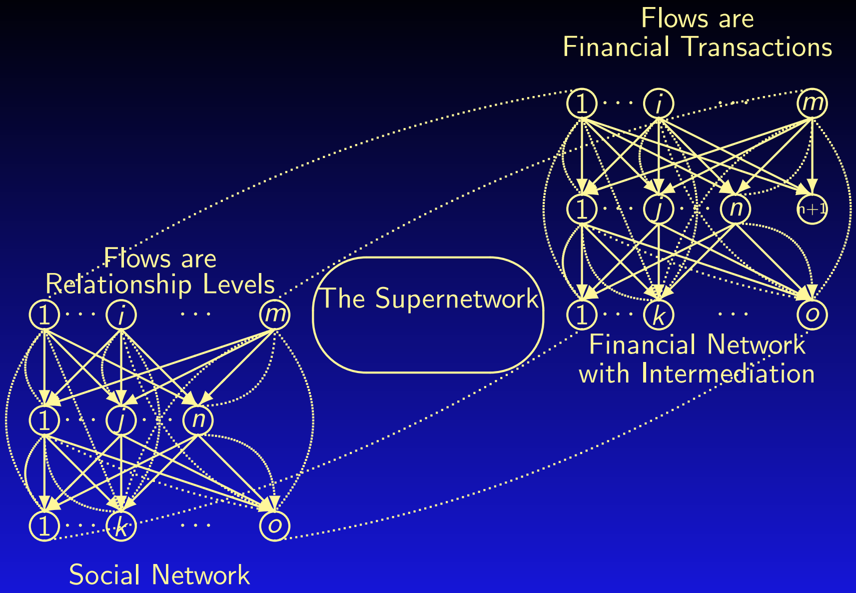


Figure 10: The Multilevel Supernetwork Structure of the Integrated Financial Network / Social Network System

Supply Chain Networks
for
Rescue, Recovery and Reconstruction in Disasters

Supply chains are the *fundamental critical infrastructure* for the production and distribution of goods and services in our globalized *Network Economy*.

Supply chain networks also serve as the primary conduit for *rescue, recovery, and reconstruction in disasters.*

Recent disasters have vividly demonstrated the importance and vulnerability of our transportation and critical infrastructure systems

- 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;
- The Indonesian tsunami (and earthquake), December 26, 2004;
- Hurricane Katrina, August 23, 2005;
- The Minneapolis I35 Bridge collapse, August 1, 2007;
- The Mediterranean cable destruction, January 30, 2008;
- The Sichuan earthquake on May 12, 2008;
- The Haiti earthquake that struck on January 12, 2010 and the Chilean one on February 27, 2010;
- The triple disaster in Japan on March 11, 2011.

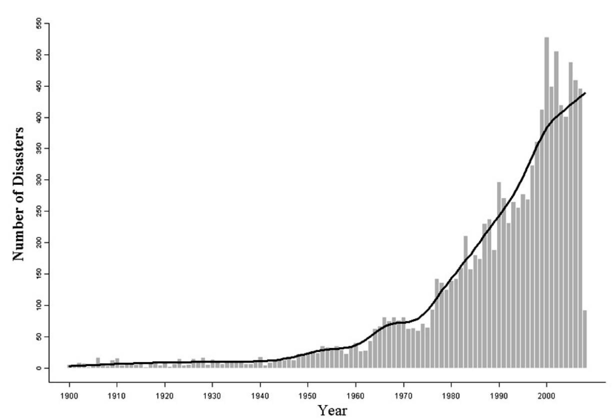
Hurricane Katrina in 2005


Hurricane Katrina has been called an *"American tragedy,"* in which essential services failed completely.

The Haitian and Chilean Earthquakes

The Triple Disaster in Japan on March 11, 2011

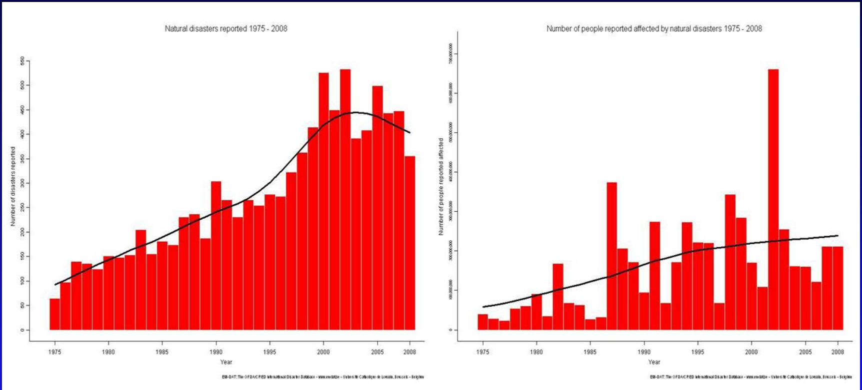
Disasters have brought an unprecedented impact on human lives in the 21st century and the number of disasters is growing. From January to October 2005, *an estimated 97,490 people were killed in disasters globally; 88,117 of them because of natural disasters*.



Frequency of disasters [Source: Emergency Events Database (2008)]

Disasters have a catastrophic effect on human lives and a region's or even a nation's resources.

Natural Disasters (1975–2008)



Which Nodes and Links Really Matter?

The Nagurney-Qiang (N-Q) Network Efficiency / Performance Measure

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

Definition: A Unified Network Performance Measure

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

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

where recall that n_W is the number of O/D pairs in the network, and d_w and λ_w denote, for simplicity, the equilibrium (or fixed) demand and the equilibrium disutility for O/D pair w, respectively.

The Importance of Nodes and Links

Definition: Importance of a Network Component

The importance of a network component $g \in \mathcal{G}$, $I(g)$, is measured by the relative network efficiency drop after g is removed from the network:

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

where $\mathcal{G} - g$ is the resulting network after component g is removed from network $\mathcal{G}$.

The Approach to Identifying 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.

The N-Q measure is well-defined even in the case of disconnected networks.

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*.

- It can be applied to *assess the efficiency/performance of a wide range of network systems, including financial systems and supply chains under risk and uncertainty*.

- It is applicable also to *elastic demand networks*.

- It is *applicable to dynamic networks*, *including the Internet*.

Some Applications of the N-Q Measure

The Sioux Falls Network

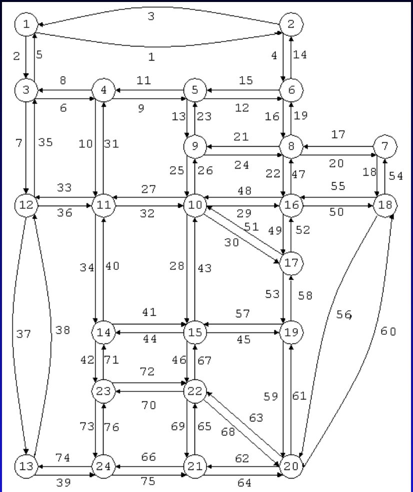


Figure 11: The Sioux Falls network with 24 nodes, 76 links, and 528 O/D pairs of nodes.

Importance of Links in the Sioux Falls Network

The computed network efficiency measure $\mathcal{E}$ for the Sioux Falls network is $\mathcal{E} = 47.6092$. Links 27, 26, 1, and 2 are the most important links, and hence special attention should be paid to protect these links accordingly, while the removal of links 13, 14, 15, and 17 would cause the least efficiency loss.

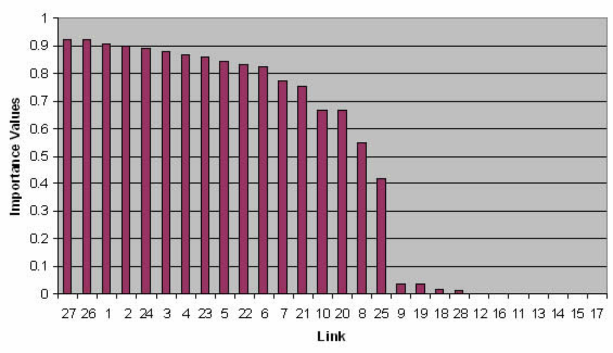


Figure 12: The Sioux Falls network link importance rankings

According to the European Environment Agency (2004), *since 1990, the annual number of extreme weather and climate related events has doubled, in comparison to the previous decade*. These events account for approximately 80% of all economic losses caused by catastrophic events. In the course of climate change, catastrophic events are projected to occur more frequently (see Schulz (2007)).

Schulz (2007) applied *N-Q network efficiency measure to a German highway system in order to identify the critical road elements* and found that this measure provided more reasonable results than the measure of Taylor and DEste (2007).

The N-Q measure can also be used to assess which links should be added to improve efficiency. *This measure was used for the evaluation of the proposed North Dublin (Ireland) Metro system* (October 2009 Issue of *ERCIM News*).

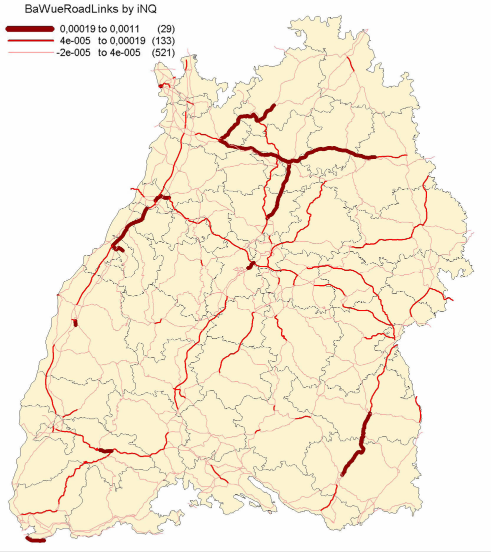


Figure 13: Comparative Importance of the links for the Baden - Wurttemberg Network – Modelling and analysis of transportation networks in earthquake prone areas via the N-Q measure, Tyagunov et al.

What About Disaster Relief?

Humanitarian Relief

The period between 2000-2004 experienced an average annual number of disasters that was 55% higher than the period of 1995-1999 with 33% more people affected in the more recent period.

Humanitarian Relief

Humanitarian Supply Chains

The supply chain is a critical component not only of corporations but also of humanitarian organizations and their logistical operations.

At least 50 cents of each dollar's worth of food aid is spent on transport, storage and administrative costs.

Vulnerability of Humanitarian Supply Chains

Extremely poor logistical infrastructures: Modes of transportation include trucks, barges, donkeys in Afghanistan, and elephants in Cambodia.

To ship the humanitarian goods to the affected area in the first 72 hours after disasters is crucial. The successful execution is not just a question of money but a difference between life and death.

Corporations expertise with logistics could help public response efforts for nonprofit organizations.

In the humanitarian sector, organizations are 15 to 20 years behind, as compared to the commercial arena, regarding supply chain network development.

Illustrations of Supply Chain Risk

It is clear that better-designed supply chain networks in which transportation plays a pivotal role would have facilitated and enhanced various emergency preparedness and relief efforts and would have resulted in less suffering and lives lost.

Design of Supply Chains for Critical Needs Products

Critical Needs Products

Critical needs products are those that are *essential to the survival of the population*, and can include, for example, vaccines, medicine, food, water, etc., depending upon the particular application.

The demand for the product should be met as nearly as possible since otherwise there may be additional loss of life.

In times of crises, a *system-optimization* approach is mandated since the demands for critical supplies should be met (as nearly as possible) at minimal total cost.

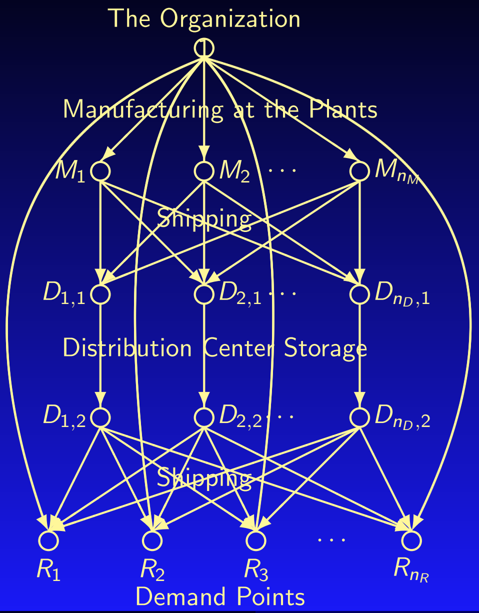
We have now developed a framework for the optimal design of critical needs product supply chains:

"Supply Chain Network Design for Critical Needs with Outsourcing,"

A. Nagurney, M. Yu, and Q. Qiang, *Papers in Regional Science* (2011), **90**, 123-142,

where additional background as well as references can be found.

Supply Chain Network Topology with Outsourcing



Applications to Vaccine Production

By applying the general theoretical model to the company's data, the firm can determine whether it needs to expand its facilities (or not), how much of the vaccine to produce where, how much to store where, and how much to have shipped to the various demand points. Also, it can determine whether it should outsource any of its vaccine production and at what level.

The firm by solving the model with its company-relevant data can then ensure *that the price that it receives for its vaccine production and delivery is appropriate* and that it recovers its incurred costs and obtains, if negotiated correctly, an equitable profit.

Applications to Emergencies

A company can, using the model, prepare and plan for an emergency such as a natural disaster in the form of a hurricane and identify where to store a necessary product (such as food packets, for example) so that the items can be delivered to the demand points in a timely manner and at minimal total cost.

Summary, Conclusions, and Suggestions for Future Research

- We discussed the *new era of networks of networks*.
- We emphasized the *importance of capturing behavior* in network modeling, analysis, and design and various paradoxes.
- We noted a *variety of supply chain network issues*: the addition of links; the integration of networks as in mergers and acquisitions; disaster relief issues.
- We presented a competitive sustainable fashion supply chain network model;
- We presented the *Nagurney-Qiang network performance / efficiency measure* and how it has been applied to identify the importance and rankings of nodes and links along with various applications.

- We noted an *integrated framework for the design of supply chain networks for critical products* with outsourcing and discussed humanitarian operations applications.
- Our recent research in network design has also considered oligopolistic markets.
- In addition, we have been heaving involved in *constructing mathematical models that capture the impacts of foreign exchange risk and competition intensity* on supply chain companies who are involved in offshore outsourcing activities.
- Our research in supply chain networks has also led us to other time-sensitive products, and
- Finally, we have continued our research on modeling *disequilibrium dynamics and equilibrium states in ecological predator-prey networks*, that is, supply chains in nature.

- We expect that future research will include supply chain network design for robustness and resiliency.

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