From Supernetworks to Supply Chains in the Pandemic

Anna Nagurney

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Chancellor's Donor Appreciation Breakfast – November 6, 2021

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Alumnus Jack Smith Jr. and the Chaired Professorship

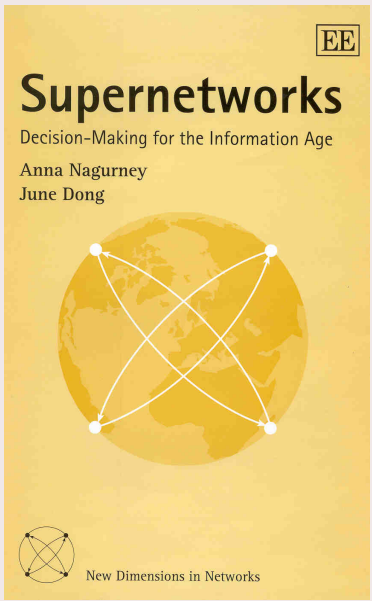
In 1998, I had the honor of being appointed the John F. Smith Memorial Professor and meeting the benefactor, Jack Smith Jr., class of 1960, who endowed this chaired professorship in honor of his father.

- Jack Smith Jr. was the Chairman of the Board of General Motors from 1996 to 2003 and the CEO from 1992 to 2000.
- He was a member of Delta's Board of Directors from 2000 and the Chairman of the Board of Directors of Delta Air Lines from 2004 until his retirement in 2007.

Alumnus Jack Smith Jr. and the Chaired Professorship

The Supernetworks Book and the Founding of the Center

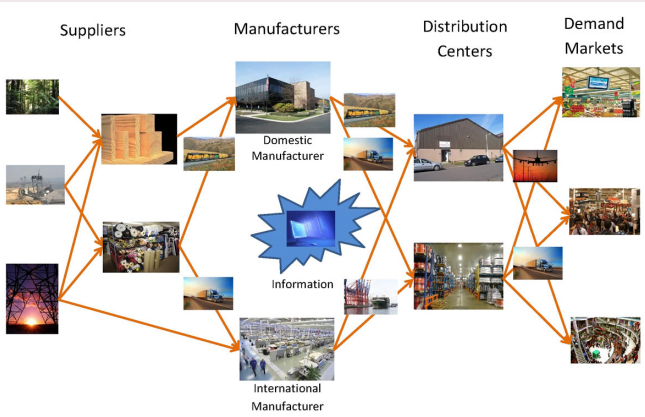
The book, "Supernetworks: Decision-Making for the Information Age," was written in 2001.

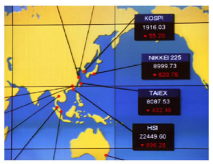


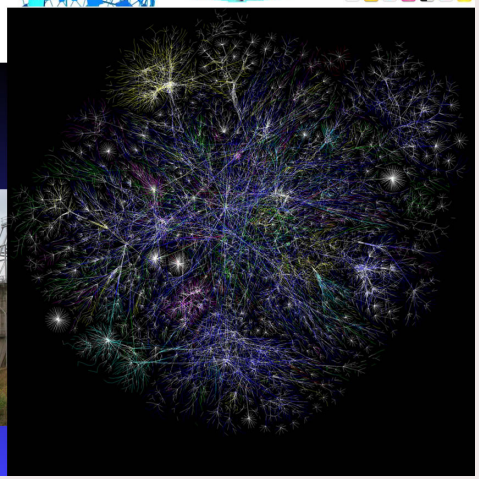
The Virtual Center for Supernetworks was established in the Fall of 2001, after several NSF grants plus an AT&T Industrial Ecology Fellowship.

Supernetworks

Supernetworks are networks of networks and their applications are vast and growing.







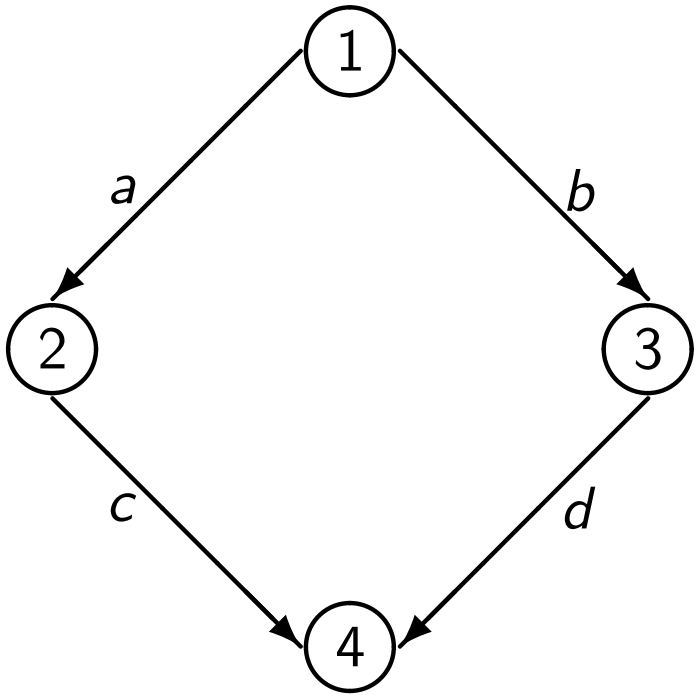
The study of supernetworks focuses on the interactions among networks that underpin our societies and economies.

Importance of Capturing Behavior on Networks - The Braess (1968) Paradox and User-Optimizing (U-O) Behavior

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



$$c_a(f_a) = 10f_a, \quad c_b(f_b) = f_b + 50,$$
$$c_c(f_c) = f_c + 50, \quad c_d(f_d) = 10f_d.$$

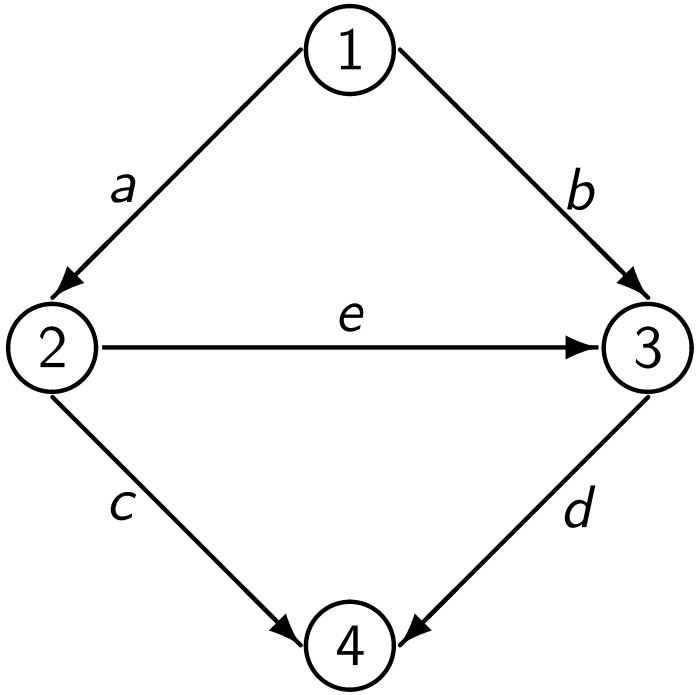
Adding a Link Increases Travel Cost for All!

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
$x^*_{p_1} = x^*_{p_2} = x^*_{p_3} = 2$.

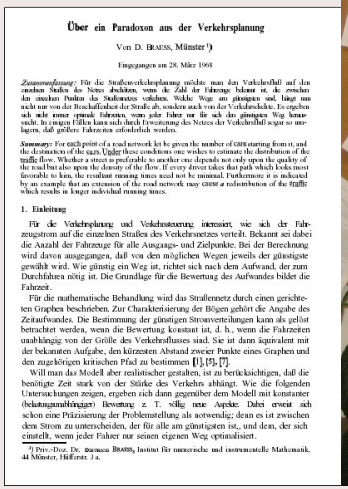
The equilibrium path travel cost: $C_{p_1} = C_{p_2} = C_{p_3} = 92$.



$c_e(f_e) = f_e + 10$

We Translate the Braess Article from German to English and Host Braess

The 1968 Braess article has been translated from German to English: "On a Paradox of Traffic Planning," D. Braess, A. Nagurney, and T. Wakolbinger, *Transportation Science* **39 (2005), pp 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 verlangsamen, 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.

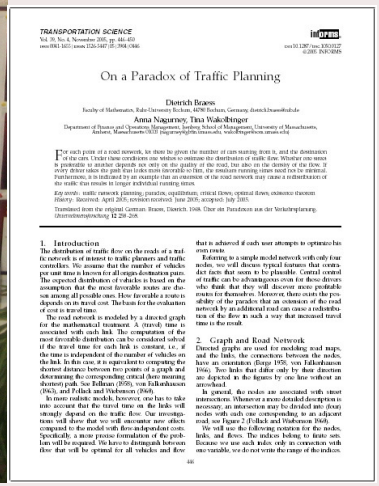
1. Einleitung

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, Hittorfstr. 3 a.



TRANSPORTATION SCIENCE
Vol. 39, No. 4, November 2005, pp. 446–450

On a Paradox of Traffic Planning

Dietrich Braess
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Department of Finance and Operations Management, Isenberg School of Management, University of Massachusetts, Amherst, Massachusetts 01003 {nagurney@gbfin.umass.edu, wakolbin@som.umass.edu}

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; extension 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 Ballman (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 such index only in connection with one variable, we do not write the range of the indices.

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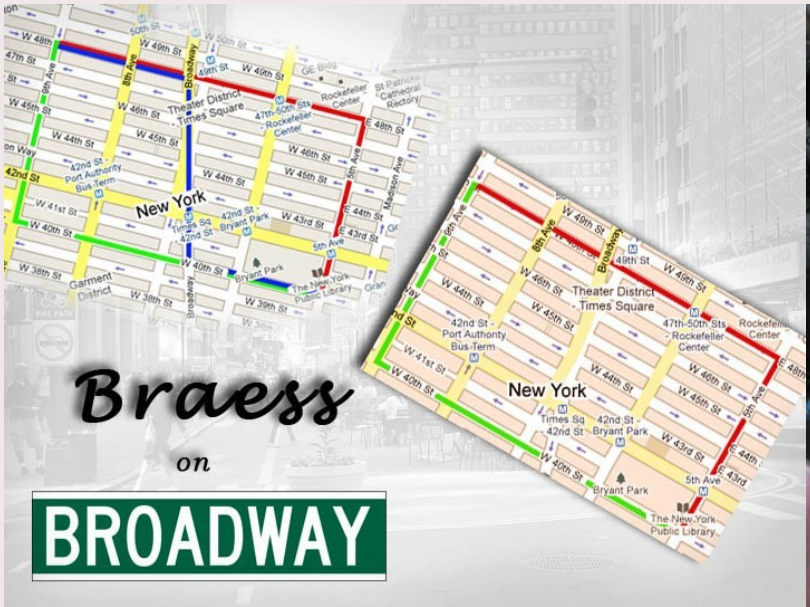
Interview on Broadway for PBS *America Revealed*



Inclusion of Undergraduates

- **Multiple undergraduates have taken part in research at the Center.**
- **Several of these – Christina Calvaneso and Steve Davis – went on to receive 21st Century Leaders Awards from UMass Amherst at graduations, an award that I nominated them.**
- **Two OIM CHC undergraduates, Emilio Alvarez-Flores and Karen Li, who also received a 21st Century Leaders Award, have worked with Supernetwork Center Associates and have written theses (as did Calvaneso) and have had journal articles published.**

Supply Chains Are One of the Most Important Applications of Supernetworks

Supply Chains Are One of the Most Important Applications of Supernetworks

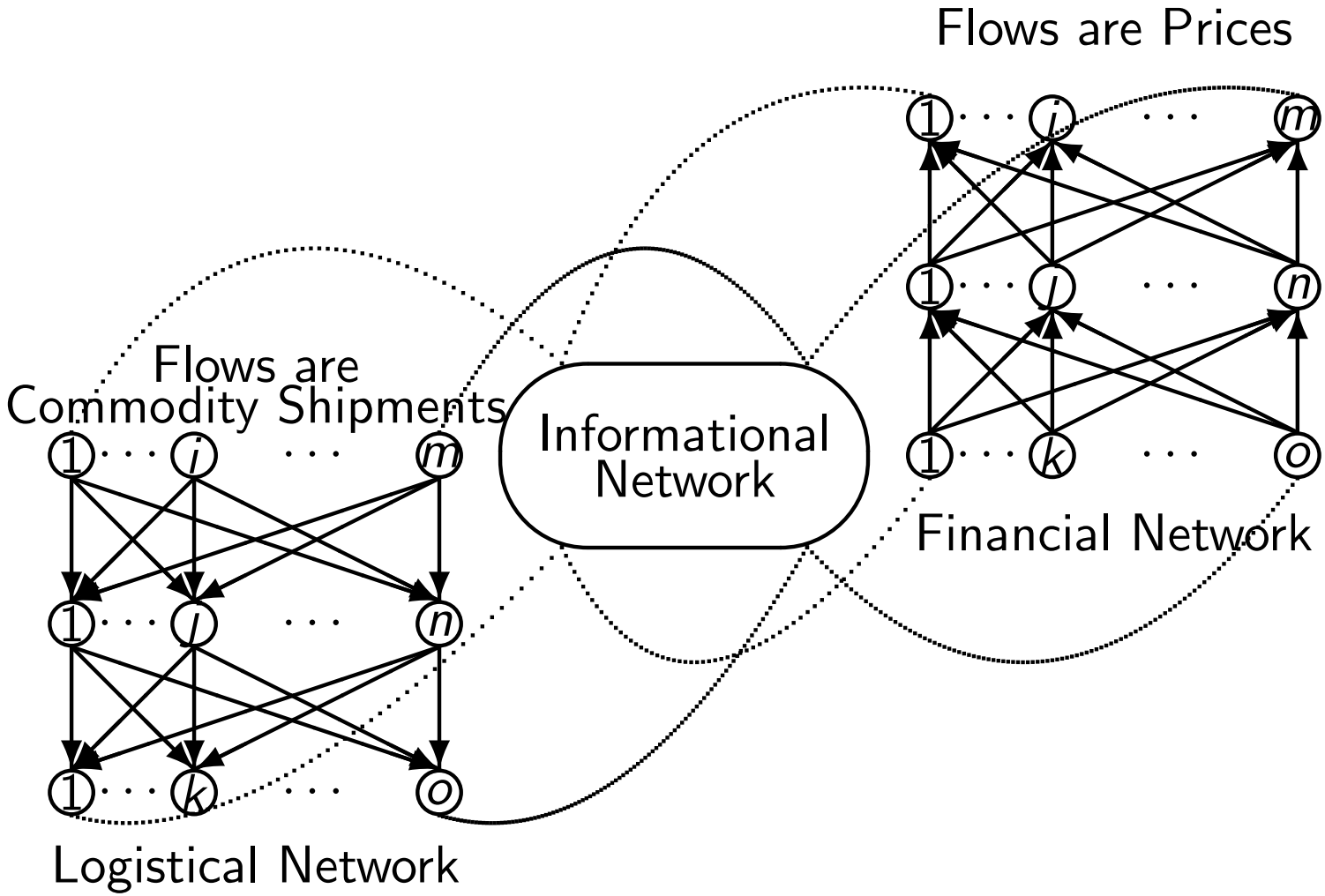


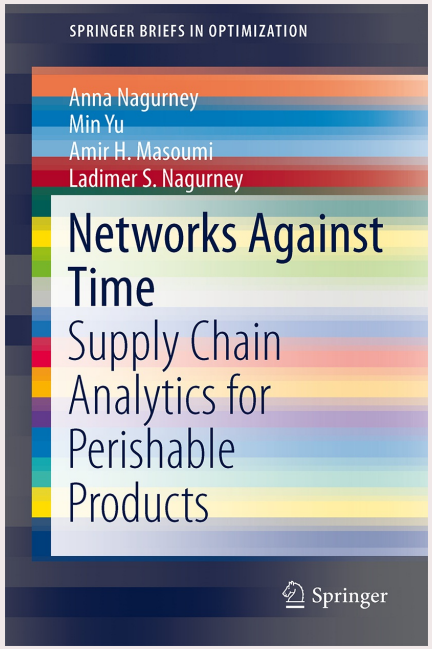
Figure 1: Multilevel Network Structure of the Supply Chain System

Books


Competing on Supply Chain Quality
A Network Economics Perspective
Networks Against Time
Supply Chain Analytics for Perishable Products
FRAGILE NETWORKS
Supply Chain Network Economics
Innovations in Financial and Economic Networks
Supernetworks
Decision-Making for the Information Age
NETWORK ECONOMICS
Environmental Networks
Financial Networks
SUSTAINABLE TRANSPORTATION NETWORKS

A Multidisciplinary Approach to Supply Chain Networks

In our research on perishable and time-sensitive product supply chains, we utilize results from physics, chemistry, biology, and medicine in order to capture the perishability of various products over time.



- **food**
- **blood**
- **medical nucleotides**
- **pharmaceuticals**
- **vaccines.**

Many such supply chains are essential and have been severely challenged in the pandemic due to various disruptions and negative impacts on labor!

It's All About People

A major research theme of ours in the COVID-19 pandemic is the inclusion of labor in supply chains, using optimization and game theory.

ORMS TODAY informs membership magazine

NEWS FEATURES PODCASTS

January 29, 2021 in Supply Chain Networks

In the End, It's All About People

COVID-19 vaccine production reveals dependency on supply chains, labor workforce in the U.S.

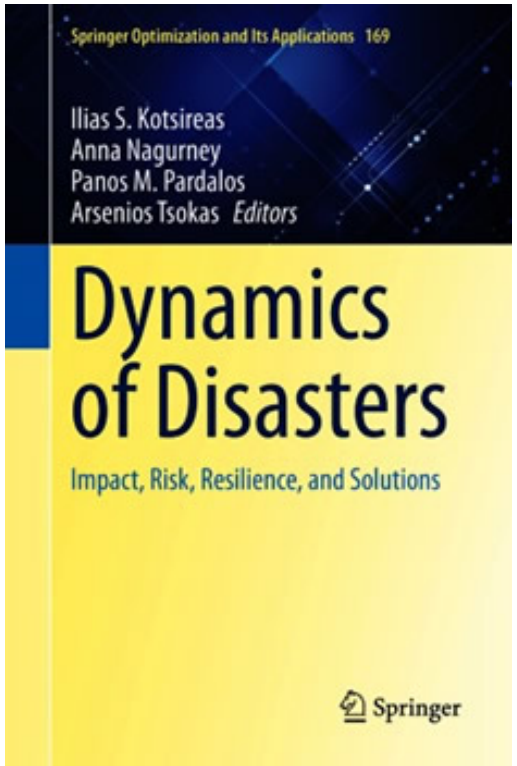
By Anna Nagurney

SHARE: PRINT ARTICLE: https://doi.org/10.1287/orms.2021.01.17

The COVID-19 pandemic has dramatically revealed how dependent we are on supply chains and the availability of labor. Without the human element, meatpacking plants cannot function; fresh produce cannot be picked; grocery stores cannot be shelved; PPEs cannot be produced and distributed; and products cannot be delivered to our homes through e-commerce. Also, COVID-19 vaccine production may lack the human resources to ensure product quality and efficacy, as well as its distribution and ultimate administration into our arms. Without healthcare workers to administer COVID-19 vaccines, the battle against the coronavirus cannot be won. Many hospitals are already short-staffed because of the pandemic.

Research and Publications

"Perishable Food Supply Chain Networks with Labor in the Covid-19 Pandemic," A. Nagurney, in: *Dynamics of Disasters - Impact, Risk, Resilience, and Solutions*, **I.S. Kotsireas, A. Nagurney, P.M. Pardalos, and A. Tsokas, Editors, Springer International Publishing Switzerland, 2021, pp 173-193.**



Perishable Food Supply Chain Network Model with Labor

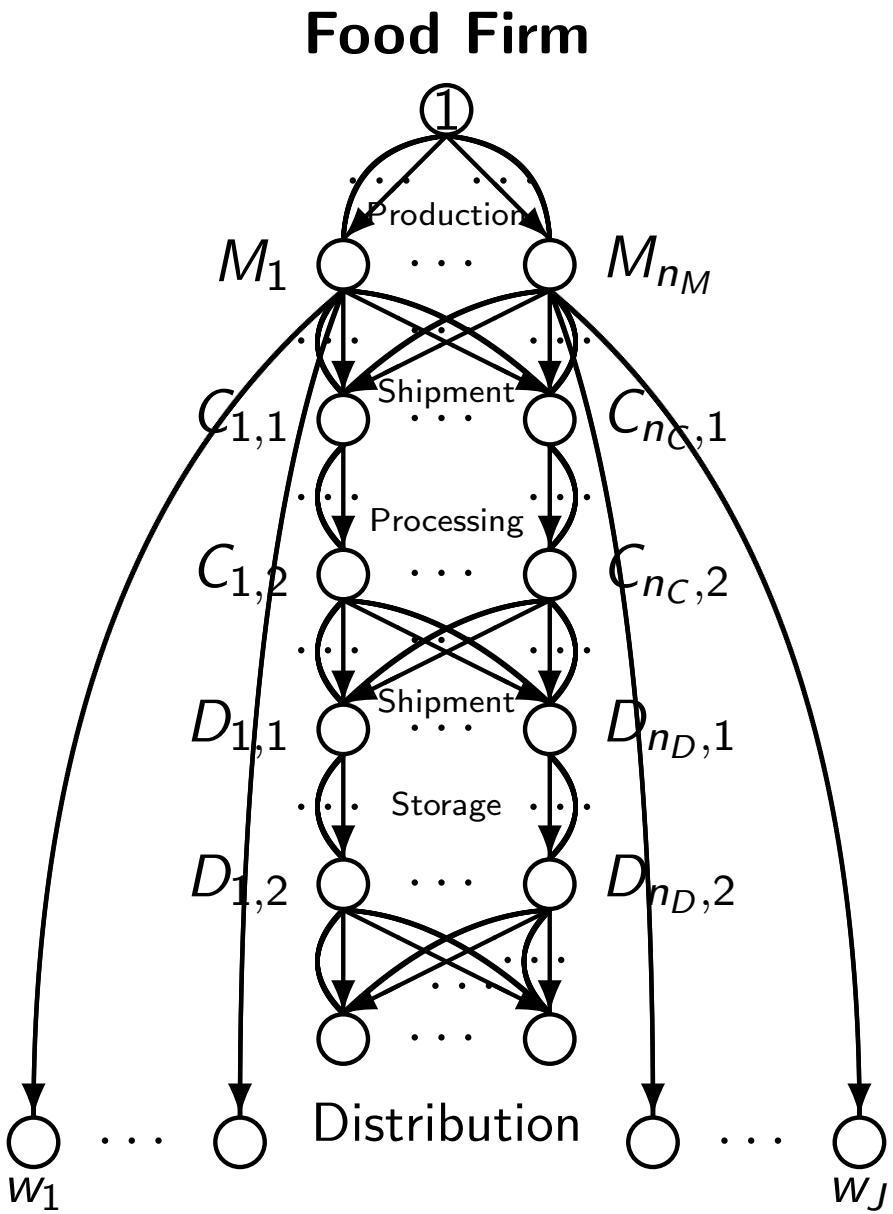


Figure 2: The Perishable Food Supply Chain Network Topology

Research and Publications

In a series of papers we constructed supply chain network models with labor that included productivity factors and constraints on labor in order to identify the impacts of disruptions and to suggest possible mitigation procedures.

International Journal of Production Economics
Available online 25 February 2021, 108080
In Press, Journal Pre-proof

Optimization of Supply Chain Networks with Inclusion of Labor: Applications to COVID-19 Pandemic Disruptions

Anna Nagurney
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https://doi.org/10.1016/j.ijpe.2021.108080 Get rights and content

Abstract

In this paper, we respond to the COVID-19 pandemic by constructing supply chain network optimization models, which explicitly include labor as an important variable in the network economic activity links, along with associated capacities. Labor is a critical resource in supply chains from production to transportation, storage, and distribution. In a pandemic, the availability of labor for different supply chain network activities may be disrupted due to illness, fear of contagion, morbidity, necessity of social/physical distancing, etc. The modeling framework considers first elastic demands for a product and then fixed demands, coupled with distinct types of labor capacities in order to capture the availability of this valuable resource in a pandemic, as well as possible flexibility. The supply chain network framework, which includes electronic commerce, is relevant to many different supply chain applications including protective personal and medical equipment, as well as to particular food items. Theoretical results as well as computed numerical examples are presented.

European Journal of Operational Research
Available online 3 January 2021
In Press, Corrected Proof

Production, Manufacturing, Transportation and Logistics

Supply chain game theory network modeling under labor constraints: Applications to the Covid-19 pandemic

Anna Nagurney
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Abstract

The Covid-19 pandemic has brought attention to supply chain networks due to disruptions for many reasons, including that of labor shortages as a consequences of illnesses, death, risk mitigation, as well as travel restrictions. Many sectors of the economy from food to healthcare have been competing for workers, as a consequence. In this paper, we construct a supply chain game theory network framework that captures labor constraints under three different scenarios. The appropriate equilibrium constructs are defined, along with their variational inequality formulations. Computed solutions to numerical examples inspired by shortages of migrant labor to harvest fresh produce; specifically, blueberries, in the United States, reveal the impacts of a spectrum of disruptions to labor on the product flows and the profits of the firms in the supply chain network economy. This research adds to the literature in both economics and operations research.

European Journal of Operational Research

Editors' Award

2021

Presented to

Anna Nagurney

in recognition of an outstanding contribution to the quality of the Journal with sincere thanks and very best wishes from the Editors of European Journal of Operational Research and the Directors of Elsevier B.V.

Prof. Roman Slowinski
Co-ordinating Editor of EJOR

Simon Jones
Publisher, Elsevier B.V.

Supply Chain Model with Different Labor Constraints

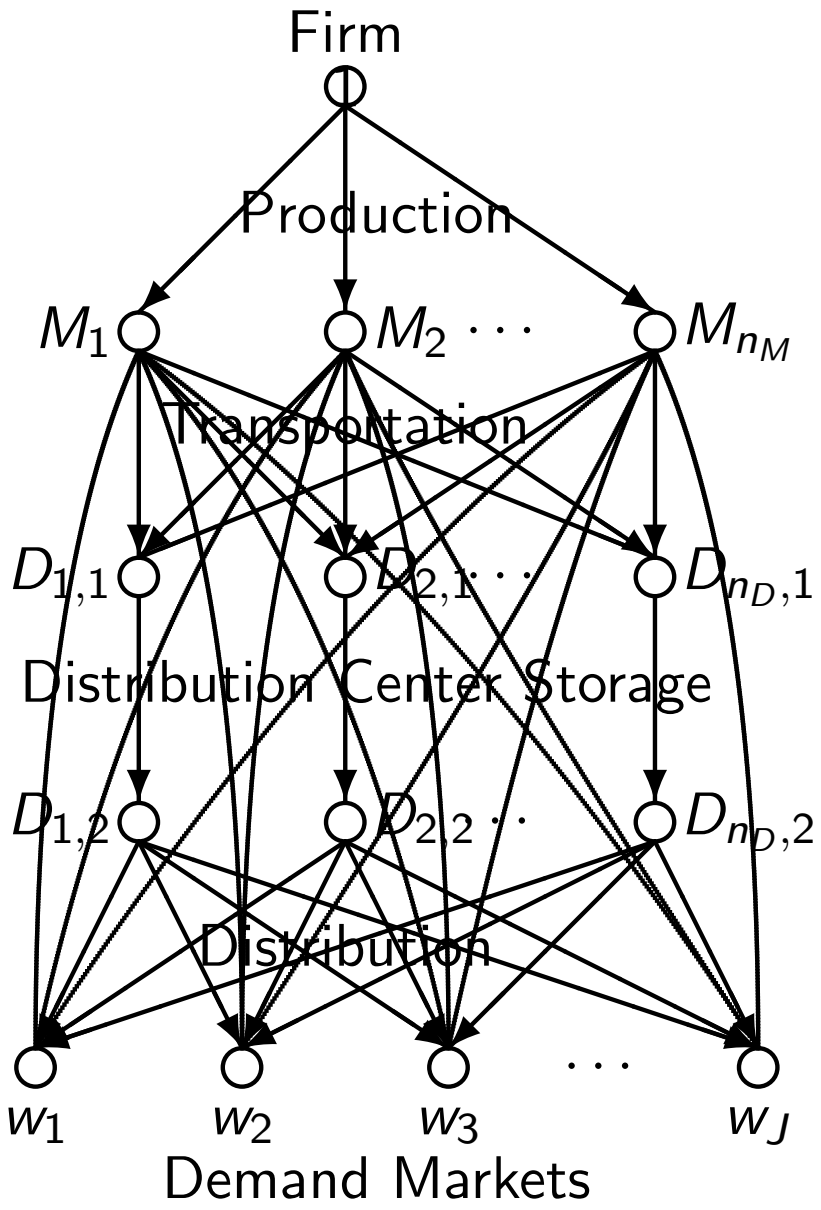


Figure 3: The Supply Chain Network Topology for the Optimization

Game Theory Supply Chain Network Model with Labor

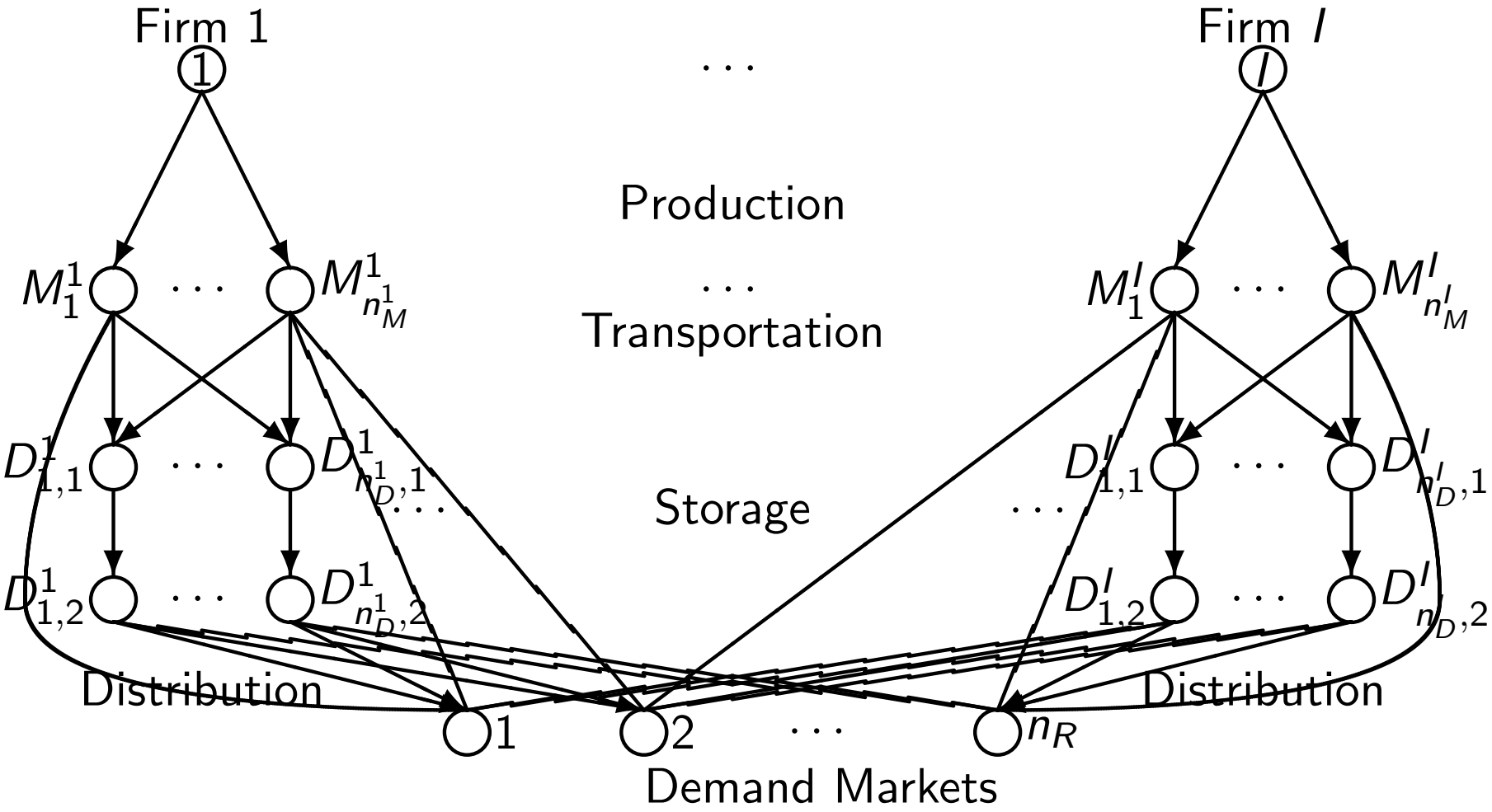


Figure 4: The Supply Chain Network Topology for the Game Theory Model with Labor

Some Additional Research

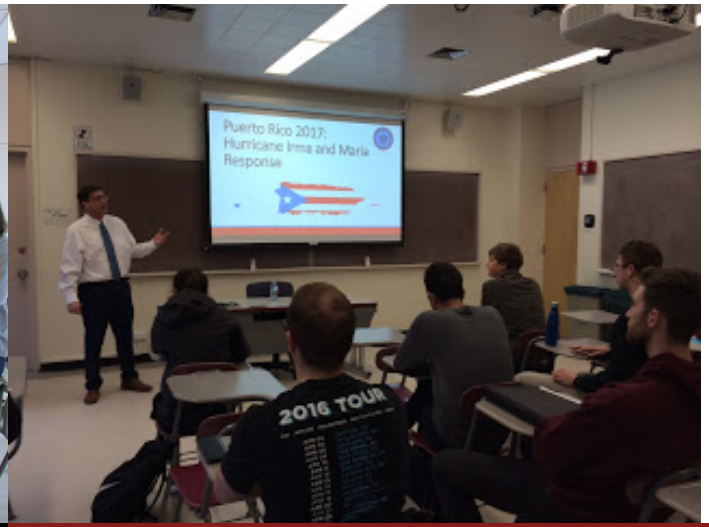
The fierce competition for PPEs and other medical supplies also inspired the following work:

"Competition for Medical Supplies Under Stochastic Demand in the Covid-19 Pandemic: A Generalized Nash Equilibrium Framework," A. Nagurney, M. Salarpour, J. Dong, and P. Dutta, in: *Nonlinear Analysis and Global Optimization*, **T.M. Rassias, and P.M. Pardalos, Editors, (2021), Springer Nature Switzerland AG, pp 331-356.**

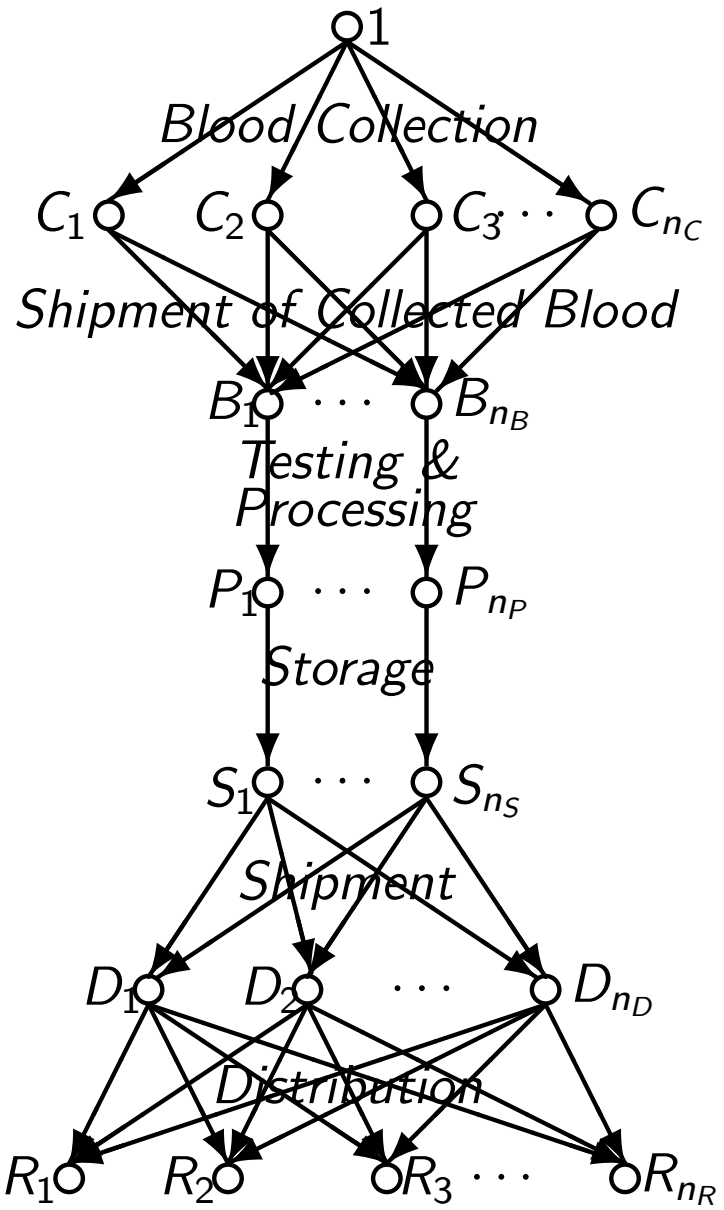
In this paper, we modeled the competition for medical supplies in the Covid-19 pandemic under stochastic demand and a fixed amount of supplies at different points.

Blood Supply Chains for the Red Cross

Our research on blood supply chains, a topic I teach in my Humanitarian Logistics and Healthcare class, has also been influential in the pandemic.



Supply Chain Network Topology for a Regional Blood Bank



ARC Regional Division

Blood Collection Sites

Blood Centers

Component Labs

Storage Facilities

Distribution Centers

Demand Points

Writing OpEds in the Pandemic

On March 11, 2020 the WHO declared the pandemic. On March 12 my article on blood supply chains in *The Conversation* appeared and, on March 24 my article in INFORMS *Analytics Coronavirus Chronicles*.

THE CONVERSATION

Academic rigor, journalistic flair

How coronavirus is upsetting the blood supply chain

March 12, 2020 8.05am EDT

Email
Twitter 28
Facebook 1.1k
LinkedIn
Print

The coronavirus, which causes the disease COVID-19, has created enormous anxiety, uncertainty, and disruption to our lives. Much has already been written about potential shortages of medicines and face masks, but little has been said about something only you and I can provide – lifesaving blood.

Our nation's blood supply is essential to our health care security. Blood transfusions are integral parts of major surgeries. Blood is used in the treatment of diseases, particularly sickle cell anemia and some cancers. Blood is needed for victims who have injuries caused by accidents or natural disasters. Every day, the U.S. needs 36,000 units of red blood cells, 7,000 units of platelets, and 10,000 units of plasma.

I am a professor and director of the Virtual Center for Supernetworks at the University of Massachusetts Amherst. Because of the escalating coronavirus health care crisis, I am deeply concerned the U.S. blood supply chain is under stress. The timing could hardly be worse; the COVID-19 outbreak coincides with our seasonal flus and colds.

Patients need blood in many states

Many states, including Washington, California, Kansas, Pennsylvania, the Carolinas, Massachusetts and Rhode Island, are now calling for blood donations. At the same time, some states are closing schools and other sites that typically

Analytics

DRIVING BETTER BUSINESS DECISIONS

informs

March 24, 2020 in Coronavirus Chronicles

The COVID-19 Pandemic and the Stressed Blood Supply Chain

By Anna Nagurney

SHARE: PRINT ARTICLE: https://doi.org/10.1287/LYTX.2020.02.18

Blood is essential to our nation's healthcare security. It is a life-saving product that cannot be manufactured and comes solely from volunteer donors. No substitute for blood has yet been invented. Blood transfusions are integral parts of major surgeries. Blood is a must for saving victims of accidents and natural disasters. Blood is also used in the treatment of certain diseases, including certain cancers. In the United States, 36,000 units of red blood cells are needed daily as are 7,000 units of platelets and 10,000 units of plasma. A typical donation of one pint, which can be divided into red blood cells, plasma and platelets, can save up to three lives. Adults have 8-12 pints of blood.

Even in the best of times, the complex blood supply chain in the United States is under stress. Although 38% of the U.S. population is eligible to donate blood, less than 10% actually does so in a year. Furthermore, issues of seasonality come into play with flu and colds cutting donations; the same for weather-related events and holidays. To further complicate matters, blood is perishable; platelets last five days and red blood cells have a shelf life of 42 days.

The blood banking industry, entrusted with maintaining a sufficient supply of blood, is facing a battle of the century with the COVID-19 pandemic. The timing could not be worse with this year's heavy flu and cold season, and the blood banking industry having recently undergone a massive transformation due to both economics and changes in medical procedures [1]. For example, there is increased competition among blood service organizations for donors [2]. The American Red Cross has closed some testing facilities and even eliminated mobile collection units in parts of the country. There have also been mergers and acquisitions of blood service organizations [3]. On the other hand, hospitals are now requiring less blood for certain procedures as compared to a few years ago because of changes in medical practices. This has resulted in requests for lower prices for blood from blood banks, who still have to cover costs, and some of the new costs include higher testing costs due to diseases such as Zika. And now, because of the COVID-19 pandemic, a major source of blood donations – schools – is removed.

The critical blood supply chain is unique from others that we study in operations research (O.R.) because it requires altruistic donations, collection, testing, processing and distribution to hospitals and medical centers. The blood supply chain can be visualized, modeled and studied as a network [4]. The coronavirus can disrupt the links in the blood supply chain network through a variety of means. If donors are ill, they cannot donate; if the staff is ill, they cannot collect, test, process and distribute blood. If our healthcare workers are compromised, they cannot transfuse

Writing OpEds in the Pandemic

On August 4, 2020, I published an article in *The Conversation*,

"The Raging Competition for Medical Supplies is not a Game, but Game Theory Can Help."

On September 18, 2020, I published another article in *The Conversation*,

"Keeping Coronavirus Vaccines at Subzero Temperatures During Distribution Will Be Hard, but Likely Key to Ending Pandemic."

Writing OpEds in the Pandemic

On January 8, 2021, my article,

"Vaccine Delays Reveal Unexpected Weak Link in Supply Chains: A Shortage of Workers," appeared in *The Conversation*.

On September 21, 2021, I published the article,

"Global Shortage of Shipping Containers Highlights Their Importance in Getting Goods to Amazon Warehouses, Store Shelves and Your Door in Time for Christmas," also in *The Conversation*.

Writing OpEds in the Pandemic

My article, in one month, was read by over 315,000 readers; was reprinted by Fast Company, and remains the most read article authored by a UMass Amherst Professor in *The Conversation* since its founding 10 and a half years ago.

Some of the Media Coverage of Our Work During the Pandemic

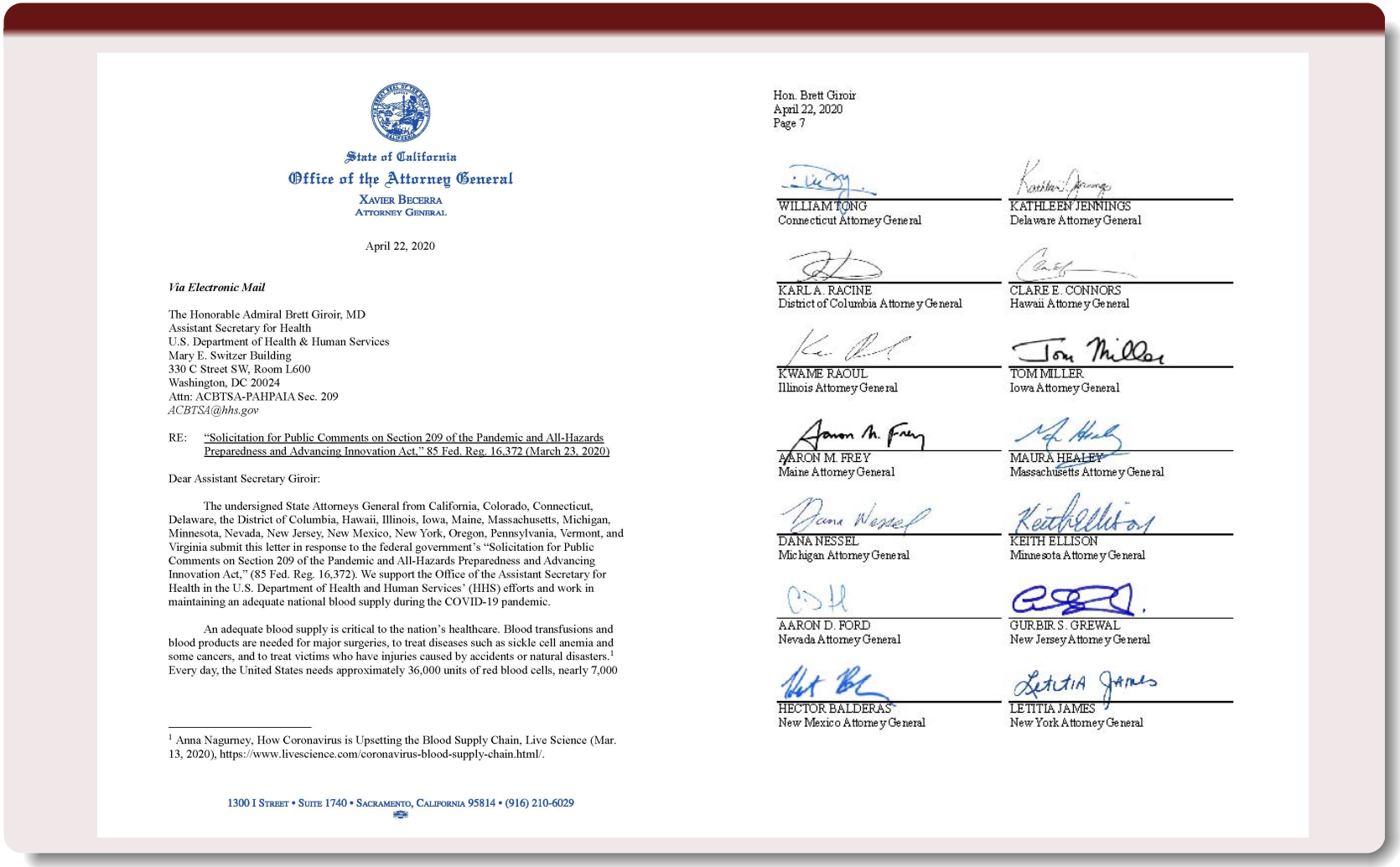
Many of the Media Interviews Have Been Fascinating

Impacting Policy

On April 22, 2020, a letter from California Attorney General Xavier Becerra to the Admiral Brett Giroir, the Assistant Secretary of the US Department of Health & Human Services, and signed by US Attorney Generals of 21 other states, requested updates, because of the pandemic blood shortages, to blood donation policies that discriminate.

My article on blood supply chains in *The Conversation*, which was reprinted in LiveScience, was the first reference and was cited on the first page.

Impacting Policy



State of California
Office of the Attorney General
XAVIER BECERRA
ATTORNEY GENERAL

April 22, 2020

Via Electronic Mail

The Honorable Admiral Brett Giroir, MD
Assistant Secretary for Health
U.S. Department of Health & Human Services
Mary E. Switzer Building
330 C Street SW, Room L600
Washington, DC 20024
Attn: ACBTSA-PAHPAIA Sec. 209
ACBTSA@hhs.gov

RE: "Solicitation for Public Comments on Section 209 of the Pandemic and All-Hazards Preparedness and Advancing Innovation Act," 85 Fed. Reg. 16,372 (March 23, 2020)

Dear Assistant Secretary Giroir:

The undersigned State Attorneys General from California, Colorado, Connecticut, Delaware, the District of Columbia, Hawaii, Illinois, Iowa, Maine, Massachusetts, Michigan, Minnesota, Nevada, New Jersey, New Mexico, New York, Oregon, Pennsylvania, Vermont, and Virginia submit this letter in response to the federal government's "Solicitation for Public Comments on Section 209 of the Pandemic and All-Hazards Preparedness and Advancing Innovation Act," (85 Fed. Reg. 16,372). We support the Office of the Assistant Secretary for Health in the U.S. Department of Health and Human Services' (HHS) efforts and work in maintaining an adequate national blood supply during the COVID-19 pandemic.

An adequate blood supply is critical to the nation's healthcare. Blood transfusions and blood products are needed for major surgeries, to treat diseases such as sickle cell anemia and some cancers, and to treat victims who have injuries caused by accidents or natural disasters.[1] Every day, the United States needs approximately 36,000 units of red blood cells, nearly 7,000

[1] Anna Nagurney, How Coronavirus is Upsetting the Blood Supply Chain, Live Science (Mar. 13, 2020), https://www.livescience.com/coronavirus-blood-supply-chain.html/.

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Hon. Brett Giroir
April 22, 2020
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HECTOR BALDERAS
New Mexico Attorney General

LETITIA JAMES
New York Attorney General

Xavier Becerra is now President Biden's Secretary of the Department of Health and Human Services.

Good News Arrives

I would like to thank the UMass Board of Trustees and President Martin T. Meehan for my appointment on April 14, 2021 to the Eugene M. Isenberg Chair in Integrative Studies. I would also like to thank the Isenberg School Dean Anne P. Massey for her support and leadership and that of Provost John McCarthy and Chancellor Kumble R. Subbaswamy.

Many thanks to the Isenberg Family for their extraordinary philanthropy.

Thank You Very Much!

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