Supernetworks: Decision-Making in the 21st Century

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Presented to the Deans’ Council May 4, 2004
Funding provided by:

AT&T Foundation
National Science Foundation
John F. Smith Memorial Fund - University of Massachusetts at Amherst

THE ROCKEFELLER FOUNDATION
Virtual Center for Supernetworks

• Established in 2001 at the Isenberg School of Management to serve as a resource for researchers, educators, students, and practitioners.

• In 2003, founded the Supernetworks Laboratory for Computation and Visualization.
The center emphasizes the importance of critical infrastructure networks, their interrelationships and analysis, and expands upon *scientific and management network tools for decision-making*. 
The *center team* is multidisciplinary and multicultural and at present consists of students from four different continents.

The *center* supports *undergraduates in research* since they are our future and provide new and fresh perspectives.

*Center associates* from different academic institutions and industry work closely with the center director and student associates.
New International Associates

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We are in a New Era of Decision-Making characterized by:

- increasing risk and uncertainty;
- importance of dynamics and realizing a fast and sound response to evolving events;
- complex interactions among decision-makers in organizations;
- alternative and at times conflicting criteria used in decision-making;
- global reach of many decisions, and
- high impact of many decisions.
The complexity of today's decision-making environments in organizations requires the development and harnessing of *appropriate and rigorous scientific tools* which must be based on *information technology* since only such technology provides one with the speed and accuracy needed to model complex interactions and to optimize accordingly.
The New Era is Network-Based with the Internet providing critical infrastructure along with transportation/logistical networks as well as other telecommunication networks and energy networks.

No longer are networks independent of one another but critically linked with major questions arising regarding decision-making and appropriate management tools.
Indeed, the events of 9/11 coupled with the recent computer worm and viruses along with the biggest blackout in US history demonstrate irrevocably that we must as a nation harness the best and most powerful methodologies for the modeling, analysis, and solution of complex decision-making problems.
Background
Throughout history, **networks** have served as the foundation for connecting humans to one another and their activities.

- Roads were laid, bridges built, and waterways crossed so that humans, be they on foot, on animal, or vehicle could traverse physical distance through **transportation**. The airways were conquered through flight.

- **Communications** were conducted using the available means of the period, from smoke signals, drum beats, and pigeons, to the telegraph, telephone, and computer networks of today.
Importance of Networks to the Economy and the Nation

- US consumers, businesses, and governments spend annually over $950 billion on transportation (US DOT).

- Corporate buyers spend annually over $517.6 billion on telecommunications (Purchasing).

- Energy expenditures in the United States exceed $515.8 billion a year (US Dept. of Commerce).
Information technology has transformed the ways in which individuals work, travel, and conduct their daily activities, with profound implications for existing and future networks.

The decision-making process itself has been altered due to the addition of alternatives and options which were not possible or even feasible.

The boundaries for decision-making have been redrawn as individuals can now work from home or purchase products from work.
We live in an era in which the freedom to choose is weighted by the immensity of choices and possibilities:

- Where should one live?
- Where should one work? And when?
- How should one travel? Or communicate? And with whom?
- Where should one shop? And how?
Not only has individual *decision-making* been transformed in this new era but *organizations* have as well.

How do we capture in a rigorous manner *cooperation vs. competition* and the ramifications, *centralized control vs. decentralized control*, and different *criteria* in decision-making?

Moreover, what are the results on the flows on the networks be they in the form of vehicles, messages, products, and/or services, as well as financial?

*Who wins and who loses?*
# Classical Networks

<table>
<thead>
<tr>
<th>Network System</th>
<th>Nodes</th>
<th>Links</th>
<th>Flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation Urban</td>
<td>Intersections, Homes, Places of Work</td>
<td>Roads</td>
<td>Autos</td>
</tr>
<tr>
<td>Air</td>
<td>Airports, Railyards</td>
<td>Airline Routes, Railroad Track</td>
<td>Planes, Trains</td>
</tr>
<tr>
<td>Rail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing and Logistics</td>
<td>Distribution Points, Processing Points</td>
<td>Routes, Assembly Line</td>
<td>Parts, Products</td>
</tr>
<tr>
<td>Communication</td>
<td>Computers, Satellites, Phone Exchanges</td>
<td>Cables, Radio, Cables, Microwaves</td>
<td>Messages, Voice, Video</td>
</tr>
<tr>
<td>Energy</td>
<td>Pumping Stations, Plants</td>
<td>Pipelines</td>
<td>Water, Gas, Oil</td>
</tr>
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</table>
Reality of Today’s Networks
Reality of Today's Networks:

- *large-scale nature* and complexity of network topology;
- *congestion*;
- alternative behavior of users of the network, which may lead to *paradoxical phenomena*;
- the *interactions among networks* themselves such as in transportation versus telecommunications networks;
- *policies* surrounding networks today may have a *major impact* not only economically but also *socially, politically, and security-wise*. 
Large-Scale and Complexity

- Chicago's Regional Transportation Network has 12,982 nodes, 39,018 links, and 2,297,945 origin/destination pairs.

- AT&T's domestic network has 100,000 origin/destination pairs. In the detail graph applications in which nodes are phone numbers and edges are calls, there are 300 million nodes and 4 billion edges.
Congestion

• In the case of transportation networks in the United States alone, congestion results in $100 billion in lost productivity, whereas the figure in Europe is estimated to be $150 billion.

• In terms of the Internet, the FCC reports that the volume of traffic is doubling every 100 days, which is remarkable given that telephone traffic has typically increased only by about 5 percent a year.
System-Optimization versus User-Optimization

In transportation networks, travelers select their routes of travel from an origin to a destination so as to minimize their own travel cost or travel time, which although optimal from an individual's perspective (user-optimization) may not be optimal from a societal one (system-optimization) where one has control over the flows on the network.
The Braess’ 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)=10\ f_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 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 $p_3$, $C_{p3}=70$.

The new equilibrium flow pattern network is $x_{p1}^* = x_{p2}^* = x_{p3}^*=2$.

The equilibrium path travel costs:

$C_{p1} = C_{p2} = C_{p3} = 92$.
This phenomenon is also relevant to telecommunications networks and, in particular, to the Internet which is another example of a noncooperative network.
Recently, we have discovered paradoxes in networks with zero emission links such as telecommunication networks:

- The addition of a zero emission link may result in an increase in total emissions with no change in demand!
- A decrease in demand on a network with a zero emission link may result in an increase in total emissions!
One must *incorporate the network topology*, the relevant cost and demand structure, as well as the behavior of the users of the network(s) into any network-based policy!

These paradoxes further illustrate the interconnectivity among distinct network systems and that they cannot be studied simply in isolation!!!
Supernetworks: A New Paradigm
Supernetworks

- Supernetworks may be comprised of such networks as transportation, telecommunication, logistical, and/or financial networks.
- They may be *multilevel* as when they formalize the study of supply chain networks or *multitiered* as in the case of financial networks with intermediation.
- Decision-makers may be faced with multiple criteria; thus, the study of supernetworks also includes the study of *multicriteria decision-making*.
The tools that we have been using in our supernetworks research include:

- network theory
- optimization theory
- game theory
- variational inequality theory and
- projected dynamical systems theory (which we have been instrumental in developing)
- network visualization tools.
A Multidisciplinary Paradigm

Supernetworks

Computer Science

Engineering

Management Science

Economics and Finance
We are interested not only in addressing topological issues in terms of connectivity but in predicting the various flows on the networks whether physical or abstract subject to human decision-making under the associated constraints, be they budget, time, security, risk, and/or cost-related.
Some Successes
• We were the first to lay down the theoretical foundations for dynamical systems with constraints (called projected dynamical systems) which allows for the qualitative analysis of such systems including stability analysis along with discrete-time algorithms.

• The applications that we have studied range from dynamic transportation networks to global supply chains and international financial networks with risk management.
• We have demonstrated through several distinct network systems how risk and stochastic components could be directly incorporated into a variational inequality framework.

• We were the first to quantify and model decision-making on multitiered networks as well as multilevel networks (along with the dynamics).

• We have made fundamental extensions to multicriteria decision-making on networks with multiple decision-makers.
Novel Applications
Applications of Supernetworks

- Telecommuting/Commuting Decision-Making
- Teleshopping/Shopping Decision-Making
- Supply Chain Networks with Electronic Commerce
- Financial Networks with Electronic Transactions
- Reverse Supply Chains with E-Cycling
- Energy Networks/Power Grids
- Knowledge Networks
A Supernetwork Conceptualization of Commuting versus Telecommuting
A Supernetwork Framework for Teleshopping versus Shopping

Diagram showing the locations of consumers/shoppers before and after the shopping experience, with links for access, telecommunications, transportation, transaction, shipment, and completion.
The Supernetwork Structure of a Supply Chain Network
Supply Chain -Transportation Supernetwork Representation

Transacation cost information

Demand or order information

Travel time information

Unexpected issues information

Real-Time Information System

Two-way information exchanges between specific decision-makers
International Financial Networks with Electronic Transactions
The 4-Tiered E-Cycling Network

Sources of Electronic Waste

Recyclers

Processors

Demand Markets

Landfill

1 \ldots h \ldots r\n
1 \ldots i \ldots m

1 \ldots j \ldots n

1 \ldots k \ldots o

m+1

n+1

o+1
Power Grids
New Directions
A Knowledge Supernetwork

Knowledge Product 1

Knowledge Product 2

Knowledge Product k

1

2

3

4

n
The framework is rigorous in its foundations and both qualitative and computational in its perspective.

We are partnering with the American Quality and Productivity Center of Houston, Texas to apply the results to HP and the AID.
Within the past 2 academic years, student associates have presented the results of their research in

- China
- Japan
- England
- Sweden
- Arizona
- Arkansas
- California
- Connecticut
- Florida
- Massachusetts
- Rhode Island
- Texas
Additional Recognitions

• Featured several times in *Mass High Tech*, *OR/MS Today*, and *CNN/Money*.

• Subject of a documentary out of Boston.

• Associates awarded numerous fellowships, prizes, etc., including a *Chow Fellowship*, *AT&T Industrial Ecology Fellowships*, a *Distinguished Chaired Fulbright*, a *President’s* and two *Provost’s Awards*, and two *UMASS Leaders for the 21st Century*. 
Visit the Virtual Center for Supernetworks
http://supernet.som.umass.edu

The Virtual Center for Supernetworks

The Virtual Center for Supernetworks at the Isenberg School of Management, under the directorship of Anna Nagurney, the John F. Smith Memorial Professor, is an interdisciplinary center established to:

- stimulate activities related to supernetworks
- explore applications of supernetworks
- bring together faculty, students, and those in industry and government for education and collaboration
- expand the knowledge base of network research
- disseminate information concerning networks and their roles in today's Information Age and Network Economy.

Experiences from a Rockefeller Foundation Team Residency at the Bellagio Center by Nagurney, Daniele, and Cojocaru

NEW!
Welcome New International Center Associates, Professors Cojocaru and Daniele!!!

The Supernetwork Sentinel
The Newsletter of the Virtual Center for Supernetworks
Winter 2004

Congratulations to
Jose Cruz after his successful PhD defense!!!
Thank you!