Supernetworks: Opportunities and Challenges for Decision-Making in the 21st Century

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I would like to thank the organizers of PAKDD 2011 for the opportunity to deliver this keynote talk.

Special acknowledgments and thanks to my students and collaborators who have made research and teaching always stimulating and rewarding.
Outline

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- Why Behavior Matters and Paradoxes
- Methodologies for Formulation, Analysis, and Computations
- An Empirical Application to Electric Power Supply Chains
- Network Design Through Mergers and Acquisitions
- Which Nodes and Links Really Matter?
- What About Disaster Relief?
- Summary, Conclusions, and Suggestions for Future Research
Background and Motivation
Supernetworks are *Networks of Networks*, and their prevalence in the world around us is illustrated by:

- *multimodal transportation networks*;

- *complex logistical networks consisting of manufacturers, shippers and carriers, distributors, and retailers*;

- *electric power generation and distribution networks*,

- *multitiered financial networks*, and

- *social network platforms such as Facebook and Twitter*, along with the Internet itself.
Financial Networks
Characteristics of 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, financial, 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**.
Many of today’s networks are characterized by both a large-scale nature and complexity of the underlying network topology, so we are in an era of Supernetworks.

In Chicago’s Regional Transportation Network, there are 12,982 nodes, 39,018 links, and 2,297,945 origin/destination (O/D) pairs, whereas in the Southern California Association of Governments model there are 3,217 origins and/or destinations, 25,428 nodes, and 99,240 links, plus 6 distinct classes of users.

In the case of the Internet, in 2010, there were 1.8 billion users.

Supernetworks, according to Nagurney (2011) is the Science of Complexity.
Change in Annual Average Congestion Delay Hours for Commuters in the US from 1982 - 2009
Congestion costs continue to rise: measured in constant 2009 dollars, the cost of congestion has risen from $24 billion in 1982 to $115 billion in 2009 in the United States. (Texas Transportation Institute’s Urban Mobility Report (2010)).

There is a freight capacity crisis in parts of the US.
In a typical user link travel time (or cost) function, the free flow travel time refers to the travel time to traverse the link when there is zero flow or traffic on the link (zero vehicles).
Why Behavior Matters and Paradoxes
Network Models from Analysis to Design Must Capture the Behavior of Users
Behavior on Congested Networks

*Decision-makers select their cost-minimizing routes.*

- Decentralized vs. Selfish vs. Centralized
- User-Optimized or Equilibrium vs. Unselfish vs. System-Optimized

*Flows are routed so as to minimize the total cost to society.*
Two fundamental principles of flow (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 $p \in P_w$:

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

**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 $p \in P_w$:

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

where $\hat{C}_p'(x) = \sum_{a \in L} \frac{\partial \hat{c}_a(f_a)}{\partial f_a} \delta_{ap}$, and $\mu_w$ is a Lagrange multiplier.
The Braess Paradox Illustrates Why Behavior on Networks is Important
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 $C_{p_1} = C_{p_2} = 83$.

$c_a(f_a) = 10f_a, \quad c_b(f_b) = f_b + 50, \quad c_c(f_c) = f_c + 50, \quad c_d(f_d) = 10f_d$. 
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:
\[
C_{p_1} = C_{p_2} = C_{p_3} = 92.
\]

\[c_e(f_e) = f_e + 10\]
Under S-O behavior, the total cost in the network is minimized, and the new route $p_3$, under the same demand of 6, would not be used.

*The Braess paradox never occurs in S-O networks.*
The 1968 Braess article has been translated from German to English and appears as:

"On a Paradox of Traffic Planning,"

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 - 42nd 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
Interview on Broadway for America Revealed on March 15, 2011
Other Networks that Behave like Traffic Networks

The Internet, electric power networks, and even multitiered financial networks!
Methodologies for Formulation, Analysis, and Computations
The Variational Inequality Problem

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

**Definition: The Variational Inequality Problem**

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

\[
\langle F(X^*)^T, X - X^* \rangle \geq 0, \quad \forall X \in K,
\]

where \( F \) is a given continuous function from \( K \) to \( R^N \), \( K \) is a given closed convex set, and \( \langle \cdot, \cdot \rangle \) denotes the inner product in \( R^N \).
The variational inequality problem contains, as special cases, such mathematical programming problems as:

- systems of equations,
- optimization problems,
- complementarity problems,
- and is related to the fixed point problem.

Hence, it is a natural methodology for a spectrum of congested network problems from centralized to decentralized ones as well as to design problems.
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 supernetworks*, including transportation networks and 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)).
Question: When does the U-O solution coincide with the S-O solution?

Answer: In a general network, when the user link cost functions are given by:

\[ c_a(f_a) = c_a^0 f_a^\beta, \]

for all links, with \( c_a^0 \geq 0 \), and \( \beta \geq 0 \).

In particular, if \( c_a(f_a) = c_a^0 \), that is, in the case of **uncongested networks**, this result always holds.
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 (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 \textit{the Addition of a New Link (Path) Makes Everyone Worse Off}! In Demand Regime III, when the travel demand exceeds 8.89, \textit{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!
We showed that, *for the specific Braess network*, the paradox no longer occurred as the demand for travel increased, once the demand reached a certain level.

This leads us to the *hypothesis*:

*Under a higher demand, the Braess Paradox is negated in that the new route, which resulted in increased travel time at a particular demand, will no longer be used.*

Under fairly reasonable assumptions, there exists a $\Delta d_{w_1}$ positive for which the Braess Paradox is negated in that the flow on the path $r$ that resulted in the Braess Paradox occurring at a fixed level of demand, will no longer occur at the new level of demand since that path will not be used and, hence, it cannot result in an increase in travel cost.
The Theorem demonstrates that, as demand increases, the Braess Paradox *works itself out*.

One would expect that at a higher level of demand the network gets even more congested and that more of the paths/routes would then be used!

However, the Theorem establishes that the route that resulted in the Braess Paradox at a particular level of demand will no longer be used at a higher level of demand.

This suggests that there may be an underlying *Wisdom of Crowds Phenomenon* taking place.

*It is worth noting that the qualitative results in the above Theorem also hold for nonlinear, strongly monotone cost functions.*
An Empirical Application to Electric Power Supply Chains
We have 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).

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,
1. Maine
2. New Hampshire
3. Vermont
4. Connecticut (excluding Southwestern 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/Northeastern Massachusetts
The Electric Power Supply Chain Network with Fuel Supply Markets

Fuel Markets for Fuel Type 1
Fuel Markets for Fuel Type a
Fuel Markets for Fuel Type A

Generating Units of Gencos in Regions (genco, region, unit)
Power Pool
Demand Market Sectors Region 1
Demand Market Sectors Region r
Demand Market Sectors Region R
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)
Network Design
Through
Mergers and Acquisitions
Network design (and redesign) can be accomplished through link and node additions (as well as their removals).

It can be accomplished by modifying the link capacities (expanding certain ones and, if applicable, reducing or selling off others).

It can also be accomplished through the integration of networks as in mergers and acquisitions and, as we will show later, through the design of the network from scratch.
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.
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)).
A successful merger depends on the ability to measure the anticipated synergy of the proposed merger (cf. Chang (1988)).

Figure 1: Case 0: Firms A and B Prior to Horizontal Merger
Figure 2: Case 1: Firms A and B Merge
Figure 3: Case 2: Firms A and B Merge
Figure 4: Case 3: Firms A and B Merge
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:

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

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 $S^i; i = 1, 2, 3$ 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

Humanitarian Logistics: Networks for Africa

Rockefeller Foundation Bellagio Center Conference, Bellagio, Lake Como, Italy
May 5-9, 2008
Conference Organizer: Anna Nagurney, John F. Smith Memorial Professor
University of Massachusetts at Amherst

See: http://hlogistics.som.umass.edu/
The Supply Chain Network Oligopoly Model

Figure 5: Supply Chain Network Structure of the Oligopoly

Mergers Through Coalition Formation

Figure 6: Mergers of the First $n_1'$ Firms and the Next $n_2'$ Firms
In addition, network design can be accomplished through the evolution and integration of disparate network systems, including social networks.

Two References:


Figure 7: The Multilevel Supernetwork Structure of the Integrated Supply Chain / Social Network System
Figure 8: The Multilevel Supernetwork Structure of the Integrated Financial Network / Social Network System
Networks are the *fundamental critical infrastructure* for the movement of people and goods in our globalized *Network Economy*.

Transportation 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

Now the world is reeling from the aftereffects of the triple disaster in Japan with disruptions in the high tech, automotive, and even food industries with potential additional ramifications because of the radiation.
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.*
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?
Definition: A Unified Network Performance Measure

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

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

where recall that $n_W$ is the number of O/D pairs in the network, and $d_w$ and $\lambda_w$ 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 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
Figure 9: 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 10: 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 11: 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?
A General Supply Chain

Diagram showing the flow of supplies from Tier 3, Tier 2, and Tier 1 suppliers to warehouses, factories, information centers, distribution centers, and stores, ultimately reaching customers.
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

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Supernetworks
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.
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

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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.
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,”


where additional background as well as references can be found.
Supply Chain Network Topology with Outsourcing

The Organization

Manufacturing at the Plants

Shipping

Distribution Center Storage

Shipping

Demand Points

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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.
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 supernetworks*.

We emphasized the *importance of capturing behavior* in network modeling, analysis, and design and various paradoxes.

We noted a *variety of network design approaches*: the addition of links; the integration of networks as in mergers and acquisitions; and the design from scratch (and redesign).

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 developed 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 heavily 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, such as *fast fashion*, and

Finally, we are now working 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 supernetwork design for robustness and resiliency.

THANK YOU!

The Virtual Center for Supernetworks

Supernetworks for Optimal Decision-Making and Improving the Global Quality of Life

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, and includes the Supernetworks Laboratory for Computation and Visualization.

Mission: The mission of the Virtual Center for Supernetworks is to foster the study and application of supernetworks and to serve as a resource to academia, industry, and government on networks ranging from transportation, supply chains, telecommunication, and electric power networks to economic, environmental, financial, knowledge and social networks.

The Applications of Supernetworks Include: multimodal transportation networks, critical infrastructure, energy and the environment, the Internet and electronic commerce, global supply chain management, international financial networks, web-based advertising, complex networks and decision-making, integrated social and economic networks, network games, and network metrics.

For more information, see: http://supernet.som.umass.edu
An Overview of Some of the Relevant Literature Chronologically


