**March 10, 2008: 10:00 – 11:15 Anna Nagurney's Fulbright Senior Specialist Presentation**
**Department of Mathematics and Computer Sciences**
**University of Catania, Italy**

**Vulnerability Analysis of Complex Networks from Transportation Networks to the Internet and Electric Power Supply Chains**

Networks provide the foundations for communication, transportation and logistics, energy provision, as well as financing. The study of networks spans many disciplines due to their wide application and importance (see, e.g., Beckmann, McGuire, and Winsten (1956), Sheffi (1985), Ahuja, Magnanti, and Orlin (1993), Nagurney (1999), Patriksson (1994), Ran and Boyce (1996), Watts and Strogatz (1998), Barabasi and Albert (1999), Latora and Marchiori (2001), Newman (2003), Roughgarden (2005), Daniele (2006), and the references therein). The subject has garnered renewed interest, since a plethora of catastrophic events such as 9/11, the North American electric power blackout in 2003, followed by blackouts in Italy and Switzerland, Hurricane Katrina in 2005, the Minneapolis bridge collapse in 2007, as well as the Mediterranean submarine cable disruption in 2008, and the snow-storm precipitated transportation and electric power failures in China in the winter of 2008, among others, have drawn great attention to the study of network vulnerability.

The recent theories of scale-free and small-world networks in complex network research (cf. Watts and Strogatz (1998) and Barabasi and Albert (1999)) have significantly enhanced our understanding of the behavior as well as the vulnerability of many important real-world networks (see also, e.g., Barabasi, Albert, and Jeong (2000), Amaral et al. (2000), Chassin and Posse (2005), and Holmgren (2007)). However, the majority of network vulnerability studies focus solely on the topological characteristics such as the connectivity or the average shortest path length of the network. Although the topological structure of a network provides crucial information regarding network vulnerability, the flow on a network is also an important indicator, as are the flow-induced costs and the behavior of the users both prior and post any disruptions. As pointed out by Barabasi (2003, pp. 225), "To achieve that [understanding of complexity] we must move beyond structure and topology and start focusing on the dynamics that take place along the links. Networks are only the skeletons of complexity, the highways for various processes that make our world hum."

Latora and Marchiori (2001, 2002, 2004) proposed a network efficiency measure that is shown to have advantages over several existing network measures. The authors then used the measure to study the (MBTA) Boston subway transportation network and the Internet. Their measure considers geodesic information.

In this presentation we will describe our recent research on the development and application of a new network efficiency/performance measure that incorporates such important network factors as flows, costs, and behaviors in order to assess the importance of network components. It will be shown that the new network measure has advantages over several existing network measures. Furthermore, the measure will be able to handle both fixed and elastic demands as well as static and dynamic networks, with the latter of particular relevance to the Internet. Moreover, it will enable a ranking of the importance of network components, that is, the nodes or links, or combinations thereof, with implication for not only planning and maintenance purposes but also for purposes of (national) security.

In addition, instead of looking at the situation where a network component is completely disrupted, network robustness, another important aspect of the vulnerability of the network, investigates cases in which network resources, such as link capacity, are reduced in stressful environments. As defined in IEEE (1990), the robustness of a system is "the degree to which a system or component can function correctly in the presence of invalid inputs or stressful environmental conditions." This topic is especially important now since it has been reported that the once world-envied U.S. infrastructures are experiencing tremendous aging and deterioration, which exposes additional vulnerability to disasters.

Moreover, due to the constant breakdowns of the U.S. transportation networks and the increasing number of vehicles, American commuters now spend 3.5 billion hours a year stuck in traffic, which translates to a cost of $63.2 billion a year to the economy (ASCE (2005)). At the same time, a recent report from the Federal Highway Administration (2006) states that the U.S. is experiencing a freight capacity crisis that threatens the strength and productivity of the U.S. economy. Hence, the construction of suitable transportation network robustness measures is of both theoretical and practical importance. In this presentation, we will also present new results on transportation network robustness based on the new network efficiency/performance measure in order to investigate the network functionality when the links are partially degraded.

Transportation network equilibrium models will serve as our network equilibrium paradigm for complex networks since a variety of networks, including the Internet, financial networks, supply chain networks, as well as electric power networks can be reformulated and solved as transportation network problems (cf. Nagurney, Parkes, and Daniele (2007), Nagurney (2006), Wu et al. (2006), and Liu and Nagurney (2007)). Hence, any insights gained from transportation networks are expected to greatly help in the understanding of the vulnerability and robustness of other complex networks. Some of the research that this presentation is based on has been reported in a series of papers by Nagurney and Qiang published in the operations research/optimization, physics, transportation/operations management, and economics literatures.

**March 12, 2008: 9:00 – 9:40 Anna Nagurney's Workshop Lecture**

**Workshop: "Complex Networks - Equilibrium and Vulnerability Analysis with Applications"**
**Co-Organizers: Professors Patrizia Daniele and Anna Nagurney**
**Department of Mathematics and Computer Sciences**
**University of Catania, Italy**

## Environmental and Cost Synergy in Supply Chain Network Integration in Mergers and Acquisitions

**Anna Nagurney and Trisha Woolley**

In this paper, we focus on synergy rather than vulnerability, and we quantify and assess, from a supply chain network perspective, the environmental effects resulting when a merger of two firms or an acquisition of one firm by another occurs. We develop a multicriteria decision-making supply chain network framework that captures the economic activities of manufacturing, storage, and distribution pre and post the merger. The variational inequality-based models yield the system optima associated with the minimization of total costs and the total emissions under firm-specific weights. We propose a synergy measure that captures the total generalized cost. We then apply the new mathematical framework to quantify the synergy obtained for specific numerical examples. This work generalizes the recent system-optimization models for supply chain network integration and associated synergies of Nagurney (2007), forthcoming in *Transportation Research E*, to the environmental and multicriteria dimensions.

**March 13, 2008: 11:00 – 13:00 Anna Nagurney's Optimization Lecture**

## Operations Research and the Captivating Study of Networks and Complex Decision-making

In this talk, I will overview some of the major early and recent contributions to the formal mathematical study of networks and associated decision-making, from the perspective of an operations researcher. I will highlight novel mathematical tools, such as nonlinear optimization, game theory, variational inequalities, and projected dynamical systems, that have been utilized for the rigorous formulation of numerous network-based problems, and their effective solution. Some of the operations-research applications that I will discuss are: congested transportation networks and the Internet, including the Braess paradox (with fixed and time-varying demands), supply chains, financial and social networks, and energy/environmental networks.

The mathematical network-based discoveries continue to impact numerous disciplines, including: engineering, computer science, physics, economics, and biology, where the formalism of networks brings new, refreshing, and unifying insights.

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