!@#$% Traffic: From Insects to Interstates

Anna Nagurney
John F. Smith Memorial Professor
University of Massachusetts – Amherst

World Science Festival
Kimmel Center, NYU - June 12, 2009
The study of the efficient operation on transportation networks dates to ancient Rome with a classical example being the publicly provided Roman road network and the time of day chariot policy, whereby chariots were banned from the ancient city of Rome at particular times of day.
Traffic Congestion
Traffic Behavior on Congested Networks

*Individuals select their cost-minimizing routes of travel.*

Decentralized vs. Selfish vs. Centralized vs. Unselfish

User-Optimized vs. System-Optimized

*Traffic is routed so as to minimize the total cost to society.*
Capturing Link Congestion

![Graph showing the relationship between link travel time and capacity. The graph indicates that as link flow increases, link travel time also increases dramatically, approaching a vertical asymptote.]
Braess on Broadway
**Braess Paradox**

*Adding a Link Increases Travel Cost for All!*

Travel Demand = 6

<table>
<thead>
<tr>
<th>Path</th>
<th>Flow</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_{p_1}^*$</td>
<td>3</td>
<td>$c_a(f_a) = 10f_a$</td>
</tr>
<tr>
<td>$x_{p_2}^*$</td>
<td>3</td>
<td>$c_b(f_b) = f_b + 50$</td>
</tr>
<tr>
<td>$x_{p_1}^*$</td>
<td>2</td>
<td>$c_c(f_c) = f_c + 50$</td>
</tr>
<tr>
<td>$x_{p_3}^*$</td>
<td>2</td>
<td>$c_d(f_d) = 10f_d$</td>
</tr>
</tbody>
</table>

U-O path travel costs:

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

$C_{p_3} = 92$
The total cost to society from the 3 path Braess Network is 11% greater under selfish behavior than under unselfish behavior!
The 1968 Braess article in German was translated into English in 2005.

What Happens if the Demand Changes

After the demand reaches 8.89 the new path is never used under U-O behavior.
1969 - Stuttgart, Germany - 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.
Other Networks that behave like Traffic Networks

The Internet

Supply Chain Networks

Electric Power Generation/Distribution Networks

Financial Networks
The Equivalence of Supply Chains and Transportation Networks

In 1952, Copeland wondered whether money flows like water or electricity.
The Transportation Network Reformulation of the Financial Network Equilibrium Model with Intermediation

We are now using the connections between traffic networks and electric power supply chains for energy studies.
New England has 10 regions, 82 power generators who own and operate 573 power plants using 5 types of fuel.
Predicted Prices vs. Actual Prices ($/Mwh)

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.