Scientist proves Braess paradox 'disappears' under high traffic demands

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A new study shows that, under high enough traffic, an additional route will not increase traffic times because the route will not be used. Image credit: The Infrastructurist.

(PhysOrg.com) -- In an urban area with a lot of traffic, adding a new road to distribute the traffic may seem like a sensible idea. But according to the Braess paradox, just the opposite occurs: a new route added in a transportation network increases the travel times of all individual travelers. Formulated in 1968 by Dietrich Braess, the paradox is not a true paradox, but rather a counter-intuitive finding regarding an everyday situation.

However, in the past few years, scientists have reanalyzed the Braess paradox and found that it stops occurring as the demand for travel increases. Scientists have hypothesized that, under higher demands, the new route is no longer used due to a “wisdom of crowds” effect.

Now, for the first time, Anna Nagurney, the John F. Smith Memorial Professor at the University of Massachusetts Amherst, has proven this hypothesis. She has derived a formula that shows that an increase in demand guarantees that the new route will not be used and will no longer increase travel times. In other words, the Braess paradox holds only for a specific range of demand.

Although the Braess paradox itself is counter-intuitive, this negation of the paradox under higher demands is also counter-intuitive. As Nagurney explained, one would expect that, at a higher level of demand, the network should get more congested and so more of the routes should be used.

Perhaps the result can be explained by an underlying “wisdom of crowds” phenomenon, Nagurney suggested. There are generally thought to be two types of travel behavior: user-optimizing behavior, in which travelers select their optimal routes of travel individually, and system-optimizing behavior, in which a central controller directs traffic. The Braess paradox and its negation occur only for user-optimizing behavior, which is generally characterized as “selfish.” But taken together, the user-optimizing behaviors of a large enough group may somehow optimize the travel times of all users.

“I would say that a certain 'tipping point' has been reached because of the high travel demand at which the traffic flows on certain roads (because of the network design and topology) add so much to travel time that commuters, over time, learn to switch their paths/routes of travel, and where the Braess paradox may have occurred, is then negated," Nagurney told *PhysOrg.com*. “Such a wisdom of crowds phenomenon has been observed by commuters -- at higher travel demands certain crossroads may be essentially empty of traffic.”

As Nagurney explained, the opposite is also known to be true: under sufficiently low levels of demand, the Braess paradox no longer holds.

“There have been studies as to what happens at very low levels of demand (when a potentially troubling new route) is added,” said Nagurney, who contributed to earlier studies on this subject. “The new road in the original Braess problem was actually attractive, under low levels of demand, and all the travelers, acting selfishly, switched from their original routes, to the new road (and no Braess paradox occurred at this low level of demand). Such switching resulted in a reduced travel time for all travelers. Only the new route was used and the original routes were abandoned. Informally, I have seen this happen during my commutes to the University when I see my colleagues and myself alter our routes based upon the time of day and the congestion.”

The new formula is applicable to any network in which the Braess paradox originally occurs, from transportation networks to electric grids and the Internet. Since Braess first proposed the paradox more than 40 years ago, many major cities have used it to make policy decisions on road closures, including Seoul, Korea; Stuttgart, Germany; and New York City.

In a sense, the negation of the paradox actually adds to the paradox's original conclusions: when designing transportation networks (and other kinds of networks), extreme caution should be used in adding new routes, since at worst the new routes will slow travelers down, and at best, the new routes won't even be used.

“Improvement of infrastructure has become a priority in the United States as well as in other developed and developing countries,” Nagurney said. “As investments are made in our roads, in our rail and air networks, the electric power grid, and even the Internet, it is important to analyze not only the old and the proposed network topologies, but also the demands, the underlying congestion-dependent costs, and the behaviors of the users of the networks so that these investments are made wisely."

More information: A. Nagurney. "The negation of the Braess paradox as demand increases: The wisdom of crowds in transportation networks." *Europhysics Letters*, 91 (2010) 48002.
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