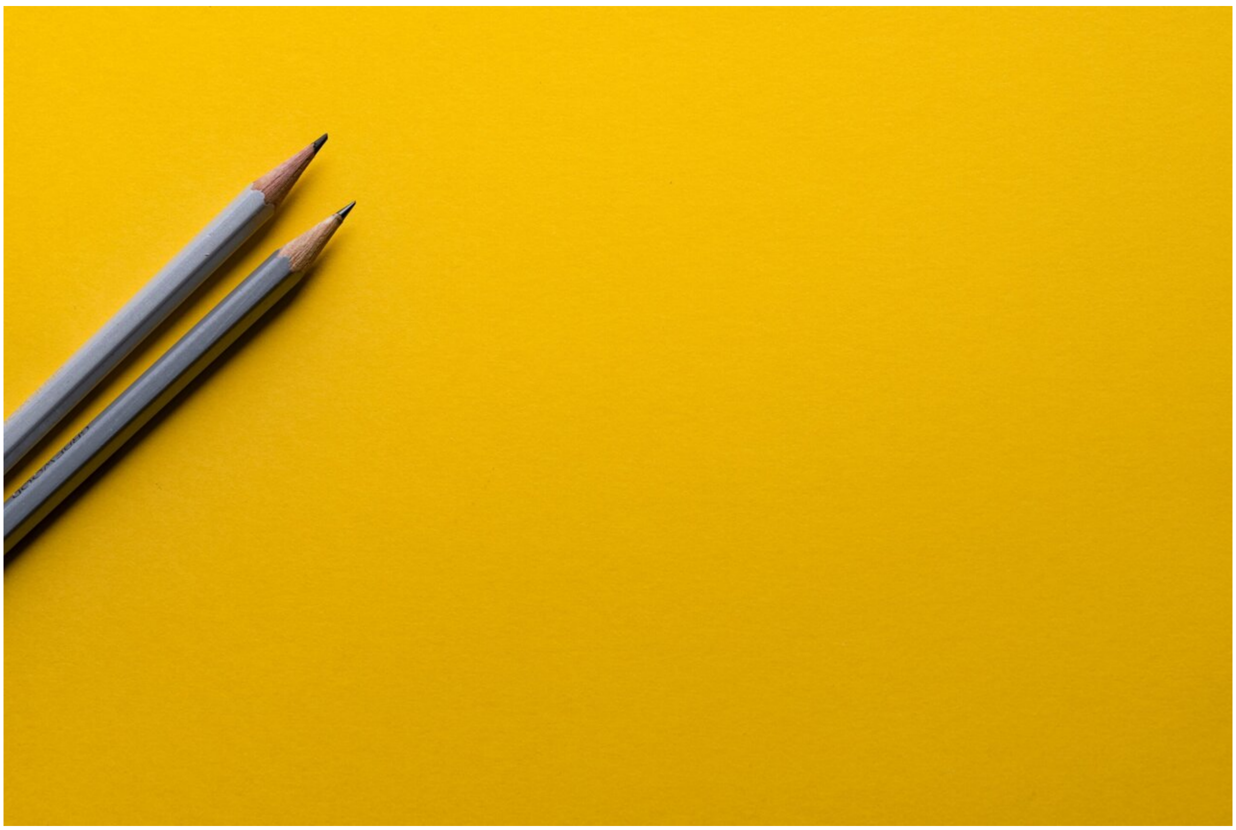
# Researchers develop a new tool to guide recovery from disasters

November 5 2015, by Thea Singer



Credit: CC0 Public Domain

The 1999 Odisha Cyclone struck the eastern coast of India, knocking out whole swaths of the Indian Railways Network, bringing the eastern IRN system to a halt. Cyclones Hudhud and Phailin caused similar mayhem in 2014 and 2013, while in 2012 power blackouts in northern and eastern India idled 300 intercity passenger trains and commuter lines. Closer to home, severe winter storms that hit Boston in 2014–2015 brought the MBTA mass-transit system to its knees.

Here and abroad, there is an urgent need for systematic strategies for recovering critical lifelines once disasters strike. Thanks to Northeastern researchers, that need is being met.

## A tool for recovery

First-year graduate student Udit Bhatia, under the direction of Auroop R. Ganguly, associate professor in the Department of Civil and Environmental Engineering, has drawn on network science to develop a computerized tool for guiding stakeholders in the recovery of large-scale infrastructure systems. In addition to the IRN and MBTA, the method can be extended to water-distribution systems, power grids, communication networks, and even natural ecological systems.

This unique tool, which has been filed for invention protection through Northeastern University's Center for Research Innovation, also informs development of preventative measures for limiting damage in the face of a disaster.

The study—which Bhatia and Ganguly coauthored with Devashish Kumar, PhD'16, and Evan Kodra, PhD'14—appears in the Nov. 4 issue of the journal *PLOS ONE.*

"The tool, based on a quantitative framework, identifies the order in which the stations need to be restored after full or partial destructions," says Bhatia, PhD'18, who is a student in Northeastern's Sustainability and Data Science Laboratory, directed by Ganguly. "We found that, generally, the stations between two important stops were most critical," he says, alluding to the network science concept of "centrality measures," which identify stations that enable a large number of station-pairs to be connected to one another.

## A new top-down approach

Bhatia credits Northeastern's interdisciplinary engineering graduate program with opening his mind to the possibility of constructing the model.

Through the program, he took courses with experts in a variety of fields. They include: "Critical Infrastructures Resilience," co-taught by Ganguly, an expert in climate, hydrology, and applied data sciences, and Stephen Flynn, a professor of political science and director of the Center for Resilience Studies and co-director of the George J. Kostas Research Institute for Homeland Security, and "Complex Networks," taught by Albert-László Barabási, Robert Gray Dodge Professor of Network Science. Insights from Jerome F. Hajjar, CDM Smith Professor and CEE Chair and an expert in structural engineering, also helped shape the model.

"Structural engineers have typically focused on rebuilding large infrastructures from the bottom up, identifying individual components or small-scale infrastructure systems," says Bhatia. For IRN, this might meant targeting the busiest station to begin repairs.

Bhatia's paper—based on a mix of real-world metrics, resilience, civil engineering principles, and network science-based algorithms—provides what Ganguly calls "a generic and quantitative top-down approach."

A comprehensive strategy requires a blend of bottom-up and top-down approaches, says Ganguly. "If these nodes of the system go down, here is a timely, resource-efficient, and overall effective way to speed recovery."

"Auroop and Udit are developing a system framework, which is a new approach for solving complex system problems," says Jalal Mapar, Director of the Resilient Systems Division, Department of Homeland Security, Science & Technology Directorate. "This new approach is very important and answers many of the complex questions that we will be facing in the next 5 to 50 years. It will help us understand the interdependencies and cascading effects of our critical infrastructure, and help us as a nation to be better prepared because we know what we are dealing with."

## Mining datasets, constructing a network

For the study, Bhatia mined open-source datasets on ticket-reservation websites to track the origins and destinations of trains running on the IRN—the world's most traveled railway in terms of passenger kilometers per day. He then constructed a complex network, with the stations as nodes and the lines connecting those nodes as the "edges," or links, between them, and overlaid it on a geographical map of the country. Next he applied natural and man-made disasters to the system, knocking out stations using network science-derived algorithms.

"We considered real-life events that have brought down this network," says Bhatia, ticking off the 2004 Indian Ocean Tsunami and the 2012 North Indian blackout due to a power grid failure, as well as a simulated cyber-physical attack, partially modeled after the November 2008 Mumbai terror attack. "We asked: Should this recovery be based on the number of trains each station handles, the number of connections each station has, the importance of the connections, where that station is located in the network, or something else?"

The researchers developed additional algorithms "to assign priority to each station," Bhatia says, indicating when it should be brought back online to produce the fastest recovery of the entire system.

## Preparing for the worst

In the IRN study, "betweenness centrality" often came to the fore. Bhatia cautions, however, that a single metric or strategy does not apply in all circumstances; for example, if just part of a network is disrupted, a particular station with an outsize number of connections might take precedence as a starting point over a station situated between two important stops.

"This model gives you the ability to say, 'These are the most critical nodes in the network, which if they failed, would cause a domino effect in the case of a disruption—meaning a cascading failure when there's a major shock,'" says Flynn, who recently testified before the U.S. House of Representatives on the prevention of and response to the arrival of a dirty bomb at a U.S. port. "'So that's obviously where we should go first.'"

If the Boston MBTA had this tool during last winter's historic snowfall, he says, they would have known where to start to get the transit system back up and running.

Moreover, Flynn says, the model gives decision-makers—urban planners, emergency managers, operations personnel who run the system day-to-day—insight into how to design the most secure system upfront. "And then," he says, "it enables them to prioritize where to put mitigation measures—resources, such as backup power, and other safeguards, including computer-security measures, to make the overall system better withstand the risk of disruption."

**More information:** Udit Bhatia et al. Network Science Based

Quantification of Resilience Demonstrated on the Indian Railways Network, *PLOS ONE* (2015). DOI: 10.1371/journal.pone.0141890

Provided by Northeastern University