Post-disaster optimization technique capable of analyzing entire cities

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This paper is the first to be published under a project called Probabilistic Resilience Assessment of Interdependent Systems (PRAISys), a collaboration between Lehigh, Florida Atlantic University and Georgia State University. The team was awarded a grant of $2.2 million by the National Science Foundation (NSF) last year, as part of NSF's $20 million investment in new fundamental research to transform infrastructure." It is part of the Obama administration's "Smart Cities" initiative to help communities tackle local challenges and improve city services. Credit: Hvass & Hannibal, courtesy of Lehigh University

Some problems, says Paolo Bocchini, cannot be solved through intuition.

"If you are trying to solve a problem that has, say, ten possible outcomes—you can probably find a way to figure out which one is optimal," says Bocchini, assistant professor of civil and environmental engineering at Lehigh University. "But what if the possible solutions number as high as 10 to the 120th power?"

To illustrate the size of that figure, 10 to the 120th power, in long form, is written as a "1" followed by 120 zeroes.

That is the massive number of possible recovery options with which civic leaders and engineers would be faced in the aftermath of a major catastrophic event, such as a hurricane or an earthquake.

"In a post-disaster recovery period, there may be one, large, very important bridge to repair that would take as long as a year to restore to full functionality," says Bocchini. "During that year, you could restore four smaller bridges which might have an even greater impact on getting the city back up and running. So, how do you figure out which choice is optimal?"

He adds: "Computational models that predict what might work for one bridge or five bridges, simply don't work when you try to scale up to 100 bridges."

To address this, Bocchini and his colleague Aman Karamlou, a doctoral assistant and structural engineering Ph.D. candidate, created a novel method that represents a major improvement in existing computational models and optimization methodologies. Their technique, Algorithm with Multiple-Input Genetic Operators—or AMIGO, for short—is described in a paper that was recently published in *Engineering Structures*.

Designed to consider very complex objectives while keeping computational costs down, AMIGO makes the search process more efficient and expedites the convergence rate (the speed at which the sequence approaches its limit). It does this by taking advantage of the additional data in the genetic operators which are used to guide the algorithm toward a solution.

In addition to being the first model to factor in so many elements, AMIGO is unique for its versatility.

"AMIGO takes the topology or characteristics of a network—as well as the damag—and then develops optimal recovery strategies. It can be used to solve a variety of scheduling optimization problems common in different fields including construction management, the manufacturing industry and emergency planning," says Bocchini.

A San Diego simulation

To demonstrate the effectiveness of their algorithm, Bocchini and Karamlou conducted a large-scale numerical analysis using an imagined earthquake scenario in the City of San Diego, California.

They chose San Diego for the size of its transportation network—it contains 238 highway bridges—as well as its importance and value as a U.S. strategic port. The total value of the port's imports and exports in 2013 has been estimated to be more than $7 billion.

The researchers identified the 80 bridges that would sustain the most serious damage based on the seismicity of the region, and used AMIGO to calculate the best restoration strategy.

In a post-disaster situation, after the initial emergency response, those responsible for the recovery of a city or region must plan a repair schedule that balances mid-term and long-term recovery goals. Because every action will have an impact on the recovery, the trade-offs of each possible action must be considered.

AMIGO is of the class of optimization solvers that uses what are called heuristic techniques and evolutionary algorithms that are inspired by the process of natural selection. These techniques are particularly useful for solving multi-objective optimization problems using a Pareto-based approach. The approach, which describes a method of assessing a set of choices, is named after Vilfredo Pareto (1848-1923), an Italian engineer and economist who used the concept in his studies of economic efficiency and income distribution.

While the total number of feasible solutions in the imagined San Diego bridge network restoration scenario is considerably large, the results show that AMIGO managed to find a set of near optimal Pareto solutions in a small number of trials (about 25 generations).

From the study: "Moreover, a new bridge recovery model is proposed. Compared to the previous studies, this recovery model is more realistic, as it takes advantage of the available restoration functions obtained by experts' surveys and scaling factors that account for the bridge cost."

The researchers compared the performance of their optimization formulation with their previous optimization techniques. The results show significant improvement both in terms of optimality of the solution and convergence rate.

"This is of great importance, since for large realistic networks, the traffic analysis procedure can be computationally very expensive," they write. "Therefore, reducing the number of required generations for convergence can considerably affect the computational cost of the problem and make this approach finally applicable to real-size networks.

Compared to previous formulations, the use of operational resource constraints and the new recovery model yield the generation of more realistic schedules."

Restore power or fix roads? Addressing interdependencies

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The interdisciplinary Lehigh team—led by Bocchini and made of up of faculty members with specialties in civil engineering, systems engineering, computer science and economics—is looking at how interdependent systems work together during and after a disaster. The goal is to establish and demonstrate a comprehensive framework that combines models of individual infrastructure systems with models of their interdependencies for the assessment of interdependent infrastructure system resilience for extreme events under uncertainty using a probabilistic approach.

"In the post-disaster phase, leaders are faced with tough choices. The impact of each decision will affect so many other areas so it's important to go beyond looking at one system—such as transportation—and look at how they all work together," said Bocchini.

More information: Aman Karamlou et al, Sequencing algorithm with multiple-input genetic operators: Application to disaster resilience, *Engineering Structures* (2016). DOI: 10.1016/j.engstruct.2016.03.038

Provided by Lehigh University

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