Finding a sensible balance for natural hazard mitigation with mathematical models

30 April 2013

Uncertainty issues are paramount in the assessment of risks posed by natural hazards and in developing strategies to alleviate their consequences.

In a paper published last month in the *SIAM/ASA Journal on Uncertainty Quantification*, the father-son team of Jerome and Seth Stein describe a model that estimates the balance between costs and benefits of mitigation—efforts to reduce losses by taking action now to reduce consequences later— following natural disasters, as well as rebuilding defenses in their aftermath. Using the 2011 Tohoku earthquake in Japan as an example, the authors help answer questions regarding the kinds of strategies to employ against such rare events.

"Science tells us a lot about the natural processes that cause hazards, but not everything," says Seth Stein. "Meteorologists are steadily improving forecasts of the tracks of hurricanes, but forecasting their strength is harder. We know a reasonable amount about why and where earthquakes will happen, some about how big they will be, but much less about when they will happen. This situation is like playing the card game '21', in which players see only some of the dealer's cards. It is actually even harder, because we do not fully understand the rules of the game, and are trying to figure them out while playing it."

Earthquake cycles—triggered by movement of the Earth's tectonic plates and the resulting stress and strain at plate boundaries —are irregular in time and space, making it hard to predict the timing and magnitude of earthquakes and tsunamis. Hence, forecasting the probabilities of future rare events presents "deep uncertainty," Stein says. "Deep uncertainties arise when the probabilities of outcomes are poorly known, unknown, or unknowable. In such situations, past events may give little insight into future ones."

Another conundrum for authorities in such crisis situations is the appropriate amount of resources to direct toward a disaster zone. "Much of the problem comes from the fact that formulating effective natural hazard policy involves using a complicated combination of geoscience, mathematics, and economics to analyze the problem and explore the costs and benefits of different options. In general, mitigation policies are chosen without this kind of analysis," says Stein. "The challenge is deciding how much mitigation is enough. Although our first instinct might be to protect ourselves as well as possible, resources used for hazard mitigation are not available for other needs. For example, does it make sense to spend billions of dollars building buildings in the central U.S. to the same level of earthquake resistance as in California, or would these funds do more good if used otherwise?"

The Japanese earthquake and tsunami in 2011 toppled seawalls 5-10 meters high. The seawalls being rebuilt are about 12 meters high, and would be expected to protect against large tsunamis expected every few hundred years. But critics argue that it would be more cost effective and efficient to focus on relocation and evacuation strategies for populations that may be affected by such tsunamis rather than building higher seawalls, especially in areas where the population is small and dwindling.

In this paper, Stein says, the authors set out to "find the amount of mitigation—which could be the height of a seawall or the earthquake resistance of buildings—that is best for society." The objective is to provide methods for authorities to use their limited resources in the best possible way in the face of uncertainty.

Selecting an optimum strategy, however, depends on estimating the expected value of damage. This, in turn, requires prediction of the probability of disasters.

It is still unknown whether to assume that the probability of a large earthquake on a fault line is constant with time (as routinely assumed in hazard planning) or whether the probability gets smaller after the last incidence and increases with time. Hence, the authors incorporate both these scenarios using the general probability model of drawing balls from an urn. If an urn contains balls that are labeled "E" for event and "N" for no event, each year is like drawing a ball. "If after drawing a ball, we replace it, the probability of an event stays constant. Thus an event is never 'overdue' because one has not happened recently, and the fact that one happened recently does not make another less likely," explains Stein. "In contrast, we can add E-balls after a draw when an event does not occur, and remove E-balls when an event occurs. This makes the probability of an event increase with time until one happens, after which it decreases and then grows again."

Since the likelihood of future earthquakes depends on strain accumulation at plate boundaries, the model incorporates parameters for how fast strain accumulates between quake incidences, and strain release that happens during earthquakes.

The authors select the optimal mitigation strategy by using a general stochastic model, which is a method used to estimate the probability of outcomes in different situations under constrained data. They minimize the expected present value of damage, the costs of mitigation, and the risk premium, which reflects the variance, or inconsistency, of the hazard. The optimal mitigation is the bottom of a U-shaped curve summing up the cost of mitigation and expected losses, a sensible balance.

To determine the advantages and pitfalls of rebuilding after such disasters, the authors present a deterministic model. Here, outcomes are precisely determined by taking into account relationships between states and events. The authors use this model to determine if Japan should invest in nuclear power plant construction given the Fukushima Daiichi nuclear reactor meltdown during the 2011 tsunami. Taking into account the financial and societal benefits of reactors, and balancing them against risks—both financial and natural—the model determines the preferred outcome.

Such models can also be applied toward other disaster situations, such as hurricanes and floods, and toward policies to diminish the effects of climate change. Stein gives an example: "Given the damage to New York City by the storm surge from Hurricane Sandy, options under consideration range from doing nothing, using intermediate strategies like providing doors to keep water out of vulnerable tunnels, to building up coastlines or installing barriers to keep the storm surge out of rivers. In this case, a major uncertainty is the effect of climate change, which is expected to make flooding worse because of the rise of sea levels and higher ferocity and frequency of major storms. Although the magnitude of these effects is uncertain, this formulation can be used to develop strategies by exploring the range of possible effects."

More information: Formulating Natural Hazard Policies under Uncertainty epubs.siam.org/doi/abs/10.1137/120891149 . Jerome L. Stein and Seth Stein, SIAM/ASA Journal on Uncertainty Quantification, 1(1), 42-56. (Online publish date: March 27, 2013).

Provided by Society for Industrial and Applied Mathematics

APA citation: Finding a sensible balance for natural hazard mitigation with mathematical models (2013, April 30) retrieved 13 October 2019 from https://phys.org/news/2013-04-natural-hazard-mitigation-mathematical.html