Two-stage stochastic integer programming models for strategic disaster preparedness

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Today's disaster management is based on scientific disciplines and involves the following phases: mitigation, preparedness, response, and recovery. Mitigation efforts attempt to prevent hazards from developing into disasters or to reduce the effects of disasters when they occur. One of the mitigation alternatives is retrofitting of structures. The resilience of structures can be increased by retrofitting actions. Preparedness mechanisms and strategies prepare the community and all organizations to a quick and efficient response when a disaster occurs. A post-disaster response requires to satisfy the relief item needs (such as shelter, food, medicine, clothes) as much as and as soon as possible. Finally, actions like repairing or rebuilding damaged structures are related with recovery phase.

The amount of relief demand and the level of disruption on transportation network depend on the pre-event resilience of buildings and roads, respectively. Therefore, the effectiveness of post-disaster response is directly related with pre-disaster retrofitting of structures. For this respect, we develop an integrated preparedness model to give efficient decisions for both mitigation and response phases. The model also takes into account the uncertainty related to the magnitude of an earthquake, which dictates the amount of relief demand and damage on the transportation network, by using different scenarios. The problem is formulated as a two-stage stochastic integer program where the objective is to minimize the total cost of retrofitting, transportation, and the relief item demand shortage under a limited mitigation budget. The pre-disaster building and transportation link retrofit decisions are the first-stage variables while the post-disaster demand point-rescue center assignments, relief flow amounts between rescue centers and demand points, and relief shortage amounts of demand points are scenario-dependent second-stage (recourse) decisions.

The earlier studies on optimization of mitigation decisions take into account either retrofitting of buildings [1, 2, 3] or retrofitting of transportation infrastructures [4, 5, 6]. In contrast, the model we propose includes both types of the retrofitting decisions. In addition, past studies evaluate the savings for reconstruction costs in the aftermath of a disaster as the benefit of building retrofit decisions. Different from those works, our model considers a tradeoff between the building retrofit levels, and the level of post-disaster response need. To the best of our knowledge, this is the first model where building and transportation link retrofitting decisions are combined with response related decisions.

Since the retrofitting decisions are considered for each single building, the number of binary variables can be very high which makes the model computationally difficult to solve. Therefore, we decompose the model by Lagrangean relaxation and propose different Lagrangean heuristics to solve it. Results on randomly generated test instances show that the proposed solution methods for the model exhibit good performance under different parameter settings. In addition, various analyses are carried out to clearly understand the model behaviour.

We also develop another model which improves the previous one by incorporating recovery decisions and time periods. The model takes into account the impact of expected earthquake occurrence time on the decisions. This periodic problem can also be formulated as a two-stage stochastic integer programming model. Here, the retrofitting actions are first-stage, while the response and recovery related actions are the second-stage decisions. The expected total recourse cost with respect to the disaster scenario and its occurrence time is minimized under a mitigation budget.

Keywords: Disaster management, two-stage stochastic programming, decomposition.

References

[1] Dodo, A., R.A. Davidson, N. Xu, and L.K. Nozick, "Application of Regional Earthquake Mitigation Optimization", *Computers and Operations Research*, Vol. 34, No. 8, pp. 2478-2494, 2007.

[2] Xu, N., R.A. Davidson, L.K. Nozick, and A. Dodo, "The Risk-return Tradeoff in Optimizing Regional Earthquake Mitigation Investment", *Structure and Infrastructure Engineering*, Vol. 3, No. 2, pp. 133-146, 2007.

[3] Vaziri, P., R.A. Davidson, L.K. Nozick, and M. Hosseini, "Resource Allocation for Regional Earthquake Risk Mitigation: A Case Study of Tehran, Iran", *Natural Hazards*, Vol. 53, pp. 527-146, 2010.

[4] Viswanath, K., and S. Peeta, "Multicommodity Maximal Covering Network Design Problem for Planning Critical Routes for Earthquake Response", *Transportation Research Record: Journal of the Transportation Research Board*, No. 1857, pp. 1-10, 2003.

[5] Liu, C., Y. Fan, and F. Ordóñez, "A Two-stage Stochastic Programming Model for Transportation Network Protection", *Computers and Operations Research*, Vol. 36, No. 5, pp. 1582-1590, 2009.

[6] Peeta, S., F.S. Salman, D. Günneç, and K. Viswanath, "Pre-disaster Investment Decisions for Strengthening a Highway Network", *Computers and Operations Research*, Vol. 37, No. 10, pp. 1708-1719, 2010.