A Multi-Stage Decision Model for Debris Disposal Operations

Gary Fetter
Dept. of Business Information Technology
Pamplin College of Business
Virginia Tech
gmf22@vt.edu

Mauro Falasca
Dept. of Information Systems and Operations Management
Sellinger School of Business
Loyola University Maryland
mfalasca@loyola.edu

Christopher W. Zobel
Dept. of Business Information Technology
Pamplin College of Business
Virginia Tech
czobel@vt.edu

Terry R. Rakes
Dept. of Business Information Technology
Pamplin College of Business
Virginia Tech
trakes@vt.edu

ABSTRACT

As shown by Hurricane Katrina, disposing of disaster-generated debris can be quite challenging. Extraordinary amounts of debris far exceeding typical annual amounts of solid waste are almost instantaneously deposited across a widespread area. Although the locations and amounts of debris can be easily summarized looking back after recovery activities have been completed, they are uncertain and difficult at best to estimate as debris operations begin to unfold. Further complicating matters is that the capacity of cleanup resources, which is dependent upon available equipment, labor, and subcontractors, can fluctuate during on-going cleanup operations. As a result, debris coordinators often modify initial resource assignments as more accurate debris estimates and more stable resource capacities become known. In this research, we develop a computer-based decision support system that incorporates a multi-stage programming model to assist decision makers with allocating debris cleanup resources immediately following a crisis event and during ongoing operations as debris volumes and resource capacities become known with increasing certainty.

Keywords

Debris Disposal, Decision Modeling, Optimization, Stochastic Programming

INTRODUCTION

Upon the onset of a crisis event, the paramount concern of responders is saving lives. Once response phase activities have been completed and there is no longer a threat to life, attention is focused on recovery activities, aimed at restoring the social, political, and economic infrastructure of the affected area. These recovery phase activities include cleaning up debris, providing temporary housing, and rebuilding lifelines and structures damaged by the disaster.

Debris cleanup is one of the most important and challenging aspects of recovery operations in need of computer-based decision support systems to help manage the complexity and to speed up the decision process. Depending on the category and nature of the disaster, recovery activities can be quite complex, require effective coordination between decision makers, and involve substantial resources and cost. More importantly, the failure of emergency management decision makers to successfully coordinate recovery activities can significantly increase the time and cost of restoring damaged communities and result in severe social, political, and economic turmoil. Nearly four years have passed since Hurricane Katrina made landfall near New Orleans in August 2005 and cleanup and recovery activities, which are estimated to cost over $150 billion, have still not yet been completed. Unfortunately, the response and recovery activities in the case of Hurricane Katrina have illuminated the consequences of poor emergency management (FEMA 2006). Officials drew criticism from

Reviewing Statement: This paper represents work in progress, an issue for discussion, a case study, best practice or other matters of interest and has been reviewed for clarity, relevance and significance.

politicians and citizens for poor planning and decision-making, slow response, and inequitable allocation of resources (Luther 2008). Similar problems can be found in the planning, response, and recovery efforts of other recent disasters, including the recent Burma Cyclone and Sichuan earthquake, which both occurred in May 2008 and left nearly 200,000 fatalities and more than two times as many more injured.

LITERATURE REVIEW

Disaster Debris Disposal Operations

Disaster debris disposal differs significantly from everyday solid waste disposal and is typically organized into two phases. In Phase 1, which is usually completed within 24 to 72 hours, activities are focused on clearing major pathways as quickly as possible to facilitate entry and exit to the area affected by the crisis. These activities practically involve pushing debris to the side of roads and highways.

Phase 2 activities, which are the focus of our study here, can take months or longer, are aimed at collecting and disposing of all debris generated during the disaster. In addition to speed of cleanup, objectives aimed at allocating resources equitably across the region become a focus in order to minimize the social, political, and economic unrest that could result from privileging one area over another, for example, because of political or economic influence. The consequences of inequitable cleanup operations were unfortunately illuminated in the case of Katrina and other recent crisis events.

In order to facilitate Phase 2 operations, disaster coordinators commonly divide the overall area into smaller debris regions. The objective for coordinators is to equitably assign debris cleanup resources to each region based on debris estimates in the region and available resource capacities in such a way so that cleanup operations are completed in each region simultaneously. The challenge is that disaster coordinators are faced with uncertain information. First, at the onset of cleanup operations, they must rely on estimates of debris volume in each region—commonly derived using the USACE debris estimating tool—that are often inaccurate by 30% or more (USACE . Second, they must also rely on contractors whose collection and disposal capacity can fluctuate based on the availability of labor, equipment, and subcontractors. Finally, as debris operations unfold, information about debris volume becomes clearer and availability of labor, equipment, and subcontractors becomes more stable. As a result, debris coordinators often modify initial resource assignments as more accurate debris estimates and more stable resource capacities become known (Chesapeake 2004). It is therefore necessary to have an information system that can manage this complexity.

Disaster debris disposal has primarily been discussed qualitatively in the published literature. In one study, Roper (2005) discussed the challenges involving debris cleanup following Hurricane Katrina stemming from the mixed-nature of disaster debris. In another case study, Dubey, et al. (2007) identified the problems associated with the amounts of arsenic treated wood in the debris from Katrina. In one of the few quantitative studies, Wei (2008) developed a decision support system for estimating debris flow resulting from a flood event and showed its usefulness in evacuation planning and mitigation activities. Many industry journals, popular press, and government agencies have published articles discussing debris disposal operations in general and for specific crisis events, the importance of debris planning, and the general nature of disaster debris. We are unaware of any software or studies that consider the stochastic nature of debris estimates and resource availability while addressing the challenge of assigning resources to regions in order to achieve equity objectives within the context of a decision support system. FEMA’s freely available HAZUS-MH software helps decision makers analyze and estimate potential damage and losses before and after a disaster event and is an example of the type of software that could incorporate our decision model for debris management.

Stochastic Programming

In a dynamic situation such as the response to a crisis, multistage stochastic programming represents a modeling technique that can be used to deal with the uncertainty that characterizes some of the parameters in disaster operations management.

Since its inception by Dantzig (1955), several authors have studied different aspects of stochastic programming with recourse (Haneveld and Vlerk, 1999, Riis and Andersen, 2005, Vladimirou and Zenios, 1997). Birge and Louveaux (1997), for example, present the most important concepts and applications in the field. Two-stage stochastic programming formulations have been one of the most widely used models. In these cases, the decision maker is required to make a decision in the first stage, prior to knowing what value some random variable will assume (e.g., the volume of debris or the available capacity). In the second stage, a recourse action is taken in order to compensate for the decision made in the first stage. The uncertain variables are usually modeled using a set of scenarios, and each scenario is assigned an associated probability of occurrence.

Multi-stage stochastic programming has been successfully applied to the study of different crisis response and management activities. In this particular line of research, Viswanath et al. (2002) focused on the transportation aspect of disaster operations. The authors developed a multi-stage stochastic program for the disaster-related strategic problem of investing in the links of a stochastic network to improve its expected post-disaster performance. In the same line of research, Barbarosoglu and Arda (2004) developed a two-stage stochastic programming model to plan the transportation of first-aid commodities to disaster-affected areas during the emergency response phase. The authors developed a multicommodity, multimodal network flow formulation that describes the flow of relief materials over a transportation network and their model was tested using problem instances generated out of earthquake data.

Tean (2006), focusing on disaster preparedness, combined transportation and relief location considerations in the development of a multi-stage stochastic optimization model to assist in the pre-positioning of relief units and assets. The model takes into consideration different budget, transportation and physical constraints with the goals of maximizing the number of survivors and the delivery of commodities. Heidtke (2007) extended the ideas presented by Tean and developed a stochastic model to determine the optimal approach to reduce the temporal gap that occurs between the exhaustion of local resources and the arrival of federal resources. The model also ensures the availability of critical supplies in the case of large-scale domestic disasters and allows the decision maker to study different pre-positioning and transportation strategies.

As implied above, the existing literature has focused on different crisis response and management aspects such as relief location and transportation decision problems. Multi-stage stochastic programming, however, has not been applied to the topic of debris disposal. For this reason, the focus of this current research effort is aimed at discussing the development of a multi-stage decision model for debris disposal operations.

RESEARCH OBJECTIVE

Our aim is to develop a model within the context of a computer –based decision support system that will assist disaster management coordinators with allocating debris cleanup resources immediately following a crisis event and during ongoing debris cleanup operations as debris volumes and resource capacities become known with increasing certainty.

PROPOSED METHODOLOGY AND ANALYSIS

In our study, we will first formulate and solve a two-stage, linear optimization model to assist decision makers with challenge of allocating resources during debris disposal operations. The model will consider uncertain parameters, such as debris volumes and available resource capacities, as well as appropriate operational and logistical constraints related to contractor and area assignments.

In our initial analysis, we will consider three possible levels of debris volume (low, medium and high) and three possible available capacity levels (low, medium and high) for a total of nine possible scenarios (See Figure 1 below).

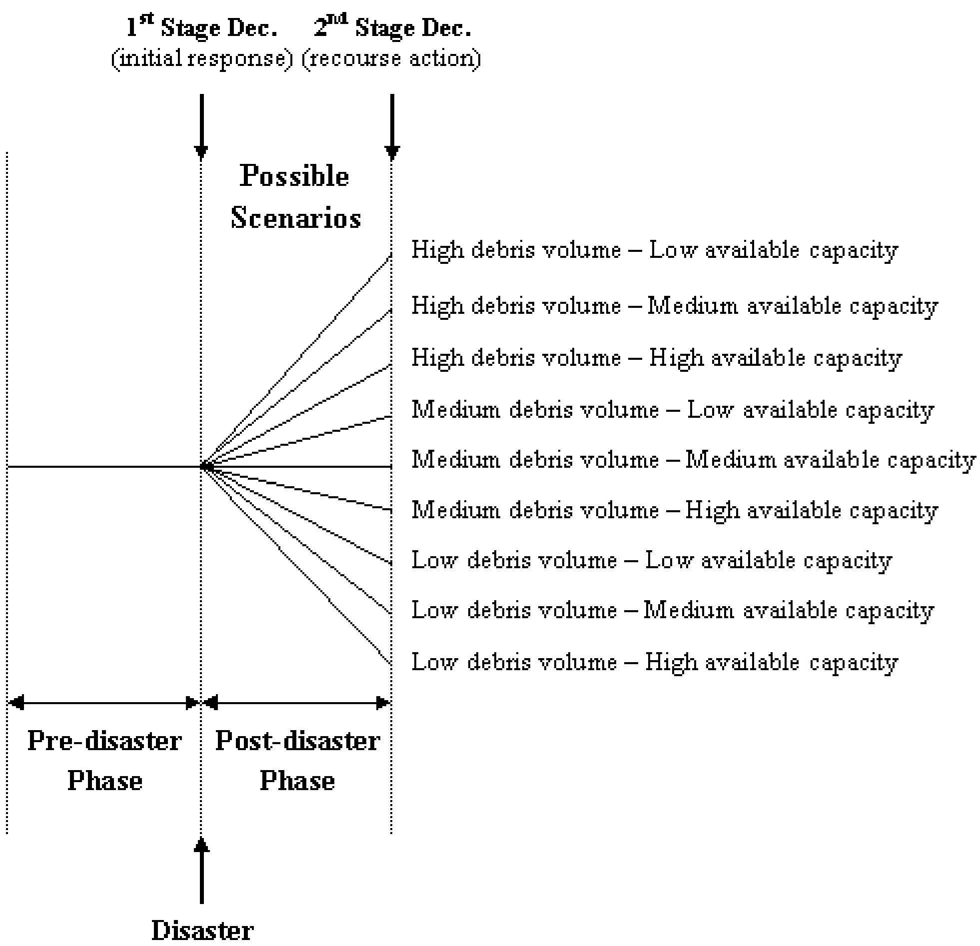

Figure 1. Representation of possible scenarios for the two-stage debris disposal operations model

As shown in the figure above, the best possible scenario is characterized by a low level of debris volume and a high level of available capacity, while the worst case scenario is characterized by a high level of debris volume and a low level of available capacity.

Using actual collection and disposal data for the Chesapeake, Virginia, area from debris cleanup operations following 2003 Hurricane Isabel, we will validate the usefulness of our model following the natural decision process of debris coordinators. First, we solve the initial-stage debris disposal operations problem using our proposed stochastic formulation. Next, we will solve the problem at subsequent stages using two additional solution approaches: The Wait-and-See solution approach (where we will assume that perfect information about future realizations of the model's uncertain parameters is readily available), and the Expected Value solution approach (where we will base the debris disposal planning process on the average value of the uncertain parameters (Birge, 1982)). This additional analysis will allow us to validate the proposed methodology, place the model results into context, and derive further relevant insights.

REFERENCES

1. Barbarosoglu, G. & Arda, Y. (2004) A two-stage stochastic programming framework for transportation planning in disaster response, *The Journal of the Operational Research Society*, 55, 1, 43-53.
2. Beraldi, P., Musmanno, R. & Triki, C. (2000) Solving Stochastic Linear Programs with Restricted Recourse Using Interior Point Methods, *Computational Optimization and Applications*, 15, 3, 215-234.
3. Birge, J. (1982) The value of the stochastic solution in stochastic linear programs with fixed recourse, *Mathematical Programming*, 24, 1, 314-325.
4. Birge, J. & Louveaux, F. (1997) *Introduction to stochastic programming*, Springer, New York.
5. Chesapeake, City of (2004) Hurricane Isabel Project Summary. City of Chesapeake, Virginia.
6. Dantzig, G. (1955) Linear programming under uncertainty, *Management Science*, 1, 197-206.
7. Dubey, B., Solo-Gabriele, H.M., & Townsend, T.G. (2007) Quantities of arsenic-treated wood in demolition debris generated by Hurricane Katrina. *Environmental Science & Technology*. 41, p. 1533.

8. FEMA (2006) *Damage Control: FEMA and the Anatomy of Emergency Management*. Federal Emergency Management Agency, Washington, D.C.
9. Haneveld, W. K. K. & Vlerk, M. H. v. d. (1999) Stochastic integer programming: General models and algorithms, *Annals of Operations Research,* 85, 39-57.
10. Heidtke, C. L. (2007) Reducing the "Gap of Pain": A Strategy for Optimizing Federal Resource Availability in Response to Major Incidents. pp. 105. Naval Postgraduate School, Monterey, California.
11. Luther, L. (2008) Disaster Debris Removal After Hurricane Katrina: Status and Associated Issues. Congressional Research Service.
12. Riis, M. & Andersen, K. A. (2005) Applying the minimax criterion in stochastic recourse programs, *European Journal of Operational Research,* 165, 3, 569-584.
13. Roper, W.E., (2005) Waste management policy revisions: lessons learned from the Katrina disaster. *International Journal of Environmental Technology and Management*, 8, p. 275.
14. Tean, E. S. (2006) Optimized Positioning of Pre-Disaster Relief Force and Assets. pp. 59. Naval Postgraduate School, Monterey, California.
15. Viswanath, K., Peeta, S. & Salman, F. S. (2002) Reducing the Vulnerability of a Network Through Investment: Decision Dependent Link Failures. pp. 17. Purdue University, Department of Economics.
16. Vladimirou, H. & Zenios, S. (1997) Stochastic linear programs with restricted recourse, *European Journal of Operational Research,* 101, 1, 177-192.
17. Wei, F. (2008) A decision support system for debris-flow hazard mitigation in towns based on numerical simulation: a case study at Dongchuan, Yunan Province. *International Journal of Risk Assessment and Management*, 8, p. 373.