Decision Support Systems 87 (2016) 13–25

Contents lists available at ScienceDirect

Decision Support Systems

journal homepage: www.elsevier.com/locate/dss

Decision support for long-range, community-based planning to mitigate against and recover from potential multiple disasters

Josey Chacko [a], Loren Paul Rees [b,*], Christopher W. Zobel [b], Terry R. Rakes [b], Roberta S. Russell [b], Cliff T. Ragsdale [b]

[a] Richard J. Bolte, Sr., School of Business, Mount St. Mary's University, Emmitsburg, MD 21727, USA
[b] Department of Business Information Technology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA

ARTICLE INFO

Article history:
Received 31 December 2014
Received in revised form 20 February 2016
Accepted 21 April 2016
Available online 30 April 2016

Keywords:
Decision support
Resilience
Sustainability
Mathematical programming
Disaster planning
Multi-hazard

ABSTRACT

This paper discusses a new mathematical model for community-driven disaster planning that is intended to help decision makers exploit the synergies resulting from simultaneously considering actions focusing on mitigation and efforts geared toward long-term recovery. The model is keyed on enabling long-term community resilience in the face of potential disasters of varying types, frequencies, and severities, and the approach's highly iterative nature is facilitated by the model's implementation in the context of a decision support system. Three examples from Mombasa, Kenya, East Africa, are discussed and compared in order to demonstrate the advantages of the new mathematical model over the current ad hoc mitigation and long-term recovery planning approaches that are typically used.

1. Introduction

Disasters, whether natural disasters like hurricanes, earthquakes, or tsunamis, or socio-technical disasters such as terrorist attacks, are a significant problem with worldwide impacts, and an increasing number of people are subject to their effects [54]. Furthermore, many areas are actually subject to the impacts of different types of disasters (such as wildfires and landslides in Southern California [19]), or to the same type of disaster striking an area multiple times over the course of many years (such as flooding in Bangladesh [59]). As communities in these areas seek to make strategic investments that can improve their ability to withstand and recover from such disasters, it is therefore important for them to adopt a comprehensive, long-term view that acknowledges the likelihood that multiple disasters will occur.

Because there is a significant amount of complexity associated with determining the most appropriate strategy to follow in such an environment, suitable analytical tools are needed in order to facilitate such efforts. This paper seeks to address this need by introducing a decision support system (DSS) framework for long-range, values-based, community-driven planning in the context of multiple potential disaster events. The focus of our discussion will be on the mathematical model at the core of this DSS, which provides communities with the new opportunity to assess strategies for both disaster mitigation and disaster recovery. As this model is the first of its kind in this genre, we will expend some effort defining the major features that it incorporates and listing caveats that it avoids.

Our discussion begins with a detailed look at disaster planning and community-driven decision making, as well as the use of analytical models to support more effective mitigation and recovery strategies. It then presents and discusses the new mathematical model, and it discusses its implementation in the context of the decision support system. Finally, the model's potential for improving multi-hazard decision making is illustrated by comparing three different real-world scenarios focused on the community of Mombasa, Kenya, in East Africa. The paper concludes with a discussion of the managerial and academic implications of the work, followed by a look at promising future research directions.

2. Background

It is well recognized that disaster operations management can be broken into five overlapping phases: *mitigation*, *preparedness*, *response*, *short-term recovery*, and *long-term recovery*, each of which occurs in a repeating cycle. *Mitigation* activities tend to be associated with strengthening capabilities in advance of a future disaster event, whereas *preparedness* activities tend to be focused on minimizing the actual social, economic, and physical impacts of a disaster before it occurs. Immediately after a disaster strikes, in the *response* phase, emergency responders

* Corresponding author.

http://dx.doi.org/10.1016/j.dss.2016.04.005
0167-9236/

initiate activities that are focused on life safety issues. *Short-term recovery* activities then are used to help transition to *long-term recovery* and the restoration of the affected community to a properly functioning state (which may be better or worse than its prior state) [22,51].

Much of the current analytical work in disaster operations management tends to focus on the emergency of the disaster—the middle three phases of disaster operations management: *preparedness*, *response*, and *short-term recovery* [22,33,45], and on the specific characteristics of a particular disaster event, or type of disaster, with which these phases are associated [24]. It is important to recognize, however, that there are broader issues of safety that encompass the entire range of hazards that may pose a risk to a city [6,42]. For example, an urban city center such as San Francisco, CA, with a population close to 850,000, is at risk not only from earthquakes but also from wildfires, tsunamis, landslides, flooding, heat waves, and droughts [4]. It is for this reason that institutions such as the U.S. Federal Emergency Management Agency (FEMA) [18] and the United Nations [53] have promoted the use of a "multi-hazard" approach to risk assessment for more than 10 years.

A multi-hazard perspective acknowledges that multiple different disasters may occur in a given location, possibly simultaneously or with cascading effects, but potentially also independently and in a serial nature. Significant synergistic benefits can be achieved by considering more than one type of hazard in the planning process, including substantial economic and outcome efficiencies [42]. In order to achieve such synergistic benefits, however, we must take a strategic, more sustainable view of disaster operations management, which requires a particular focus on the first and last phases of the disaster management cycle. Such a view allows us to simultaneously consider both actions that mitigate against disasters and actions that enable more effective recovery, and, in particular, to examine opportunities for combining both types of activities over more than just a single-disaster event. *No* academic work currently exists that explicitly combines both mitigation and recovery in the context of planning for multiple types of disasters. Over the course of our discussion below, we will demonstrate the advantage of taking such an approach over current approaches which involve *no* long-range mitigative and recovery-based analytical planning. Furthermore, we will also demonstrate the added superiority of considering multiple hazard types rather than planning for just one type—even when both mitigation and recovery are both included in the analysis.

Inherent in taking such a longer-term, multi-hazard view is the need to explicitly consider the input of the community for whom the protective or recovery actions are being taken. The voice of the affected community itself is critical to the sustainability of development-oriented programs [28], and community acceptance of a plan is crucial if investment is to be made in a disaster management solution that will be implemented over the long term. As the literature has indicated for years (e.g., [7,40,50]), disaster officials often fail to determine and include community members' needs in their planning. Whether the community provides direct input into the decision process, or whether their values and interests are instead represented by a spokesperson, actively advocating for their needs is critical.

3. Model development

Existing analytical models in disaster operations management typically consider a single type of hazard [24]. Moreover, those that consider a range of hazards (analytical multi-hazard models) typically focus on risk reduction [24], and as a result, post-disaster management is not considered. This can be seen in Table 1, which provides a summary of the main model features represented in a review of the analytical multi-hazard model literature.

According to Kappes et al. [24], appropriate multi-hazard modeling requires the following key elements: (i) accounting for the additional interactions that exist among disaster management elements; (ii) considering both pre- and post-disaster management concomitantly, which is essential for community/asset viability; and (iii) as noted in Cox [16] and in Chacko et al. [14], under budget constraints, there is a need for incorporating mathematical *optimization* models.

The only work that provides a complete mathematical optimization model, Zhang et al. [60], models only resource allocation during disaster response. Their model does not account for post-disaster management actions and, moreover, does not account for the interactions between different elements. Similarly, although Chacko et al. [14] offer discussion on the objective function and dependency constraints in a multi-hazard context, they do not develop the entire mathematical model or model the post-disaster management phase. In short, there is no extant work in the literature that, for multi-hazard analysis, optimizes over the long-term, including both recovery and mitigation, much less accounts for the unique interactions inherent in multi-hazard models. The research in this paper is intended to fill this gap.

The iterative and interactive nature of the community-based, analytical planning model presented below is particularly suited to a decision support system (DSS) (e.g., [26,47]). When a community utilizes the model and planning approach set forth in this paper, more than just a single model will be built, run, and implemented. Rather, baseline models are run, output is generated and then discussed by the community, which in turn necessitates that additional inputs be considered, and model variants be run. A unified system incorporating both the data and model components made accessible to the user (the community) in a transparent and facilitative manner is therefore preferred. DSS provides just such a framework ([47], p. 29). Fig. 1A provides a general model of a DSS, and Fig. 1B shows this general structure implemented in the context of the specific DSS developed in this paper.

3.1. Incorporating community inputs

An important consideration of this modeling framework is that communities may wish to express that either "formal policies" or "ad hoc strictures" be included in the solution generated, such as the community's saying:

- we desire equity across all regions in terms of funds disbursed for recovery per dollar of damage;
- we will not allow rebuilding in the flood plain;
- we will insist that all rebuilding meets new, tougher building codes;
- we wish to take advantage of the opportunity to improve the downtown business district when recovery is necessary, as that will attract new industry/merchants to the city.

We encourage such planning and include it, if desired, as additional constraints in our model.

Although different communities – particularly in different countries – propose and approve mitigation and recovery endeavors using different mechanisms, we assume here that whatever the specific custom may be for approval, certain minimal, basic data must be furnished. Project costs, benefits, equipment demands, personnel needs, time constraints, etc., must all be specified by region as appropriate, and any synergies obtained across projects (e.g., if projects 4 and 7 are both undertaken, a savings of 30% occurs) must also be listed. Regions may be defined in terms of existing political units, as we do in our Mombasa, Kenya, example below, or they may be defined as "areas" that contain assets that must be protected (e.g., that part of Washington, DC, around the White House), or such as "the downtown business district," "low-income neighborhoods," or any other "homogeneous" area.

3.2. Representing multi-hazard dependencies

The relationships among the common classes in the disaster management process are as follows: hazards (H) impact the community/critical assets (C), and management strategies (S) requiring available resources (R) are used to intervene to protect and recover the community/