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Multiple emergency resource allocation for concurrent incidents in natural disasters

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ABSTRACT

Emergency resource allocation, which mainly deals with how to efficiently allocate emergency resources of rescue agencies to process emerging incidents and reduce casualties and economic losses, has been one of the most fundamental and essential problems in emergency management for natural disasters. However, to our best knowledge, the existing deterministic methods concentrate on emergency resource allocation only for a single incident with constraints on response time or emergency resource cost separately, which is too simple to be applied in complex emergency scenarios. To this end, in this paper we commit ourselves to a challenging problem of allocating multiple emergency resources to multiple concurrent incidents in a parallel manner, taking response time and emergency resource cost altogether. For this purpose, we first define *disaster response coalition* as a form of team play. Besides, we propose a multiply constrained integer linear programming model and develop a differential evolution and heuristic based search algorithm to explore overlapping disaster response coalitions for concurrent incidents. Finally, the comparative experimental results show that technically, the parallel allocation of emergency resources for concurrent incidents is significantly more economical and efficient than the traditional serial allocation.

1. Introduction

Natural disasters, such as floods, volcanic eruptions, earthquakes, and tsunamis, often cause great loss of life and damage to property, and also leave big economic damage to society [1,9,26]. Especially in China, with the rapid economic development and the accelerated urbanization, the Chinese government faces increasing pressure on resource, environment, and ecology. In recent years, natural disasters occurred increasingly frequently in China and caused great loss of life and property. For example, the 2008 Wenchuan earthquake of magnitude 7.9, which is the most devastating earthquake in China in more than three decades, killed 69,225 people, left 379,640 people injured, 17,939 people listed as missing and at least 5 million people without housing, and the estimated total damages exceed about 100 billions US$ [30,38]. Consequently, in order to lessen the impact of natural disasters, governments and researchers devote increasing attention to natural disaster management [5,23,24,28].

Generally speaking, there are four main phases in disaster management [13,20]: mitigation, preparedness, response, and recovery [23,24], each of which is often described as a part of a continuous process as shown in Fig. 1. This concept of "phases" has been used since the 1930s to help describe, examine, and understand disasters as well as organize the practice of emergency management [13,20]. In this paper, we focus on the phase of "response" that mainly contains locating, allocating, and routing emergency resources. More specifically, locating is to find appropriate deployment sites within an area such that a certain response time is guaranteed to reach the potential incidents within this area [6,42], allocating is aimed at finding optimal emergency resource allocation (ERA) schemes for rescue agencies and incidents to minimize the response time or emergency cost [16,25], and routing is to find a shortest path from one rescue agency to an incident according to road situations and is often solved combined with the location problem [18,41,42]. Particularly, ERA mainly deals with how to efficiently and quickly allocate emergency resources of rescue agencies, such as health care, equipments, electricity, water, garbage removal, transportation, and communications, to process emerging incidents and reduce casualties and economic losses [6,16]. ERA is one of the most fundamental and essential problems in the response phase that may determine the success or failure of disaster rescue, can provide valuable

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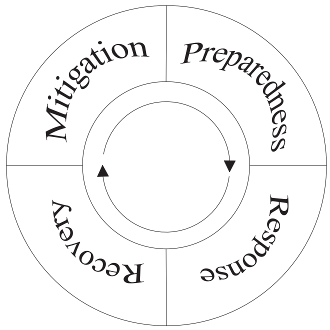

Fig. 1. The four main phases in disaster management.

references for the actual emergency decision-making, and has an important practical significance in protecting life and property, reducing economic damage, and maintaining social stability [36].

However, the traditional ERA in the literature considers only a single incident at a time with constraints on response time or resource cost separately. In fact, some natural disasters, such as earthquakes and floods, usually affect and spread to large areas, and then a large amount of incidents in disaster areas should be handled simultaneously and timely. To tackle such situations, some researchers turn their attentions to concurrent incidents in natural disasters, but they simply assume that each rescue agency cannot but respond to only a single incident at any time [16]. One fact we cannot ignore is that in practical emergency scenarios a rescue agency with sufficient emergency resources is able to be involved in executing more than one rescue task and allocating its emergency resources to several different incidents at the same time. Such overlapping properties are beneficial to improve the utilization of rescue agencies' emergency resources and increase the efficiency of disaster response.

On the other hand, in practice a rescue agency's emergency resources are often limited. When a rescue agency with rare, but highly demanded emergency resources prepares to respond to several different incidents at the same time, those incidents will compete keenly for them. Once it is unable to meet the needs of so many incidents, some possible conflicts over the usage of emergency resources will occur, which may directly result in the failure of emergency response. Accordingly, to avoid potential emergency resource conflicts, some deterministic searching methods are presented to serially allocate rescue agencies' emergency resources to incidents according to each incident's priority [3,36,40]. In these deterministic methods, each incident is dealt with separately and an incident's request can be satisfied only after its previous incidents have been assigned, so strictly speaking, these methods still belong to the category of solving a single incident. This traditional serial allocation, no doubt, is extremely adverse to the subsequent incidents. The reason is that the previously allocation schemes will inevitably influence the searching result of the scheme for the successive incidents, because some rescue agencies' emergency resources have been kept for the previous incidents' own and cannot be used by the successive incidents. Hence, the whole ERA scheme obtained by the serial algorithm [3,36,40] is not optimal and even not suboptimal. As a result, to solve ERA from a holistical point of view, we wish to allocate multiple emergency resources of multiple rescue agencies to multiple concurrent incidents in a parallel manner. That is, it is expected that we just need to execute our algorithm for once to output the whole emergency resource allocation scheme for all incidents. In particular, we will try to answer the following questions in parallel allocation of emergency resources: Which incidents will a rescue agency respond to? How many emergency resources will it separately allocate to its every concerned incident? And whether does it have sufficient emergency resources to meet the needs of those incidents at the same time?

In the light of the above considerations, we first present a multiply constrained linear integer programming model to formulate the challenging problem of allocating multiple emergency resources to concurrent incidents in a parallel manner. Additionally, we develop differential evolution (DE) [29] from traditional one-dimensional real-number encoding to two-dimensional integer vector encoding and propose a heuristic to repair infeasible encodings and uncover overlapping rescue teams for concurrent incidents. Finally, to evaluate the performance of parallel allocation, we compare our approach with the existing state-of-the-art serial allocation algorithm in the literature.

The remainder of this paper is organized as follows. Section 2 discusses related research. In Section 3, we present a model of multiple emergency resource allocation for concurrent incidents. In Section 4, we show our parallel allocation algorithm on the basis of DE and heuristic in detail, and in Section 5, we evaluate the performance of our parallel allocation algorithm for ERA. Section 6 concludes and presents future work.

2. Literature review

ERA has received a considerable amount of attention in recent research, and it has the potential to be useful in a number of emergency scenarios and disaster management systems.

Altay [2] designed two capability-based integer programming models to solve the allocation of multiple emergency resources. However, they do not give any solution for the model and the potential conflicts over the usage of the same types of emergency resources.

Arora et al. [3] discussed a cost-constrained resource allocation approach for an overwhelming demand of healthcare resources during disaster response. They showed that delaying the decision of how much to pre-allocate would lead to greater flexibility in dealing with the pandemic, thereby providing a more effective response. However, they considered only one rescue agency and one type of emergency resource in their approach.

Chen and Miller-Hooks [8] formulated the problem of optimally deploying urban search and rescue teams to disaster sites in post-disaster circumstances as a multistage stochastic program. Then, they developed a column generation-based strategy that consists of solving a series of interrelated two-stage stochastic programs with recourse within a shrinking time horizon to overcome the expensive computational effort.

Geroliminis et al. [12] proposed a hypercube, spatial queueing model and a heuristic solution on the basis of genetic algorithms for the optimal deployment of many emergency response units in an urban transportation network.

Han et al. [14] developed a method on the basis of successive subproblem solving in Lagrangian relaxation framework and optimized the route capacity and location selection in emergency relieves to avoid the congestion caused by heavy traffic.

Huang and Fan [15] studied the problem of allocating multiple emergency service resources to protect critical transportation infrastructures. They used deterministic stochastic programming to model various risk preferences in decision making under uncertain service availability and accessibility.

Huang et al. [16] proposed a mixed integer linear programming model to allocate limited emergency service vehicles including fire engines, fire trucks, and ambulances among a set of candidate stations for maximizing the service coverage of critical transportation infrastructure.

Huang et al. [17] developed an integrated multi-objective optimization model to characterize the humanitarian objectives of