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Multistage assignment optimization for emergency rescue teams in the disaster chain

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ABSTRACT

Human resources and potential secondary disasters are often neglected in the existing emergency resource allocation methods. This paper presents a multistage assignment model for rescue teams to dynamically respond to the disaster chain and develops three priority scheduling strategies defined under the burden-benefit accord principle. A designed NSGA-II, C-METRIC and fuzzy logic methods were developed to solve the above multi-objective integer nonlinear programming model. Finally, the experimental scenarios results indicated that the overall performance of the proposed method was satisfactory in comparison with current method regardless of whether the secondary disasters occurred sooner or later. It was demonstrated that the three proposed priority scheduling strategies outperformed the others; however, which of these three priority strategies is most appropriate for a specific disaster situation depends on the maximum rescue time allowed by the disaster.

1. Introduction

In recent years, many natural disasters have threatened lives and property, causing widespread concern and exposing populations to the possibility of secondary disasters [1,2]. On May 12, 2008, a 7.9 magnitude earthquake struck in Sichuan Province, Southwest China causing mountain collapses, landslides, and mudslides as well as embankment dam breaches and flooding. In Japan on March 11, 2011, an undersea earthquake triggered a massive tsunami which damaged the nearby nuclear power plants and cause massive radioactive pollution in adjacent areas and across the Pacific Ocean. These events are examples of what is known as disaster chains, whereby a major disaster causes a series of secondary disasters, the results of which could be worse than the initiating disaster [2,3]. Therefore, modeling disaster chains as part of emergency management has become vitally important.

A key step in emergency rescue, assistance and management is the allocation of emergency resources [4–6], which includes the provision of relief supplies and rescue workers. In reality, many geographically-dispersed areas in disaster impact zones require immediate action by rescue workers because these areas are under time pressure and are suffering severe resource scarcities. Therefore, one of the most critical emergency rescue tasks is the efficient allocation and scheduling of rescue teams [7]. In addition, as the disaster severity level varies across the affected areas, in accordance with the principle of humanitarian relief, emergency resources are first sent to the most severely affected areas [8,9]. However, appropriate emergency rescue scheduling strategies are vital because as time passes, some initially less seriously affected areas may become more serious because of lack of attention, thereby affecting the whole rescue effort. This type of challenge has received little research attention to date.

From a disaster chain perspective, the issues associated with urgent rescue team assignments have not been addressed in any current emergency rescue models as most research has focused on the allocation of relief supplies. For example, Camacho-Vallejo et al. [10] and Huang et al. [11] improved an existing distribution model for relief supplies and some researchers studied the dynamic optimization of relief supply distribution under uncertainty [12–15]. Research has also focused on the integration of location decisions, vehicle routing problems, and relief supply allocations [16–23].

A few studies have considered the emergency assignment of rescue workers; however, as these models have been concerned more with personnel assignment, they have ignored the differences between rescue workers cooperative efforts and the reality of on-the-ground disaster relief situations. For instance, Wex et al. [24] proposed a new assignment model for rescue workers and rescue tasks when there is incomplete and uncertain information, and Falasca et al. [25] formulated a multi-objective model that specifically considered the chaos caused by many volunteers descending on a disaster rescue situation. Yuan et al. [26] studied rescue worker qualifications for different rescue tasks and then

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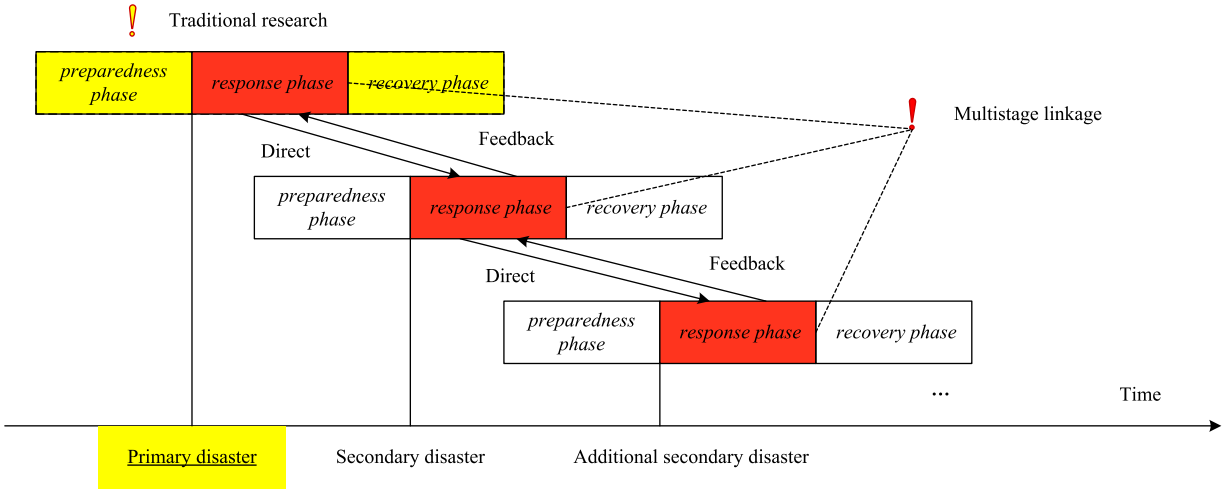

Fig. 1. Multistage emergency response linkage in the disaster chain.

developed an emergency rescue task assignment model based on these variable qualifications. Many rescue workers with different abilities are involved in disaster relief and the degree of loss and rescue difficulty in each affected area are also different. Therefore, the utility is different when the same rescue team is assigned to different disaster areas; that is, rescue teams and the disaster situation need to be matched to ensure that the talents of the rescue personnel are fully utilized in the rescue process. Zhang et al. [27] proposed an assignment model for the formation of rescue teams, but failed to account for the specific characteristics or qualifications of the rescue team members.

The aforementioned studies have provided relatively adequate modeling for the allocation and scheduling of emergency resources. However, during the evolution of post-disaster operations, disaster chains can develop, which can cause disruptions to the current emergency operations. For this reason, the allocation of all emergency resources based only on the primary disaster can result in inefficient attention to secondary disasters. To overcome such a situation, what is needed is a strategy that dynamically and efficiently allocates resources in line with potential secondary disasters.

Therefore, this paper presents a multistage assignment model to address the above issue under the emergency conditions of the disaster chain. In accordance with the post-disaster evolution, the proposed model can be divided into multiple stages: (1) an assignment model for primary emergency post-disaster operations, and (2) a re-assignment model for secondary emergency post-disaster operations. Compared to previous studies, the proposed method has the following highlights:

(1) A multistage rescue team assignment model for dynamically responding to the disaster chain is developed.
(2) The model can be extended to cover additional secondary disaster situations over the life of the disaster chain.
(3) Three priority scheduling strategies are defined and analyzed.
(4) The scheduling strategy depends on a maximum rescue time being allowed for the disaster.
(5) The overall performance of the proposed model was satisfactory regardless of whether secondary disasters occurred sooner or later.

The remainder of this paper is organized as follows. In Section 2, the multistage assignment model for rescue teams is formulated that considers the disaster chain, and three priority scheduling strategies are defined. In Section 3, an effective algorithm to solve the above model is proposed and then C-METRIC and fuzzy logic methods are utilized to select the best trade-off solutions. In Section 4, a numerical study based on an earthquake case is given to demonstrate the feasibility and advantages of the proposed method. Finally, concluding remarks and directions for future research are presented in Section 5.

2. Model formulation

A vehicle navigation system has the ability to plan the best route when given a preset destination. Moreover, it can also recalculate the route if traffic jams, road maintenance and other interference occur. With these specific operations in mind, it is believed that emergency assignment in a disaster chain could also have the ability to realize multistage emergency response linkage, that is, through data sharing and effective communication, emergency response units of each stage can integrate the emergency command system and related resources in time to achieve the real-time emergency response. As shown in Fig. 1.

2.1. Problem description

This multistage assignment problem for emergency rescue teams can be briefly described as follows. Once the primary disaster occurs in stage one, many geographically-dispersed areas are affected, each with a different disaster situation. Surrounding each of these areas are several emergency depots, each of which has a different number of rescue workers with varying abilities, such as soldiers, doctors, nurses and volunteers [28]. Based on the information available, decision makers need to develop an assignment scheme for the rescue teams as soon as possible by considering disaster severity, rescue times, and the state of the access routes. However, during the post-disaster evolution, secondary disasters may occur, changing demands and disrupting the execution of current assignments. As new demands and additional demands are the two main factors that affect rescue priorities in affected areas, decision makers need to be able to update their information to regenerate the assignment scheme. The above process can be repeated until the disaster relief is deemed to be over, as shown in Fig. 2.

This study assumes the following to rationalize the proposed model.

(1) Route conditions and the corresponding geographic relationships are given via GIS.

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