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Innovative Applications of O.R.

A multi-objective combinatorial model of casualty processing in major incident response ☆

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ABSTRACT

During the emergency response to mass casualty incidents decisions relating to the extrication, treatment and transporting of casualties are made in a real-time, sequential manner. In this paper we describe a novel combinatorial optimization model of this problem which acknowledges its temporal nature by employing a scheduling approach. The model is of a multi-objective nature, utilizing a lexicographic view to combine objectives in a manner which capitalizes on their natural ordering of priority. The model includes pertinent details regarding the stochastic nature of casualty health, the spatial nature of multi-site emergencies and the dynamic capacity of hospitals. A Variable Neighborhood Descent metaheuristic is employed in order to solve the model. The model is evaluated over a range of potential problems, with results confirming its effective and robust nature.

1. Introduction

Of the four phases of disaster management described in [1] and illustrated in Fig. 1, the *response* phase has received comparatively little attention from the OR research community, as noted in recent surveys of the field [2,3].

This gap is not due to a lack of demand. Calls for better decision making in terms of the coordination of organizations and distribution of resources during the response to mass casualty incidents (MCIs) can be found in reports on such recent disasters as the Madrid terrorist bombings of March 11th 2004 [4] and the London terrorist bombings of July 7th 2005 [5]. In this study, we seek to help satisfy this demand by identifying a specific and previously untreated decision problem met in MCI response, designing a mathematical model of this problem and specifying a solution methodology which can generate high quality solutions in a timely manner.

1.1. Casualty processing in MCI response

A significant component of any MCI response operation is the delivery of casualties to a hospital where they can undergo comprehensive treatment for their injuries. In order to complete such a delivery for any one casualty, several tasks may be required. In the case where the casualty is trapped (for example, under fallen debris), then time must be spent on their extrication. If the casualty is in a unstable condition, before this extrication can take place they will require stabilizing treatment to ensure the process can be carried out safely. Following their extrication, the casualty will be taken to a nearby safe area denoted the Casualty Clearing Station (CCS), where they will receive any necessary treatment required to ensure their safe subsequent transportation to a hospital, which must be specified from a number of candidates. This sequence of events, which we will refer to as *casualty processing*, is illustrated in Fig. 2.

In the UK the thirteen objectives shown in Table 1, which are "in no particular order of prominence" [7], are held during the response to any disaster. The importance of effective casualty processing in terms of achieving objectives (i) and (ii) is clear, with an effective casualty processing operation ensuring the timely delivery of casualties to hospitals in a manner which reflects the injury profiles of casualties and the capabilities and capacities of hospitals.

1.2. Resource management models for major incident response

Decision support tools aimed at assisting in some area of resource management in disaster response have covered a broad range of objectives and decision variables. We now review these tools with the aim of identifying to what extent they cover casualty processing, i.e. to what degree they provide support for the relevant decisions and the associated objectives of saving lives and relieving suffering.

Several examples of models which give no explicit consideration to the processing of casualties exist in the literature. Such

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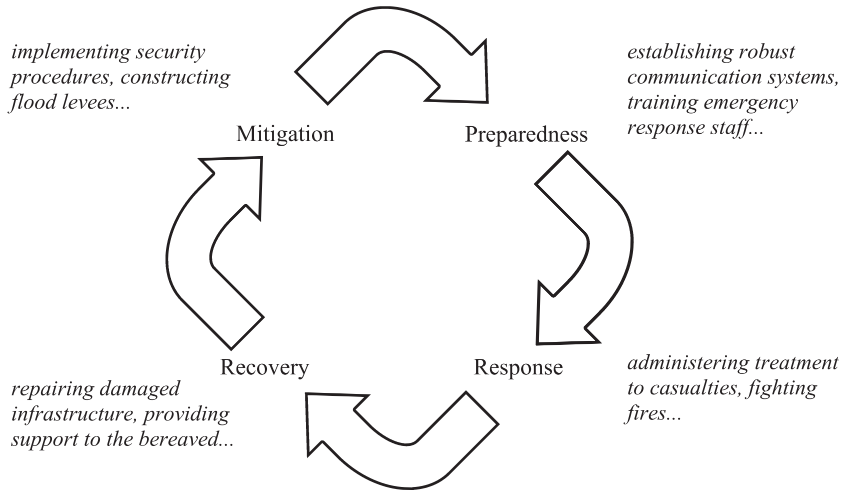

Fig. 1. The four phases of disaster management.

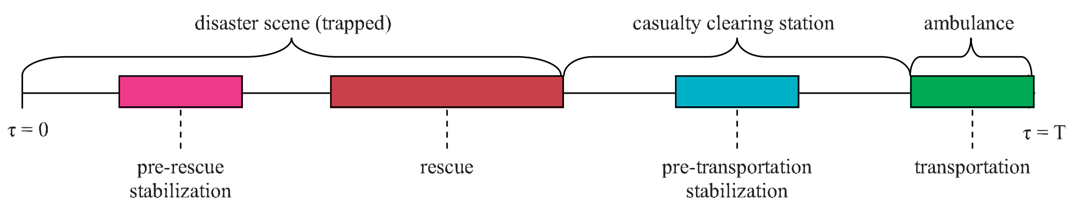

Fig. 2. An example of the processing of a single casualty in an MCI (adapted from Fig. 1 of [6]).

Table 1
The thirteen objectives of response in the UK [7].

(i)	Saving and protecting human life
(ii)	Relieving suffering
(iii)	Protecting property
(iv)	Providing the public with information
(v)	Containing the emergency; limiting its escalation or spread
(vi)	Maintaining critical services
(vii)	Maintaining normal services at an appropriate level
(viii)	Protecting the health and safety of personnel
(ix)	Safeguarding the environment
(x)	Facilitating investigations and inquiries
(xi)	Promoting self-help and recovery
(xii)	Restoring normality as soon as possible
(xiii)	Evaluating the response and identifying lessons to be learned

work has generally focussed on either the distribution of emergency responder units to areas which require their attention, or on the distribution of some vital commodities such as food and medicine around the affected area. Of the former type [8–12], a varying degree of detail in the modeling of casualties is present. Only [9] considers casualties explicitly in their model, providing a means with which to forecast the number of fatalities resulting from any proposed responder assignment which they use as an objective function. The proposed method considers the overall changes on the entire casualty group incurred due to factors such as delayed rescuing or delayed transportation to hospital. In contrast, [8,10–12] all employ objectives relating to how long the response operation takes and do not consider casualties explicitly. Due to the abstract nature of the tasks to which responders are assigned, it may be possible to interpret them as the tasks required when processing casualties. However, no details regarding how this could be implemented are given.

Considering models focussing on the distribution of vital goods [13–23], common objectives used in the models include the minimization of the cost of transporting the goods in question, minimizing the time taken to distribute the goods, and the minimization of unsatisfied demand. The models described in [17,21] are notable for their inclusion of objectives designed to maximize the "fairness" of the distribution by examining the largest difference between the unsatisfied demand at all locations in their problem environment. In all of these models, casualties are at best present in an implicit manner, assumed to be generating demand for the goods in question at various points in the problem environment but not being modeled explicitly.

A further set of models which address the distribution of vital goods incorporate the transportation of casualties into the same model. That is, the same vehicles used to distribute emergency supplies are used to transport casualties to hospitals or other appropriate treatment facilities. The model proposed in [15] is extended in this fashion in [24–26]. These models consider casualties as another good or commodity which requires transportation from supply points to demand points, and as such the same commodity flow objectives of minimizing transportation cost and unsatisfied demand as used above are employed, albeit with weights used to differentiate between casualties and goods. In [27] the authors describe a model based upon the vehicle routing problem which includes the specification of the routes to be taken by response helicopters and at which point on these routes they should collect casualties to return them to base. In [28] the problem of evacuating civilians in an urban environment whilst simultaneously directing responders into the environment is modeled, where the objective is to minimize the total travel time with different groups being assigned different priorities. The problem of assigning ambulances to clusters of casualties is described in [29] and developed in [30], where a model for online (i.e. making decision sequentially rather than simultaneously) use is described. The model advises where an ambulance should be sent once it becomes free, and then to which hospital it should transport its charge. The model does not account for other parts of casualty processing, nor does it approach the problem in a holistic manner.

The decision problem of assigning patients to operating rooms is addressed in [31], although not in the context of major incident