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# Optimal deployment of emergency resources in sudden onset disasters

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ABSTRACT

In this paper, we study the problem of allocating emergency units to affected sites and casualty groups in the initial hours after sudden-onset disasters to maximize the number of survivors. Survival rate of extricated casualties is high in the first hours following disasters, but the number of emergency (rescue and medical) units available to service casualties is often inadequate. Optimal allocation of units to the affected sites and casualty groups is necessary to maximize the number of survivors. In this paper, we determine: I) the best strategy to allocate rescue and medical units to affected sites; and II) the best strategy to allocate medical units to casualty groups at each site. The optimization models developed to answer the questions are tested on a case problem in the New Madrid Seismic Zone of Illinois to find simple and practical strategies for deploying emergency units. Results show that emergency units should be distributed among the sites in proportion to their casualty populations, regardless of the casualty mix ratios. We show that at each site, medical units should be streamed fairly among the casualty groups. Fair streaming leads to even workloads among the medical units assigned to each group of casualties. We show that casualty overflow does not make for any significant increase in the expected number of survivors, if the medical units are divided fairly among the casualty groups. However, the casualty overflow does make the expected number of survivors more robust against any likely biases in the medical units' streaming.

## 1. Introduction

Natural disasters such as tornados, hurricanes, tsunami, floods, earthquakes, etc. have caused untold misery in the past, and continue to menace societies from the perspective of economic cost and loss of human lives (Wex et al., 2013). According to the UN Office of Disaster Risk Reduction, disaster statistics for the period 2000–2012 include 1.2 million people killed and 2.9 billion people affected. Disaster management is vital, to ensure resilient and sustainable societies. Disaster cycle management has four stages (IFRC, 2012): 1) *Mitigation* stage includes a set of activities done in disaster prone societies to reduce their vulnerability against disasters; 2) *Preparedness* stage encompasses a set of pre-disaster activities done to prepare for predicted disasters and manage them appropriately; 3) *Response* stage includes a set of activities that should be carried out rapidly after a disaster to save casualties and fulfil the needs of affected people; 4) *Recovery* stage involves a set of long-term recovery actions calculated to restore affected societies to a sense of normality. Of these stages, response is the most challenging to manage, in the chaotic circumstances that prevail after disasters, compounded by resource scarcities (USAR staff, medical staff, supplies, transportation fleets, etc.) and time pressure; but if efficiently managed, it has the most important role in minimizing fatalities due to disasters (Comfort et al., 2004; Thevenaz and Resodihardjo, 2010). The focus of this paper is on casualty management operations in the response stage (Fig. 1).

Casualty management in disasters is the process of delivering casualties to hospitals to receive comprehensive medical treatment for their injuries, and this involves several on-field and out-of-field tasks (Wilson et al., 2013):

a) ***Extraction Task (ET)***: This on-field task is needed in cases where the casualty is trapped (e.g., under fallen debris). Natural disasters usually cause a large number of geographically dispersed incidences, such as collapsed buildings, fires, car crashes, etc. that need immediate search and rescue operations by Urban Search and Rescue (USAR) staff in the affected areas. USAR staff are trained to locate, extricate, and assist people who have become trapped or wounded in disasters (FEMA, 2008). Some work has been done in

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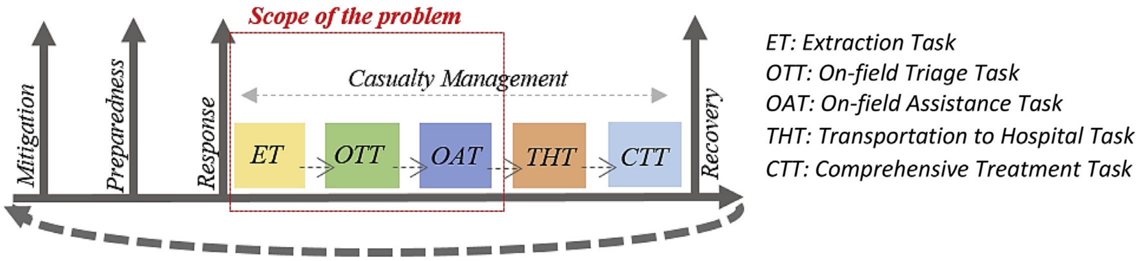


**Fig. 1.** Tasks of casualty management.

**Table 1**
Casualty management tasks studied in the literature.

| Papers | Number of disaster sites | ET | OTT | OAT | THT | CTT |
|---|---|---|---|---|---|---|
| Wex et al. (2013) | More than one | ✓ | | | | |
| Mills et al. (2013) | One | | ✓ | | | |
| Dean and Nair (2014) | More than one | | | | ✓ | |
| Rolland et al. (2010) | More than one | ✓ | | | | |
| Sacco et al. (2005, 2007) | One | | ✓ | | | |
| Chen and Miller-Hooks (2012) | More than one | ✓ | | | | |
| Haas and Havens (2008) | More than one | ✓ | | | | |
| Talarico et al. (2015) | More than one | | | | ✓ | |
| Li and Glazebrook (2010) | One | | ✓ | | | |
| Jin et al. (2015) | More than one | | | ✓ | | |
| Uzun Jacobson et al. (2013) | One | | ✓ | | | |
| Kamali et al. (2017) | One | | | | ✓ | |
| Chan et al. (2013) | No disaster | | | | | ✓ |
| Saghafian et al. (2012) | No disaster | | | | | ✓ |
| Saghafian et al. (2011) | No disaster | | | | | ✓ |
| Vaart et al. (2011) | No disaster | | | | | ✓ |
| **This paper** | **More than one** | ✓ | ✓ | ✓ | | |

the literature with regard to managing the performance of USAR staff in disasters and mass casualty incidents (see Table 1). For example, Wex et al. (2013) and Rolland et al. (2010) propose a mathematical model to allocate USAR staff to disaster sites and schedule their processing operations in such a way as to minimize the sum of their completion times. Chen and Miller-Hooks (2012) develop a multistage stochastic program for optimally deploying USAR staff to disaster sites in a way to maximize the expected number of saved people. Haas and Havens (2008) develop an efficient simulation-based tool for Canadian Coast Watch Guard to assign USAR staff to different missions considering their unknown execution times and service disruptions because of equipment malfunction.

b) ***On-field Triage Task (OTT)***: This on-field task is the process of classifying casualties according to their medical conditions and injury characteristics. There are several triage methods for disasters, such as START (Simple Triage and Rapid Treatment), STM (Sacco Triage Method), Triage Sieve, etc. START is the most widely used triage method in the USA, and categorizes casualties into four color-coded groups (Lerner et al., 2008): red triage casualties are the most critical casualties, having immediately life threatening injuries; yellow triage casualties have serious but not immediately life-threatening injuries; green triage casualties are able to walk away from the disaster scene and only have relatively minor injuries; and black triage casualties have very severe injuries and are very unlikely to survive even if medical treatment is given. Since green triage casualties are unlikely to die and black triage casualties are unlikely to survive, we only focus on red and yellow triage casualties in the casualty management process. Some research has been done in the literature in designing triage method and prioritizing casualties according to their injury severity (see Table 1). Sacco et al. (2005, 2007) develop STM as a linear programming to optimize casualty prioritization at a single disaster site. They show that the optimal solution is very complex and the priority order switches from one triage group to another triage group several times over the response effort. Li and Glazebrook (2010) study the casualty prioritization problem considering imperfect classification of casualties using a Bayesian approach. Mills et al. (2013) develop a fluid model of patient triage in a mass casualty incident considering resource limitations and survival probability deterioration of casualties with respect to time. Uzun Jacobson et al. (2012) propose a stochastic clearing model with a finite number of casualties. In this model, each casualty has a random lifetime with a distribution function depending on his/her triage group. The survival probability of casualties stays the same as long as they are alive, and drops to zero when they die.

c) ***On-field Assistance Task (OAT)***: Casualties are usually taken to a nearby safe area called Casualty Treatment Station (CTS) to receive stabilizing emergency care assistance needed to ensure safe subsequent transportation to nearby hospitals (Frykberg, 2005). Very little work in the literature studies the on-field treatment process in disasters (see Table 1). Jin et al. (2015) propose a mixed integer programming to locate and manage CTSs for supporting first-aid treatment on disaster sites. They test their model using data from a department store collapse in South Korea. Mete and Zabinsky (2010) propose a two-stage stochastic model for medical supply storage and distribution at the city level.

d) ***Transportation to Hospitals Task (THT)***: Medically stabilized casualties are sent from CTSs to nearby hospitals to receive comprehensive treatment. Ambulance fleet scarcity makes this transportation task very challenging, and its efficient implementation is critical. Some research in the literature studies the out-of-field transportation process between disaster sites and hospitals in disasters (see Table 1). Kamali et al. (2017) consider a single disaster site with a set of casualties that belong to different triage groups. There is a limited ambulance fleet to transport the casualties to a hospital. The authors develop an optimization model to prioritize the casualty transportation to hospital. Talarico et al. (2015) investigate a routing problem for ambulances at a disaster response scene. The ambulances are used to carry medical units and patients between hospitals and disaster sites. The objective is to minimize the service completion time among the casualties waiting for help. Dean and Nair (2014) develop a **S**everity-**A**djusted **V**ictim **E**vacuation (**SAVE**) model to transfer casualties evacuated from a single disaster site to several area hospitals, considering transportation and medical care resource availability. Some researchers have studied the process of procuring emergency needs for affected people such as Barbarosoglu et al. (2002), Ozdamar (2011), Li et al. (2011) and Najafi et al. (2013). Barbarosoglu et al. (2002) and Ozdamar (2011) propose optimization models for helicopter mission planning and coordinating their operations during a disaster relief operation. Najafi et al. (2013) develop a multi-objective model to manage the logistics of emergency goods and injured people in the relief operations of earthquakes. Li et al. (2011) study sheltering network planning and operations for natural disasters.