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# Methodology of emergency medical logistics for public health emergencies

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ABSTRACT

This work presents a novel model of emergency medical logistics for quick response to public health emergencies. The proposed methodology consists of two recursive mechanisms: (1) the time-varying forecasting of medical relief demand and (2) relief distribution. The medical demand associated with each epidemic area is forecast according to a modified susceptible-exposed-infected-recovered model. A linear programming approach is then applied to facilitate distribution decision-making. The physical and psychological fragility of affected people are discussed. Numerical studies are conducted. Results show that the consideration of survivor psychology significantly reduces the psychological fragility of affected people, but it barely influences physical fragility.



## 1. Introduction

A public health emergency is defined by the U.S. National Disaster Medical System as the emergency need for healthcare or medical services in response to a disaster, the significant outbreak of an infectious disease, bioterrorist attack, and other significant or catastrophic events. Examples of public health emergencies include the outbreak of H1N1 influenza, of the Ebola virus disease in Congo, of severe acute respiratory syndrome (SARS), and of the Marburg hemorrhagic fever in Angola, as well as widespread dysentery, cholera, measles, encephalitis B, and other diseases following significant disasters.

In addition to health threats and economic losses, public health emergencies also result in psychological suffering, such as feelings of helplessness, sorrow, and panic. Studies conducted on the worldwide effects of the SARS outbreak in 2003 suggest that the fear of SARS is a more severe pandemic than the disease itself (Cheng and Tang, 2004).

Most emergencies cannot be avoided, but their influence can be significantly reduced by an efficient framework of emergency medical logistics. Medical logistics that direct responses to public health emergencies are vital. However, the field of emergency logistics faces many challenges that have not been addressed effectively.

Emergency medical logistics has three characteristics that increase the complexity and difficulty of solving logistical problems in contrast to general emergency logistics. First, limited demand-related information, such as the severity of injuries and the number of casualties, challenges distribution-related decision making. In particular, the incubation period results in a time delay in demand (Li et al., 1999, Zhang and Ma, 2003). Second, a disease can spread quickly from one area to another and can even become a large-scale epidemic. Infection, recovery, and mortality rates typically vary across areas because of different physical conditions of individuals, as well as habits, customs and medical services provided by the hospitals in each area (Brauer and van den Driessche, 2001; Capaldi et al., 2012). Third, the substitutability of medical relief is

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imperfect, unlike other forms of relief such as food. A specific medicine cannot be perfectly substituted by another medicine (Mete and Zabinsky, 2010).

The available literature inadequately addresses emergency medical logistics. Thus, the current work proposes a model of emergency logistics for rapid response to public health emergencies. In particular, a modified epidemic susceptible-exposed-infected-recovered (SEIR) model is developed to forecast time-varying demand as well as a linear programming model that optimizes decisions regarding the distribution of emergency medical reliefs.

Specifically, this work contributes to the decision analysis of logistical responses to public health emergencies in the following ways:

(1) This interdisciplinary study contributes to the fields of public health and emergency logistics. Emergency medical logistics differs from general emergency logistics in that the former involves many challenges that increase the complexity and difficulty of solving logistical problems.
(2) This work applies a novel methodology to forecast the demand of multiple urgent medical reliefs and to distribute these reliefs to multiple epidemic areas. The physical and psychological situations of those affected are considered. The modified SEIR model contributes to forecasting by considering not only physical factors, such as the differences in the infection conditions of survivors and the spatial interaction relationships among epidemic areas, but also the psychological demand of exposed and undiagnosed individuals. In the distribution model, psychological fragility is formulated and discussed in detail, unlike in previous studies. The relationship between emergency medical logistics and the psychological effects on affected people is highlighted as well.
(3) This work conducts a case study using real data and a continuation study with experimental data to demonstrate the applicability of the three proposed models. These models are then compared. Observations are provided and their implements are discussed on this basis.

The remainder of this paper is organized as follows. Section 2 reviews related studies. Section 3 presents the proposed basic methodology, including time-varying demand forecasting according to the epidemic diffusion rule and the distribution of medical reliefs. Section 4 introduces two extended models. Section 5 presents a numerical study and discusses the analytical results. Section 6 provides managerial insights. Finally, Section 7 concludes and discusses the directions for future work.

## 2. Literature review

Although some studies try to combine medical rescue with emergency logistics (Sheu and Pan, 2014), only a few studies exist on emergency medical logistics for public health emergencies despite its importance and particularity. Only bioterror response logistics, a special case in emergency medical logistics, has been discussed (Kaplan et al., 2003; Craft et al., 2005; Liu and Zhao, 2011). These studies have aided in understanding the problems of evaluating existing proposals for logistics, distributing antibiotics, and providing hospital care after a bioterror attack. Methods such as atmospheric release models, dose–response models, disease progression models and epidemic diffusion models have been used. However, these studies have made limited contribution to medical logistics for public health emergencies. First, a terrorist attack has only two most feared biological agents, namely, smallpox and anthrax (Craft et al., 2005), but other public health emergencies may be aroused by other diseases that are less understood. Second, a terrorist attack focuses on only one or several cities, whereas other public health emergencies may occur in large areas at the same time. Except for the distinctiveness of bioterrorism, these studies ignored the differences in the infection conditions and survivor psychology. In practice, vulnerable groups, such as children and the elderly, face different infection, recovery, and mortality rates. Moreover, the psychological suffering of affected people in a bioterror attack is usually more serious than physical pain.

In addition, this work reviews the related literature by first focusing on demand forecasting and then discussing the approaches to logistics distribution for an emergency and their objective functions.

Typically, demand forecasting is studied based on general supply chain management in business logistics but limited to emergency logistics. The approaches adopted in business logistics forecast are based on historical values, which can be collected easily during business processes. By contrast, emergency medical logistics lacks historical data. Gaur et al. (2007) discussed demand uncertainty in business logistics, but demand history was unavailable. Based on the characteristics of the predictions of emergency resource demand, Sheu (2010) presented a dynamic model of relief-demand management for emergency logistics operations under imperfect information conditions in large natural disasters. Mete and Zabinsky (2010) proposed forecasting and optimization approaches to problems on medical storage and distribution for a wide variety of disaster types and magnitudes. Hasan and Ukkusuri (2011) developed a novel model to understand the cascade of the warning information flow in social networks during the hurricane evacuations. Fajardo and Gardner (2013) used a bi-linear integer program to model diseases spreading through direct human interaction on a social-contact network. Ekici et al. (2014) created an interesting approach to demand forecasting based on the characteristics of disease epidemics. They also developed a SEIR model with a spatial component among communities, age-based structure, heterogeneous mixing, and night/day differentiation to plan food distribution. Few studies have forecast demand in this way (Wang and Wang,