CCC 2018

Proceedings of the Creative Construction Conference (2018)
Edited by: Miroslaw J. Skibniewski & Miklos Hajdu
DOI 10.3311/CCC2018-102

Creative Construction Conference 2018, CCC 2018, 30 June - 3 July 2018, Ljubljana, Slovenia

A Probabilistic Model for Evaluating the Impact of Prepositioning of Rescue Centers of Earthquake Consequence Management

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Abstract

This study puts forward a probabilistic model for evaluating the impact of the prepositioning of rescue centers on earthquake consequence management operations. In urban areas, a disaster such as an earthquake can lead to severe casualties. Failure to provide timely medical services can increase the number of earthquake fatalities. Rescue teams can play a critical role in reducing the number of earthquake fatalities by helping those injured in the shortest possible time. In this regard, the placement of rescue centers is critically important. A probabilistic model is needed in order to evaluate the impact of prepositioning of rescue centers on earthquake consequence management operations. The proposed probabilistic model estimates the number and the distribution of the earthquake casualties based on the severity and time of the earthquake as well as the vulnerability of the buildings in the affected area. It also takes into account the expected time spent on rescuing individuals from each affected building as well as the expected time each rescue team spends traveling from one affected building to another. The model also takes into account the consequences of delays in rescuing the earthquake casualties in terms of loss of life and exacerbated injuries, and characterizes these consequences in monetary terms. This probabilistic model can be utilized in order to determine whether the existing rescue centers are appropriately-positioned and adequate, and, if not, identify the candidate positions for establishing new rescue centers before disaster occurrence.

Keywords: uncertainty; healthcare; earthquake; location analysis; rescue center.Introduction.

1. Introduction

Since 1970, more than 10,000 natural disasters have occurred across the globe, causing over the $2 trillion in estimated damage [1]. In response to a natural disaster, varieties of efforts are taken in order to limit the consequent social and socioeconomic losses by providing relief to victims and reducing the number of casualties. Emergency medical service (EMS) facilities play a unique and critical role in the delivery of services to earthquake casualties [2-4].

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 DOI 10.3311/CCC2018-102

Natural disasters such as earthquakes often damage civil infrastructures systems. These damages negatively affect the ability of infrastructure systems to function appropriately. In case of the transportation infrastructure system, the damages caused by natural disasters such as earthquake can disrupt the movement of emergency vehicles that support the disaster response operations [5]. In addition to the potential disruptions in transportation, other challenges such as the lack of information due to the failure of communication systems augments the challenges of delivering relief to the victims in a timely manner [6-11]. Appropriate pre-positioning of the resources, particularly the rescue centres, can increase the effectiveness of disaster response operations and contribute to the reduction of the casualties [12]. The geographical distribution of relief and rescue centres affect the performance of relief and rescue efforts, which in turn affects the response time and costs incurred throughout the operation.

Several past studies have investigated the positioning of the assets used in emergency and rescue operations. For instance, Jia et al. [13] present models to determine the optimal location of EMS facilities under major emergencies such as bioterrorist attacks. Maleki et al., [14] formulate two models to assign ambulances to calls using mixed integer programming. The objective of the first model is to minimize the total travel time of ambulances. The objective of the second model is to minimize the maximum time travelled by ambulances. Simultaneous application of both models leads to a plan that reduces the travel time and improves the area covered by the ambulances. Naoum-Sawaya and Elhedhli [15] present a two-stage stochastic optimization model for the ambulance relocation problem that minimizes the number of relocations and maximizes coverage. Other methods such as queuing theory [16] and hypercube models [17-18], dynamic programming [19] have also been applied in order to investigate the positioning of the EMS resources. Simulation has also been used in order to analyse the performance of EMS resources following a disaster. Ross [20] examines the various methods of dispatching and their impact on the workload of the call center employees by using simulation. Su and Shih [21] develop a simulation model and evaluate the ambulance service system of Taipei under various staff levels and number of assigned emergency network hospitals. Kozan and Mesken [22] analyse the effects of changing call rates, distribution of workload and personal resources on the call centre efficiency by developing simulation model. Meanwhile, Berchi et al. [23] use simulation approach to estimate the optimal location and number of ambulances for ambulance service system in Italy.

The overview of literature indicates that the existing models for evaluating the performance of EMS assets are subject to a key limitation. Specifically, existing models do not take into account the multiple uncertainties associated with the demand for EMS resources and their operations including the uncertainty about the intensity of the disaster, the number of casualties, the severity of injuries sustained by the victims, the geographical distribution of the victims, the number of available emergency vehicles, and state of the transportation and health infrastructure systems. In order to address the limitation of existing models, this paper presents a simulation model that characterizes the uncertainties mentioned above and can be used in order to evaluate the impact of prepositioning of rescue centres on earthquake consequence management and provide a valuable insights for decision making about the location of rescue canters. By taking into account the multiple sources of uncertainty, the proposed model provides valuable insights that if used within a decision analysis framework, facilitate the development of a better plan for disaster management.

2. Model

The proposed framework simulates the performance of ambulance service systems that are dispatched from rescue centres. This framework contains several integrated models. **Fig. 1.** presents an overview of the proposed framework and its integrated models. In this framework, occurrence time and magnitude of earthquake, population and occupancy ratio of buildings as well as building structure (model building) types affect distribution and number of causalities in each severity level. There are four severity levels of causalities that are demonstrated in Table 1. It should be noted that for each severity type, if medical care is not provided to the patients during a pre-specified period, the severity of their injuries exacerbates. According to the findings of the past studies, for severity 1, this period is 390 minutes after initial trauma. Severity 2 and severity 3 require treatment within 270 and 80 minutes [25-26]. In this study, the survivability time is a function of the severity level and time of arrival to hospital. Transfer time to the hospital itself depending on the condition of the roads, and has been investigated probabilistic. Survivability time is also expressed in random and probable terms.

 DOI 10.3311/CCC2018-102

Table 1: Injury Classification and, Ratio [24]

Injury Severity Scale	Injury Description
Severity 1	Injuries requiring basic medical aid
Severity 2	Injuries requiring medical technology
Severity 3	Injuries that pose an immediate life threatening condition
Severity 4	Instantaneously killed or mortally injured

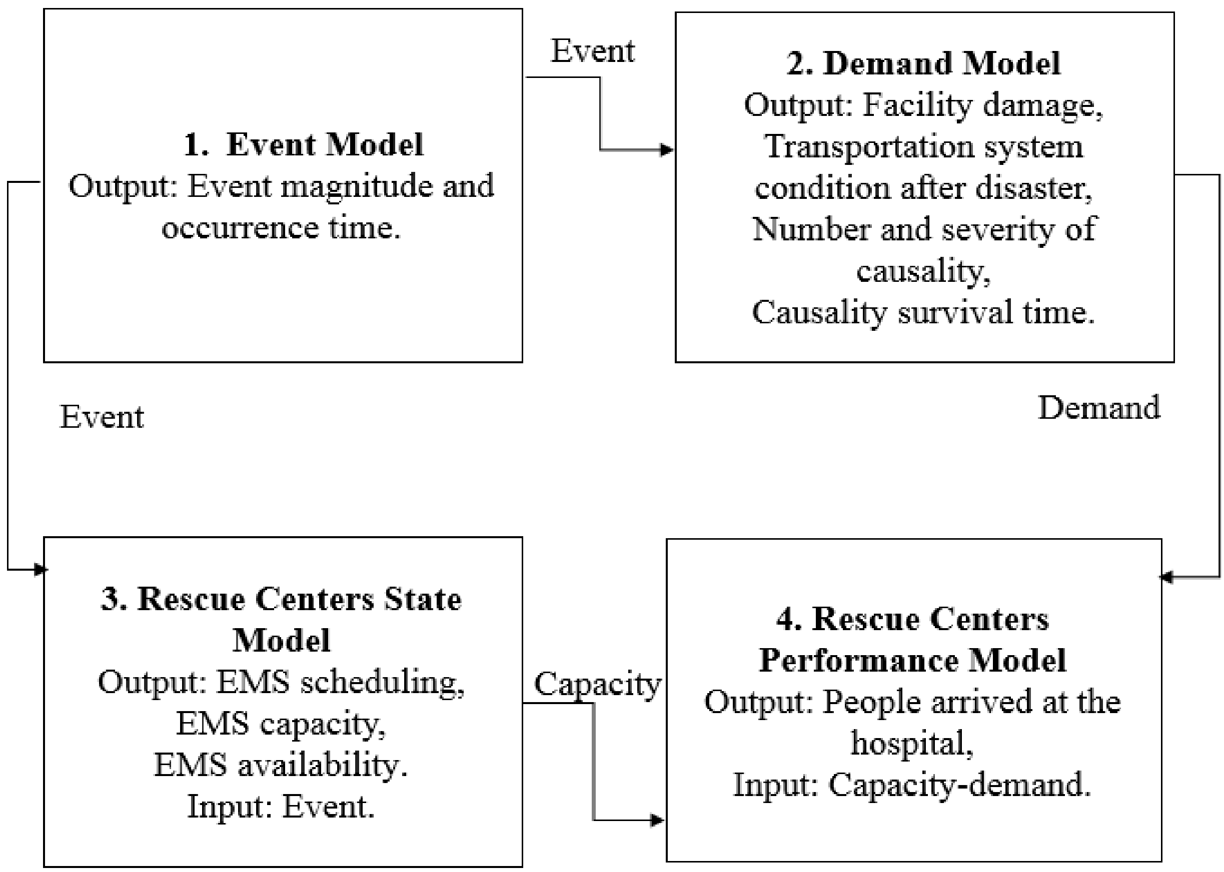

Fig. 1. Interactions among the Stock Models of the Location planning for rescue centres.

In the following, these models are discussed in details.

Event Model

Using this model, the magnitude and time of future earthquakes are generated. To accommodate earthquake magnitude uncertainties, various earthquakes with low to high intensity simulated to capture uncertainty regarding the magnitude of any potential earthquake in the region.

Demand Model

For each scenario, based on the magnitude and time of disaster occurrence, the number of injured and the level of their injuries have been investigated with regard to population density and various types of damage of the five main types of buildings.

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Rescue Centres State Model

This model evaluates effect of magnitude and time of disaster occurrence on rescue centres location and EMS units that are dispatched from them.

Rescue Centres Performance Model

Using this model, the post-earthquake serviceability of EMS units is compared against the demand based on the prepositioning station of rescue centres. Potential sites for ambulance's station are chosen with regard to access to the streets, geographical specifications, location of population centres, and proximity to the hospital(s) and final objective is to better distribute EMS units throughout the region.

3. Example

This proposed model is made to the case post-earthquake rescue in a city. The city is assumed to have a hospital. The buildings located in the city are categorized into are five main types. Specific to each class is the vulnerability in face of earthquakes. The seismic vulnerability of the building, the earthquake intensity, and the number of occupants at the time of earthquake are the key determinants of the number of earthquake victims in a building. It is also assumed that there are 10 candidate sites for the prepositioning of the rescue centres. These candidate sites are selected considering factors such as access to the main roads, geographical features, location of population centres, and proximity to hospital(s). Among these candidate sites, the most appropriate must be selected with the objective of improving the distribution of EMS resources from rescue centres throughout the region.

The proposed simulation model was implemented in Any Logic simulation software. In each scenario, time and intensity of earthquake occurrence are different, and resident's numbers in each buildings as well as type of buildings are selected randomly. In each scenario, the location of population centres and the deployment location of rescue centres are selected around the hospital, randomly. For example, fig.2 shows the coverage of population centres and deployment centres for four selected scenarios and table 2 presents distribution of total number of patients with severity 3 that are arrived to hospital for each scenario in 100 iteration, after 24 hours of disaster occurrence, probabilistically.

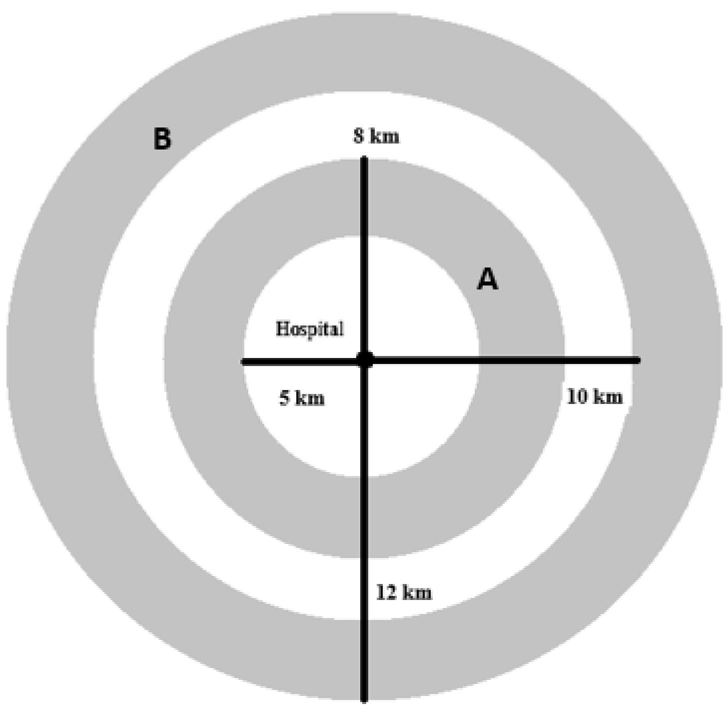

Fig. 2. Candidate points for population centres and rescue centres location.

Table 2. Distribution of total number of patients with severity 3 arrived at the hospital in different scenarios for 100 iterations, after 24 hours.

Rescue center location	Buildings location	No. of severity 3 patients		
A	B	13% 40-44		87% 45-47
A	A	3% 40-44	95% 45-47	2% 48-52
B	B	36% 40-44		64% 45-47
B	A	11% 40-44		89% 45-47

To show effect of location on response time, fig. 3 presents total no. of patients that are arrived in hospital, in term of time. If the distance between two sites is about 5-8 km, they are considered far, and they are considered close if distance between them is 10-12 km.

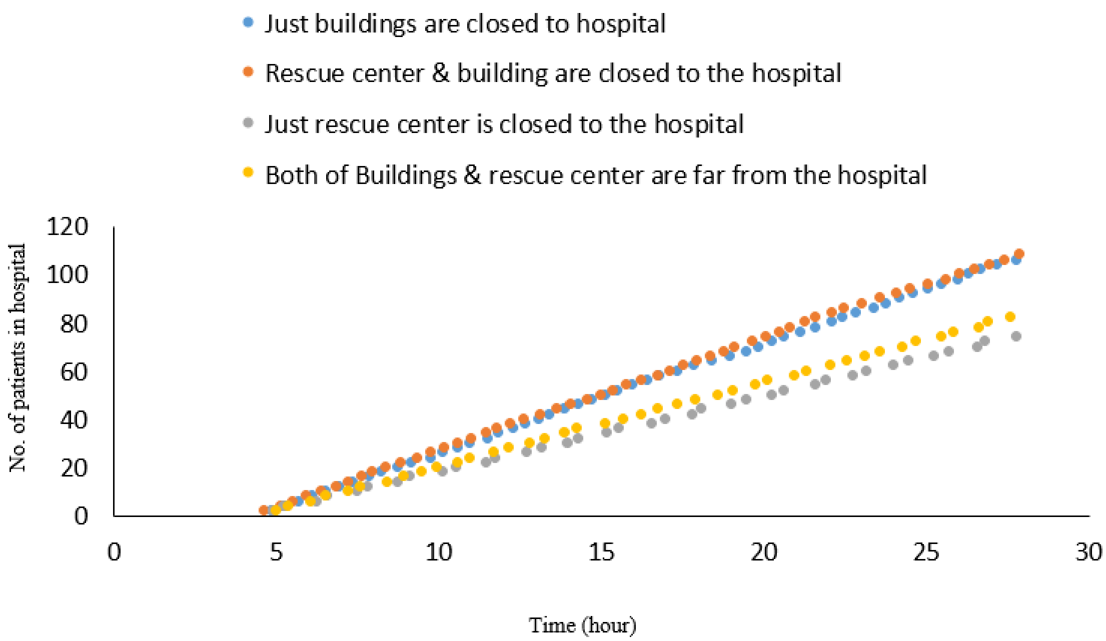

Fig. 3. No. of patients in hospital in term of time.

4. Conclusion

This study presents a probabilistic model for evaluating the impact of the prepositioning of rescue centres in the pre-disaster phase of disaster response operations. Rescue teams can play a critical role in reducing the number of earthquake fatalities by servicing those injured and arriving them to hospital by using ambulances. The more time for receiving medical service, lead to increase the number of earthquake fatalities. The objective is to choose the rescue centres location and then dispatch EMS units from them to maximize the efficiency of the EMS units by decreasing service time for patients. The risk for building is estimated as the multiplication of the (probability) disaster intensity and time of occurrence and the vulnerability of the building structure. In addition, the proposed probabilistic model estimates the number and the distribution of the earthquake casualties based on the severity and time of the earthquake as well as the vulnerability of the buildings in the affected area. It also takes into account the expected time spent on rescuing individuals from each affected building as well as the expected time each rescue team spends traveling from one affected building to another. The model also takes into account the consequences of delays in rescuing the earthquake casualties in terms of loss of life and exacerbated injuries, and characterizes these consequences in monetary terms. This probabilistic model can be utilized in order to determine whether the existing rescue centres are appropriately positioned and adequate, and, if not, identify the candidate positions for establishing new rescue centers before disaster occurrence. This model can be tailored for any EMS system in which location of buildings and hospital are available.

This study shows that the position of individuals towards the hospital has a significant impact on the response time and receiving hospital services. Secondly, the positioning of EMS relative to individuals has a tremendous impact on improving the level of service to patients. The more EMS is closer to the population centres, the more survivors will be. Then, it is necessary to identify the high-risk and congested areas in order to find the appropriate location for EMS stations.

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