Advances in Intelligent Systems Research, volume 168
International Conference on Modeling, Analysis, Simulation Technologies and Applications (MASTA 2019)

Dynamic Prediction of Casualties after Earthquakes Based on Systematic Review and Empirical Data

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Keywords: Earthquake, Modeling, Casualty.

Abstract. Background: To understand the occurrence trend of earthquake casualties and identify key risk factors. **Methods**: We constructed a dynamic estimation model to analyze and simulate the occurrence of casualties after earthquakes and to predict the influence of earthquake magnitude and rescue team arrival speed on incidence of injuries and deaths. The model was conducted in MATLAB software. **Results**: In general, half the total casualties are usually certified in the first 23 hours after an earthquake; 80 percent of all casualties of an earthquake are usually certified in the first 77 hours after an incident, and usually 164 hours after an incident 99 percent of the total deaths are certified and the death toll tends to stabilize. If all rescuers arrive in earthquake-stricken areas in the first three days after an earthquake, casualty status can be greatly improved. **Conclusions**: Our research put forward a dynamic estimation model to simulate casualty occurrence in changing environments.

Introduction

Destructive earthquakes have caused more deaths than other natural disasters[1]. China, Indonesia, and Turkey in particular as well as many other countries have been marked by massive economic losses and high rates of mortality and disability in since the mid-2000s[2]. Previous studies found that early and prompt rescue in the right stage of disaster response can prevent the deterioration of injuries and saves lots of lives[3]. In this sense, casualties should be estimated rapidly after the earthquake, and, according to the estimation made, reasonable rescue measures should be deployed to carry out an effective rescue.

Several models for estimating casualties have been introduced in scholarly literature on disaster. Traditionally, casualty projection has been based on engineering methods, which focus on the association between damage to the built environment and number of casualties[4, 5]. Also, several studies have proposed predictive models that focus on the association between mortality and morbidity during the immediate post-earthquake period and the demographic and geographic characteristics[6, 7]. Recently, the impact of behavioral attributes on earthquake-induced injuries and deaths has also been assessed in the complex process of casualty modeling[8].

In our previous study with the data from two big earthquakes occurred in China in 2008 and 2010, the Wenchuan and Yushu earthquake[9], we found that the occurrence of death and injury in the aftermath of an earthquake is a dynamic process with its own time-distributed pattern, which we described in a “two-stage” theory. After the rapid growth period (RGP) of casualties at the early stage of the aftermath of an earthquake, a distinct inflection point emerges and RGP transitions into a stable growth period(SGP)of casualties with a gradually decreasing growth rate till the rescue work ends. This “two-stage” theory is applicable to the Wenchuan, Yushu, Lushan, and Ludian earthquakes in China in our previous study, but there is still the question of whether it may be verified in other earthquakes worldwide. Moreover, we also found that management by both the government and the military of medical rescue efforts plays an important role in the number of casualties[3]. As we have noted, existing casualty estimation models have not taken the dynamic seismic casualties trend into consideration and can only predict the number of *immediate* casualties. Such models also ignored rescue behavior after the earthquake(e.g., arrival speed). The present study attempts to address these two issues.

Methods

Verification of "Two-Stage" Theory

To verify the "two-stage" theory, we conducted a systematic search using the electronic databases from the website of the Chinese Earthquake News Centre from January 1999 to February 2016. In order for earthquakes to be eligible for inclusion in our study, they had to fulfill the following criteria: (1)any deaths were caused, and(2)a cumulative death toll was recorded at specified time intervals. Finally, 28 earthquakes throughout the world were included in our study.

A random coefficient model was used to merge the casualty data from all 28 earthquakes to determine the time-distributed death pattern[10]. The random coefficient model is realized through a mixed process in SAS9.4 software.

Dynamic Estimation Model of Casualties

The authentic data from Yushu earthquake were used in our dynamic estimation model of casualties [11]. Detailed injury and death data and rescue-related data from the Yushu earthquake was obtained through 50 documents assembled from daily medical rescue and epidemic prevention reports submitted by the front-line military rescue organization.

Our earthquake dynamic casualty estimation model was established based on a casualty index combined with a matrix function. [12]. C (casualty) represents the degree of injury of a person buried by buildings after earthquake. When C = 0, it indicates no injury; when C = 1, it indicates individual death.

It has been verified that the "two-stage" theory of casualty growth conforms to Pareto distribution[9]. The model was conducted in MATLAB software.

Procedures and Results

Verification of "Two-Stage" Theory

The accumulated death number(accumulated over time following an earthquake)prediction functions are shown in Figure 1.In general, the time series casualty pattern gives a logarithmic convex function that shows a parabola in which the accumulated death total values increase rapidly at first in the *rapid growth period*(RGP) After this RIP, the values then meet an inflection point after which the rate of increase slows with time during the *stable growth period*(SGP).

Based on the calculations performed by forecasting models, half the total casualties are usually certified in the first 23 hours after an incident. Eighty percent of the total casualties are usually certified in the first 77 hours after an incident. Finally, and usually 164 hours after an incident, 99 percent of the total deaths are certified, and the death toll tends to stabilize (Figure 1A).

We also divided these 28 earthquakes into three subgroups according to the death toll: one in which the total number of casualties > 1,000, one in which the total number of casualties was between 100 and 1,000, and one in which the total number of casualties <100. Similarly, the casualty pattern of these three subgroups also showed a logarithmic convex function. By comparing the three sub-groups, we found that a greater magnitude for an earthquake results in a greater number of casualties, a longer duration for the rapid growth period, and a longer time is needed for the total number of deaths to stabilize (Figure 1).

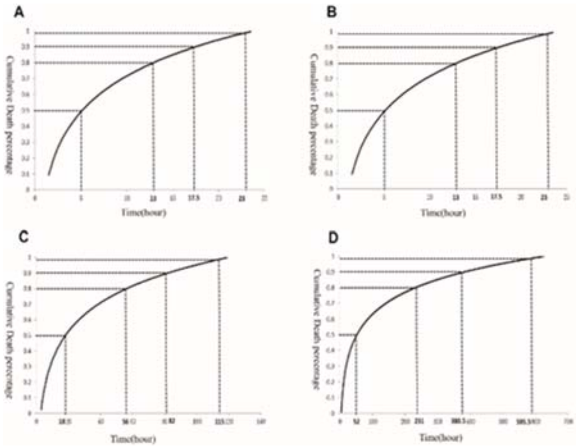

Figure 1. Death Toll Trend after earthquakes.(A)Death Toll Trends after earthquakes with different death toll. Accumulated_deaths=-0.2836+0.2497ln(hour) (B) Death Trend after earthquakes with death toll<100.Accumulated_deaths=-0.03818+0.3278ln(hour) (C) Death Trend after earthquakes with death toll between 100-1000.Accumulated_deaths=-0.2678+0.2652ln(hour) (D) Death Trend after earthquakes with death toll>1000. Accumulated_deaths=-0.2936+0.2009ln(hour)

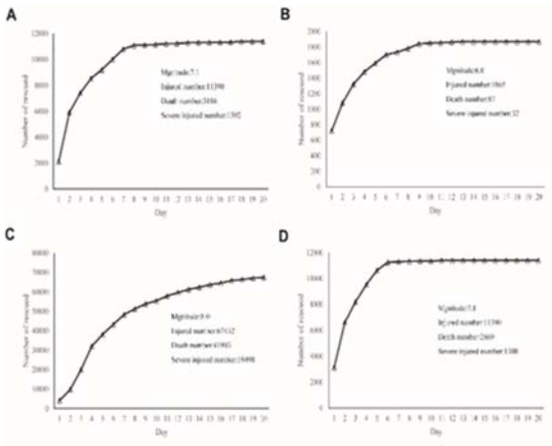

Figure 2. Simulation results of rescued numbers. (A) Simulation results of Yushu earthquake. (B) Simulation results of a below-magnitude 6 earthquake. (C) Simulation results for a below-Magnitude 8 earthquake. (D)Simulation results under rescue team arrival within three days.

Dynamic Estimation Model of Casualties

Model Simulation and Intervention Scenarios

The result of the casualty simulation result after the Yushu earthquake in our model is shown in Figure 2. In our simulation results, the total number of dead persons was 3,186(close to the actual number of 2,968), the total number of injured persons was 11,390(slightly lower than the actual number of 12,135), and the number of severely wounded persons was 1,502(close to the actual number of 1,434). In the fifth day after the earthquake event, the accumulated number of rescued injured people reached 80 percent of all casualties. The deviation between the simulated results and the actual results remained below 10 percent, indicating that it could be used in forecasting future earthquake disasters(Figure 2A).

The following constant parameters—earthquake magnitude and rescue response speed—were selected for use in the intervention trials. In the first scenario, we adjusted the magnitude to 6.0 and 8.0 on the Richter scale while keeping other risk factors unchanged. The simulation results were shown in Figure 2B and C and demonstrate that there is a positive correlation between the total number of casualties and earthquake magnitude. When the magnitude of the earthquake was 6, only 1,865 people were injured and 87 people died; when the magnitude of the earthquake was 8, by contrast, the total injured number was 67,432,and the number of deaths was 41,903, out of at total population of 283,100 for Yushu Prefecture. In other words, casualties (both deaths and surviving injured) constituted 38.62 percent of the total population of the prefecture. In the second simulation scenario for the Yushu earthquake, we changed the rescuers' arrival speed in our model to determine its influence on the overall number of people rescued. When we set our model to assume that all rescuers arrived in the stricken area within three days of an earthquake (in actuality, the teams fully arrived in the stricken areas within six days), the total injured number was still 11,390; however, but the number of deaths decreased to 2,869.Moreover,the accumulated number of injured people reached 80 percent before the 4th day(Figure 2D).As a result, we find that if all the rescuers finish arriving the stricken areas in the first three days, the casualty status can be greatly improved.

Discussion

As our results show, a majority of the casualties occurred within the RGP. Also, a higher magnitude earthquake indicates a longer RGP. This is partly due to the fact that a high magnitude quake often results in a large number of casualties while rescue capacity cannot meet the corresponding medical need. What's more, in the event of much stronger earthquakes, the effects of other risk factors (such as the time of occurrence) will be magnified, resulting in a larger scale of casualties[13,14]. As a result, rapid deployment and effective coordination of rescue forces during this period are essential to significantly reduce the number of earthquake casualties [15].

Our model also indicates that rescue teams should arrive in an earthquake-stricken area within three days. This is of utmost significance in order to reduce casualty severity. Within the first seventy-two hours after an earthquake, it is important that rescuers arrive as early as possible to avoid having severe injuries develop and intensify to a life-threatening situation. Seventy-two hours after the earthquake, the optimal treatment time for severely injured survivors has passed, and if rescue workers arrive then, their help is ineffective in preventing severe injuries from worsening and even preventing death among the most critically wounded. However, it is difficult for all the rescuers to arrive within three days, especially for victims of a high-magnitude earthquake with big magnitude. For example, it took two weeks for medical rescue forces to cover the entire disaster area of the Wenchuan earthquake and meet the most basic treatment needs[3]. The number of deaths continued to rise during in this period, suggesting that rescue teams were unable to meet the demand for timely medical services. This is partly due to the fact that the earthquake influence was underestimated and the initially dispatched rescue team had resources that were insufficient to meet local medical demand; thus, a follow-up deployment of complementary rescue forces was dispatched past the most critical period of time. On the one hand, this indicates the importance of rescue speed. On the other hand, this also indicates the importance of predicting the occurrence law of earthquake casualties before they happen.

In conclusion, our research put forward a dynamic estimation model of earthquake casualties using the MATLAB tool. Our model proofed most seismic casualties agree with the "two-stage" theory and allowed us to simulate the occurrence of casualties in changing environments.

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