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A scenario-based model for earthquake emergency management effectiveness evaluation

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ABSTRACT

Earthquakes usually produce a complex disaster chain including fires, landslides, floods, plague, and social panic, which eventually leads to disastrous consequences. In such situations, earthquake emergency management is vital for reducing the risks and the disastrous consequences. Scenario-based methods have often been used by decision makers in different fields as an instrument to manage the uncertainty of the effects of earthquakes. This paper adopts a scenario-based model to evaluate the effectiveness of earthquake emergency management. The model extracts the key elements of earthquake emergency management, simulates possible earthquake disaster scenarios, and obtains an evaluation according to the real situation. It is verified by comparing it with the real situation of the Wenchuan earthquake in China through scenario deduction and simulation. It shows that the scenario-based model can be used to reproduce the development process of an earthquake, identify the key factors which can effectively reduce earthquake losses and then help policy makers to have a better understanding of the earthquake disaster from which to put forward practical measures for emergency management.

1. Introduction

Among natural disasters, earthquakes represent one of the most unpredictable, lethal and devastating phenomena from an economic and social standpoint. Besides the collapse of a large number of buildings and mass damage to critical lifeline engineering infrastructure, an earthquake usually also triggers a series of secondary derivative disasters such as landslides, fires, floods, plague, and social unrest. There is a strong possibility that it will cause serious casualties, huge economic losses and other catastrophic consequences. Since earthquakes disaster is a great threat to human lives, economic development and social system, immense effort has been made to control risks and mitigate losses. Most of the studies have been limited to single earthquakes disaster. But the emergency strategies for single disaster may be less effective when there are other unexpected secondary events (Kumasaki et al., 2016). For the reliable effective emergency management of earthquakes, secondary disasters should be taken into account in management strategies. However, the occurrence of each specific secondary event depends on the local geological conditions, economic development, cultural identity, political factors and so on. The secondary disasters chain is a complex system which is difficult to predict accurately.

The scenario method, aimed at developing alternative visions of the future, is well known as an approach to studying situations that can lead to vital changes and in which it is difficult to create explicit relationships among events. Moreover, the scenario model can be integrated with other predictive models which enable diverse flexible approaches to face uncertain issues (Bañuls et al., 2013; Carpenter et al., 2006; De Lattre-Gasquet, 2006; Yang et al., 2017). It can help decision makers analyze a variety of the possible future trends, identify the key factors and make the best decisions. Several researchers from different domains of knowledge have already contributed different approaches to scenario-generation techniques. In this paper, a scenario-based model is proposed to estimate possible evolutions of earthquakes. This model aims to evaluate earthquake emergency management effectiveness.

The high death of the Wenchuan earthquake makes this issue a focus in China. The model is applied to the Wenchuan 8.0 earthquake occurred in Sichuan, China on May 12, 2008. The epicenter was located in Yingxiu Town, Wenchuan County. > 100,000 km^2 of land were damaged. Apart from the collapse of a large number of buildings and serious damage to the critical infrastructure, this devastating earthquake also caused a series of secondary disasters, including aftershocks, landslides, debris flows, etc. According to statistics, the Wenchuan

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earthquake killed > 69,000 killed people, with > 37 million injured, and nearly 18,000 missing. Direct economic losses totaled > 840 billion RMB. Significantly, more than one third of the casualties and economic losses were caused by the various types of secondary disasters and other emergencies triggered by the earthquake.

The rest of the paper is organized as follows. The relevant literature on earthquakes, scenario methods and emergency management are reviewed in Section 2. Section 3 outlines the methodology adopted by the study. A scenario-based model is constructed by considering the whole process of earthquake emergency management. The other purpose of Section 3 is to identify the key factors in earthquake emergency management through a sensitivity analysis. In Section 4, the model is applied to the Wenchuan earthquake for scenario deduction and simulation, and is followed by results. Section 5 discusses the implications of the model for emergency management decision-makers. And the study is compared with other related researches. Section 6 is the conclusion and is focused on presenting specific recommendations for the goal of improving earthquake emergency management.

2. Literature review

The research on earthquakes has focused on seismic fragility assessment, earthquake loss evaluation and seismic secondary derivative disasters. Del Gaudio and Ricci (2016) believed that the consequences in terms of casualties and direct or indirect damage to the structures and infrastructures are related to the quality and type of constructions. They use a simplified analytical method for a seismic fragility assessment of reinforced concrete buildings on a large scale. The US Federal Emergency Management Agency and the US National Institute of Architecture jointly developed a model called HAZUS for assessing the loss caused by an earthquake, and with further improvements, the model can make basic loss estimates, detailed regional loss estimates and more specific loss estimates of buildings (Wang, 2014). Wang (2005) confirmed that the method of predicting casualties caused by earthquakes with GDP and population density as parameters is applicable to small areas. The research on seismic loss assessment is developing rapidly, and various evaluation methods are becoming more mature. Most of this research is focused on casualties and direct economic losses, but there is a lack of research on secondary derivative disaster losses and indirect economic losses from the impact of the secondary disaster chain. The disasters triggered by earthquakes have been highlighted as the initial earthquake disaster is compounded by those secondary events (Kumasaki et al., 2016). The study of earthquake secondary derivative disaster chains is mainly confined to earthquake-induced fires, poison gas leaks, and explosion disasters. Longinow et al. (1990) considered the failure of the gas and electrical systems during earthquakes and constructed a risk model of secondary fire disasters. Antonioni et al. (2007) analyzed the secondary hazards induced by earthquakes such as the leakage of hazardous substances and fire. Ji et al. (2008) used cellular automata to study the risk assessment method of the earthquake disaster chain and included social factors such as population density and sensitivity to provide a scientific basis for the emergency response to the disaster chain. Baiocchi et al. (2017) identified possible urban microclimate changes in a city after a seismic event. Contreras et al. (2017) analyzed spatial resilience in the recovery process in L'Aquila. They concluded that the allocation of facilities was oriented to supply basic services but neglected other needs of the community which reduces its resilience. Human have an emotion that is quite prevalent in response to a sudden natural disaster. The study calls this emotion panic. The consequences of panic for earthquake response behavior are complex. Social unrest is a kind of group response behavior (Nardulli et al., 2015; Khaldun et al., 2016; Lavin et al., 2017). Goltz and Bourque (2017) suggested that behavior during a rapid onset disaster is diverse, varies with social context, and is largely rational, adaptive and consistent with norms and role performance. They also mentioned that fear, this study calls it panic, proved to be a very interesting variable and a component in motivating certain behaviors. The above research on the earthquake disaster chain is generally focused on a specific secondary derivative hazard caused by an earthquake. As to a more integrated earthquake secondary disaster chain, there is qualitative and descriptive analysis, but a lack of quantitative analysis.

Postma and Liebl (2005) indicated several methods of scenario construction in order to enhance the practicality of scenario analysis in decision management. Mahmoud et al. (2009) put forward a formal framework for scenario development in support of environment-based decision-making. Pomerol (2001) addressed the question of how decision-makers manage the combinatorial explosion in scenario development under uncertainty and suggested some ideas for scenario management. Alizadeh et al. (2016) presented a scenario-building framework to help energy industries develop more resilient conservation policies when faced with uncertainties. Fink and Schlake (2000) explained how CI professionals can develop corporate, industry, market and global scenarios, and described the integration of these scenarios into the processes of competitive intelligence and strategic management. Chang et al. (2007) relied on scenario analysis to develop a decision-making tool that can be used by government agencies in planning for flood emergency logistics. Jenkins (2000) studied how to select one or two of the most informative scenarios for environmental disaster planning for disasters like the release of thousands of tons of crude oil or chemicals in large quantities. Bañuls et al. (2010) proposed a step-by-step model for clustering scenarios via cross-impact and added tools for detecting critical events. Scenario-based methods were also combined with other methods to solve specific problems based on the real situation, see Alizadeh et al. (2016), and Banuls and Salmeron (2007).

Government-led disaster emergency management is currently adopted by most countries. It is important for reducing risks and protecting people and property. Some studies have been made about the assessment of earthquake emergency management. Wex et al. (2014) came up with a decision support model to help solve the rescue unit assignment scheduling problem which is one of the key issues in emergency management. Avvenuti et al. (2014) used Social Media to gather updated information about earthquakes in order to improve earthquake emergency management. Ren et al. (2016) assessed earthquake emergency plan implementation by evaluating 30 indicators in terms of operational mechanism, emergency response, and emergency safeguards. David (2005) offered some suggestions, guidelines, and models for the assessment of emergency plans. Vu and Noy (2015) summarized that the Chinese government was fairly effective at distributing resources across its extensive reach after large natural disasters and could mitigate some of the indirect adverse impacts. Cole et al. (2017) examined the impact of pre-disaster planning and post-disaster aid on firms recover after a natural disaster. They found that pre-disaster policies such as having alternative transport arrangements and a diversified supplier network positively affect post-disaster sales. And the post-disaster aid from banks and trading partners also has a positive influence. Evaluating and improving emergency management capabilities by taking into account possible future disaster scenarios under the current emergency preparations and possible emergency response scenarios is a new idea. There is no integrated model of earthquake emergency management effectiveness evaluation. However, it is believed that the scenario method can be one of the solutions.

3. Methodology

3.1. Scenario-based assessment model construction

A scenario-based model is proposed to make a comprehensive evaluation of the effectiveness of earthquake management work. This tool is a combination of the Delphi Method, Cross-impact Method (CIA) and Interpretive Structural Modeling (ISM). By means of the Delphi Method and CIA, the correlation among events related to an earthquake

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