Socio-Economic Planning Sciences 48 (2014) 235–248

Contents lists available at ScienceDirect

Socio-Economic Planning Sciences

journal homepage: www.elsevier.com/locate/seps

Fuzzy multicriteria for developing a risk management system in seismically prone areas

Kamran Vahdat [a, *], Nigel J. Smith [a], G. Ghodrati Amiri [b]

[a] Institute for Resilient Infrastructure, School of Civil Engineering, University of Leeds, Woodhouse Lane, Leeds LS2 9JT, UK
[b] Center of Excellence for Fundamental Studies in Structural Engineering, School of Civil Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran

ARTICLE INFO

Article history:
Available online 2 June 2014

Keywords:
Seismic risk management
Fuzzy MCDM
Uncertainty
Vulnerability

ABSTRACT

Earthquakes pose a predominant risk to cities in seismically prone areas. This paper addresses the need to mitigate the exposure of cities to seismic risk in general and to existing and new build structures in particular. The many and complex factors to be considered require a form of Multi-Criteria Decision making system to be adopted. To cope with the interactions between socio-economic factors and the roles of multiple participants, criteria and alternatives the paper proposes the use of a fuzzy multi-criteria model. The fuzzy methodology forms the basis for the development of a composite fuzzy risk index for prioritizing different regions in Iran. The findings suggest that early risk assessments in seismically prone areas should be conducted in order to determine the multi-dimensional aspects of seismic risk including vulnerability and emergency response management.

1. Introduction

Seismic risk management can be viewed as a process of complex dynamics involving the interactions of many factors. These factors typically include the physical environment, the social and demographic characteristics of the communities that experience seismic risk and the buildings, infrastructure and other facilities that are known to be vulnerable in the environment [3]. The purpose of seismic risk management is to mitigate the consequences of seismic events in prone areas. To accomplish this, a broad range of operations, planning and decision making needs to be performed. Seismic risk management is characterized in multiple dimensions, such as social, economic, political, environmental and others which can often be in conflict with each other. Several alternatives may need to be considered and evaluated in terms of the many different criteria which results in a vast body of data that are often imprecise or uncertain. A large number of people are usually involved in the risk assessment process, including decision makers, planners, experts and other interest groups from organizations and the community all of whom may have conflicting preferences [1]. The scope of seismic risk management involves balancing these variables as shown in Fig. 1. The multiple views and interests of individuals and organizations within the seismic risk management process cause an inherent complexity that requires a systematic, structured reconciliation of these disparate, often conflicting factors with the contradictory information [43]. Clearly, no single, objective, or best solution exists for this kind of problem, and thus seismic risk mitigation decisions require a compromise solution to address a wide range of criteria at different levels of organization, operation and among experts or local users.

Generally, aggregating a large number of inputs within a complex system requires a heuristic methodology that is capable of interacting with a range of information, facts, algorithms and experiences. The challenges to existing approaches are three fold. First, there are many factors involved in seismic risk management, each with varying importance from place to place; thus, the factors should adequately represent the situation and the scope of the application. Second, expert opinions and experiences play a major role in assessment and but add significant uncertainty into the process; this needs to be accounted for. Third, the adopted methodology should be consistent with needs and allow result tracking so that decisions can be updated.

Viewed from this perspective, several approaches have been reported in the literature with various levels of accuracy, complexity and uncertainty, though to varying extents most share a common statistical base [44–46]. Deterministic and probabilistic seismic risk assessment are traditional methods that have been commonly used in industry and rely on either temporal or spatial

* Corresponding author. Tel.: +44 113 3437835.
E-mail address: cnkv@leeds.ac.uk (K. Vahdat).

http://dx.doi.org/10.1016/j.seps.2014.05.002
0038-0121/

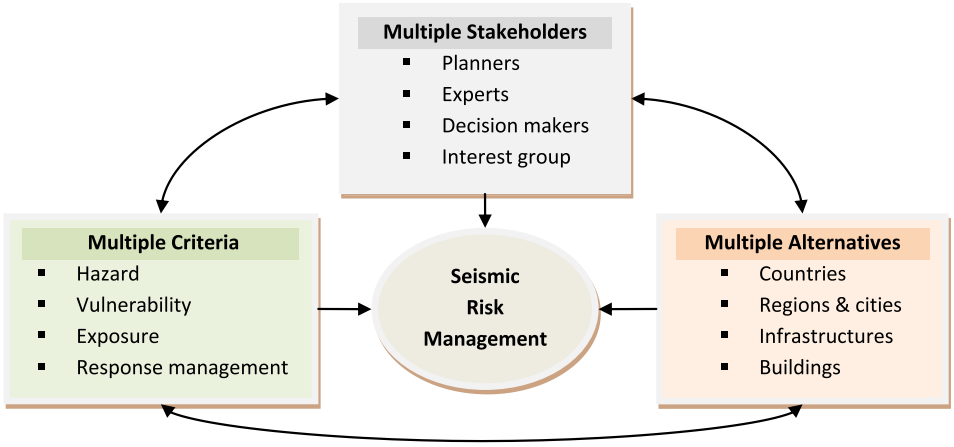

Fig. 1. Multifaceted aspects of seismic risk management.

variations in earthquakes, in terms of the most probable earthquake or the frequency of exceeding levels of ground motion. Deterministic models are high-precision analytical approaches because there is no compromise between the simplification of structural models and the efficiency of the analysis [47]. However, these analyses are limited to high-importance applications and critical infrastructure, for example, dams and nuclear plants, due to the complexity and sophistication of the tools and the expertise needed to create them. Probabilistic models use analytical and empirical methods to estimate seismic hazards in a region and hence the vulnerability of the buildings and regular infrastructures. Quantification of the most probable damage for various types of structures is the main concern in probabilistic models. Models require a large amount of historical data and high-precision, site-specific information, such as detailed seismologic and geologic data, which may not always be available. The probabilistic models can capture the randomness and stochastic nature of input; however they do not capture the epistemic uncertainty resulting from vagueness, imprecision and subjective judgment, which is predominance in seismic risk management. According to Shaheen et al. [12] risk modeling should be capable of handling different types of uncertainty; while implicitly accounting for the factors that affect the input in the form of a probabilistic distribution. Furthermore, multicriteria analysis of a region in terms of multi-dimensional aspects of risk is at the core concept of seismic risk management and this lies beyond the practical reach of conventional probabilistic models. A new holistic approach is required specifically to address the existing limits. The prospective model should capable of handling the following:

- Multidisciplinary processes
- Multiple sources, criteria and uncertain data
- Conflict among variables
- Multiple stakeholders
- Multiple causes and effects
- Multiple alternative comparisons and rankings

Given the diversity in the criteria, alternatives and participating decision makers, the constraints describe a multicriteria decision making, (MCDM), problem. An MCDM approach can be viewed as a common denominator, unifier and unique integrator that acts as a bridge between various disciplines involved in seismic risk management. A key feature of MCDM is its emphasis on expert opinions to establish criteria, estimate relative importance weights and judge the contribution of each alternative towards each evaluated attribute. However, like many normative modeling disciplines, the utility of MCDM models depends on the initial assumptions and user consistency. Imprecise and uncertain judgment can import great uncertainty into the model. While it is difficult to address the uncertainties and subjectivities associated with seismic risk management through probability theory; the application of the fuzzy set theory may systemically improve the ability of a MCDM to handle uncertainty. Fuzzy MCDM not only allows incorporation of imprecise, uncertain data, but it also provides more structure, more flexibility and more openness to the decision class by taking advantage of the characteristics of both MCDM and the fuzzy set theory.

According to Hewings [2] disaster impact analysis is an 'inexact science'. Imprecise measurements of the damage and loss in a disaster are often the major issues in probabilistic approaches. Their imprecise and vague nature is often characterized by the use of natural linguistic terms such as high, medium and low. In addition, the risk assessment process usually involves expert opinions, experienced analysis and rules of thumb that are vague or ill-defined. It is more reliable to express the risk factors on a linguistic scale, but conventional probabilistic variables are limited in their representation, or mapping, of this linguistic or descriptive information [3]. Moreover, the main challenge of the risk assessment process is in handling non-precise subjective information in order to establish criteria for which performance indicators have been defined. Therefore, there is a need for a new method to characterize risk by relying on subjective values that are not subject to precise measurement. Fuzzy set theory, which was introduced by Zadeh [4], is able to deal with imprecise, uncertain information by using linguistic terms that are based on subjective judgment and is appropriate for evaluating seismic risk system because the assessment process involves knowledge based information and expert opinions [5].

The proposed methodology aims to provide a new insight into seismic risk management by recognizing the multiplicity of the problem utilizing a common platform. In this process a systems approach to the task of identifying, analyzing, aggregating, ranking and monitoring risk is applied. The study focuses primarily on developing a hierarchical risk breakdown structure to characterize seismic risk and to apply fuzzy MCDM for aggregating the relevant factors.

2. Seismic risk system

Disaster risk management employs the systematic management of information, decisions and operational abilities to cope, respond, recover and relieve at different stages of an event; pre,