RISK-SENSITIVE MITIGATION PLANNING IN SEISMICALLY VULNERABLE URBAN AREAS

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ABSTRACT

Over the past decade, several number of commercial and non-commercial catastrophe risk models have been developed to assess the financial losses caused by natural catastrophes including earthquakes. The output of such models are in different sectors such as disaster risks management, financial institutions and also research centers. Generally, due to great amount of inherent uncertainty in these models the direct deployment of the results by the user is a tough process. As an example, in disaster risk reduction sector a common missing link in this context is a decision-support medium that interprets the risk analysis outputs to the non-technical stakeholders. To overcome this problem, user-friendly analytical tools can be employed to translate the disaster risk analysis results into an understandable language for the potential stakeholder user. Presenting two models, attempts to address two different examples of such decision-support tools. The first model, UERI, is structured to incorporate several urban risk components (hazard, physical vulnerability, disaster management facilities and human exposure) based on a number earthquake risk indicators. The second tooles the use of a mixed integer quadratic programming (MIQP) model to finds an opt spatil land-use allocation patter a given urban environment area.

Both models are capable of assisting decision-makers in using the output results of existing damage and loss estimation methodologies and also facilitating the process of risk reduction planning by providing basic solutions for stakeholders. The proposed models have been applied to a vulnerable urban area in Tehran, Iran and their performances have been examined.

KEYWORDS: *Seismic risk index, Land-use allocation, Seismic risk reduction, Optimization analysis, Urban Planning*

1. INTRODUCTION

The city of Tehran is the political, economical and social capital of Iran. It is located on a seismically active zone at the foot of the Alborz Mountains and is surrounded by three main active faults which have caused serious damages to the city in cycles of approximately 180 years. The earthquake of 1830 has been the last outstanding event that devastated Tehran, however, local seismologists are expecting the possibility of another large quake in the near future (Berberian et al. 2001, Abbasi et al. 1999, Hessami 2003). Hitherto, different researchers have attempted to make estimations of potential seismic losses in Tehran and have shown that the occurrence of an expected large earthquake can bring about intensive human and economic consequences (JICA 2000, Ghafory-Ashtiany et al. 1992, Ghafory-Ashtiany 2001, Ghafory-Ashtiany and Jafari 2003).

Having an estimated static population of more than 8 million, Tehran has experienced the highest rate of urbanization compared to any other city in the country. In the absence of an appropriate urban planning and a sound construction practice, the city is considerably vulnerable to natural hazards, namely earthquakes (Amini-Hosseini et al., 2006). High population density, galloped expansion of the city, inappropriate structural design and poor construction standards, and insufficient urban planning are the main contributors of vulnerability against earthquakes in Tehran.

To date, several earthquake hazard analyses and risk assessment studies have been conducted for the city of Tehran (JICA 2000, 2004, 2010, Jafari 2005). Moreover, a limited number of funded projects have proposed mitigation policies and improving measures aiming to reduce the seismic damage cost (JICA 2004, Amini et al. 2007). Arguably, an important challenge is the lack of methodological processes and practices that incorporate results of risk analysis and catastrophe modelling into the decision-making in the institutions that are in charge of land use and urban planning, environmental management construction and building licensing, and social welfare (Amini-Hosseini and Jafari 2007, Amini-Hosseini et al. 2009). This requires a sufficient degree of knowledge about the technical elements of earthquake risk assessment and alsoparallelly, high level disaster risk management approach. Given these points, tools that support non-technical decision-makers in using the outputs of disaster risk analysis for large scale planning, can create a better stream of information and ultimately helps increase the chance of successful mitigation adoptions.

In the first part of this paper, based on the information collected in a survey, a qualitative approach has been adopted to evaluate key components of earthquake risk in Tehran. In the second part of the study, a quqntitative models is presented that is capable of assisting urban planners in urban disaster risk reduction process. The performance of the proposed model has been examined by applying to a vulnerable urban area in Tehran city.

2. URBAN EARTHQUAKE RISK INDEX (UERI)

2.1. Background

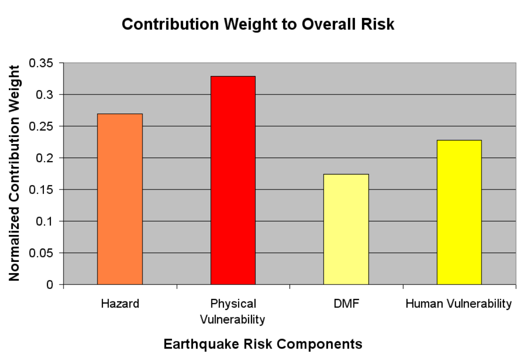
As a pioneer study, in 1997 Davidson and Shah presented a composite index (EDRI) for measuring earthquake disaster risk. They first define the list of key factors contributing to urban earthquake risk as hazard, exposure, vulnerability, external context and emergency response. Afterward, based on the constraints of quantitativeness, measurability and data availability, they selected a set of indicators to represent those factors. The final composite risk index was calculated by mathematically combining all the indicators (Davidson and Shah, 1997).

In 2001, the European commission conducted a comprehensive research project called RISK-UE (2004) to assess the different aspects of earthquake risk in seven earthquake-prone towns based on defined scenarios. Apart from physical dimensions of earthquake risk, this study covered socio-economic and emergency response aspects of seismic risk in the pilot cities. An index-based technique also was employed to estimate the physical damage caused by earthquakes (Mouroux et al, 2004). In 2007, Carreno et al. introduced an urban seismic risk incorporating physical damage, number and levels of injuries, economic losses, and also the conditions relating to social fragility and lack of resilience, that facilitate the second indirect effects of earthquake in urban settlements (Carreno et al, 2007).

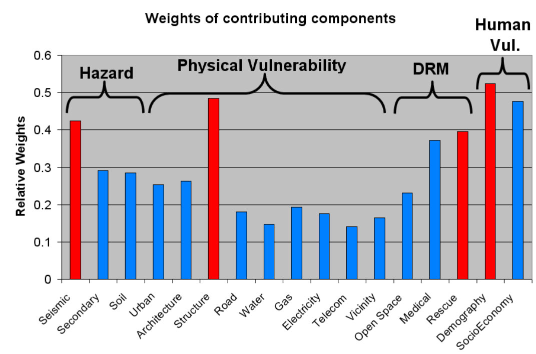
In recent years, researchers tried to capture other components of disaster in addition to physical loss, to cover the organisational, development capacity and institutional actions taken to reduce overall vulnerability and losses from disasters (Cardona and Carreno, 2011). They applied the proposed model for 19 countries of the Latin America in Caribbean region.Furthermore, a number of some researches addressed the performance of the critical facilities and urban utilities and derived index-based model to quantify the performance and functionality of such infrastructures in aftermath of disasters (Cavalieri et al, 2010, Motamed et al, 2012).

2.2. Earthquake Risk Components

A survey was conducted to ask a chosen set of people from academia and governmental organisations about the key factors contributing to earthquake risk. Results showed that hazard, physical vulnerability, human vulnerability and disaster risk DRM centres (e.g. critical facilities) were among the top ranked risk components. Accordingly a set of risk indicators adopted to quantify these components. Based on the results of this stage of study, a questionnaire was designed and distributed to a larger number of sample interviewees and their opinion about the relative importance of indicators were collected using pairwise AHP methodology. Figure (1a) and Figure (1b) show the contribution weights of earthquake risk components and risk indicators respectively.



Fig(1.a): The contribution weight of risk components



Fig(1b): The contribution weight of risk indicators

Based on the findings of this section (main risk components), a quantitative model to allocate urban land-use has been developed which is described in section 3.

3. An Earthquake Risk–Sensitive Model for Spatial Allocation

3.1. Literature Review

Dokmeci et al. (1993) developed a generalized land-use model to find the most efficient distribution of land based on two interactive objectives: that (1) Maximized the return; and (2) minimized the sum of weighted distances among the different land-use units. In 2003,Aerts et al made use of spatial optimization techniques to solve the problem of land-use allocation to pilot area. They solved an MLUA problem using four different integer programs (IP), of which three were linear integer programs. They formulated the IPs for a raster-based GIS environment in a way that to minimizes the development costs and maximizes compactness of the allocated land use. They used a weighting factor system to find the best trade off between development expenses compactness provision. Banba et al. in 2004, focused on land use management planning processes identified the optimal land -use planning for Marikina City, Philippines. Ligmann-Zielinska et al. (2008), designed a new multi objective spatial model, that incorporated a number of different objectives such as minimization of open space development, and land redevelopment, and also maximization of compatibility between neighboring land uses. Tudes and Ygiter (2010), determined six land use categories for Adana city (Turkey), using an analytical hierarchical process (AHP) and GIS analysis. According to the authors information, little work had been done to employ optimization techniques for disaster risk reduction purposes.

3.2. Model Design

The proposed model is capable of choosing the optimal spatial distribution of land-uses from several possible combinations by solving a problem of mixed integer quadratic programming (MIQP) which takes into account the boundary conditions. . Due to the need of topological assessment in spatial allocation of land-uses, a raster model for the pilot area has been used. This raster model allows the mathematical core to benefit from topological data of different pixels. However, in the process of coverting a vector model to its corresponding raster, some degrees of uncertainty have been added to the analysis (Motamed et al, 2012b).

The purpose of the presented model is to find the answer to a multi-objective optimization problem by using a weighted summation method. The objectives are (1) to minimize the susceptibility to earthquake hazard, (2) to maximize the permeability of critical facilities, (3) minimize the average distance to critical facilities, (4)to maximize the compatibility of adjacent land-uses, and (5) to minimize the redevelopment. Figure (2) illustrates the sequential steps taken in using the proposed land-use allocation model.

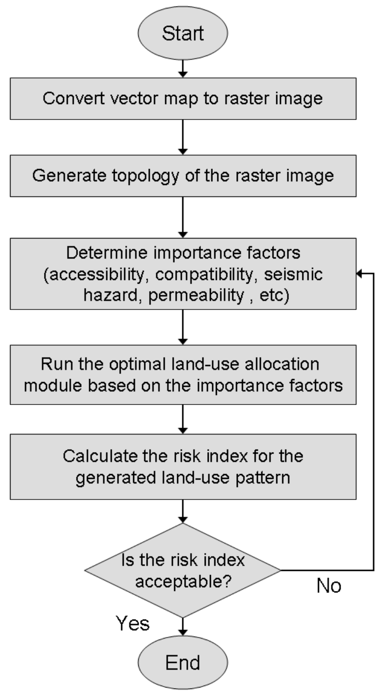


Fig (2): The sequential steps of using the land-use allocation model

3.3. Implementation of Model in Pilot Area

The proposed land-use allocation model was applied to a neighbourhood in the 17th district of Tehran city, Iran. The earthquake hazard in the upper part of the area is at its lowest and it gradually increases to its highest value (the most severe) in the lower part. A risk index was used to evaluate the performance of the model for different importance factors. Figure (3) shows the trade-off between importance factors of earthquake hazard and accessibility. As the accessibility importance factor exceeds the earthquake hazard factor, the land-use pattern takes a more uniform shape to provide the maximum accessibility. On the contrary, when hazard importance factor is dominant, all the critical facilities concentrate in the upper part where the earthquake hazard is the lowest.

The results generated by the model were benchmarked against actual land-use distribution designed by an urban planning expert. The automated results have very close risk index values to the real allocation pattern which shows an acceptable degree of performance of the model. The proposed model might be used as a tool to assist urban planners in determining spatial distribution of land-uses in a city.

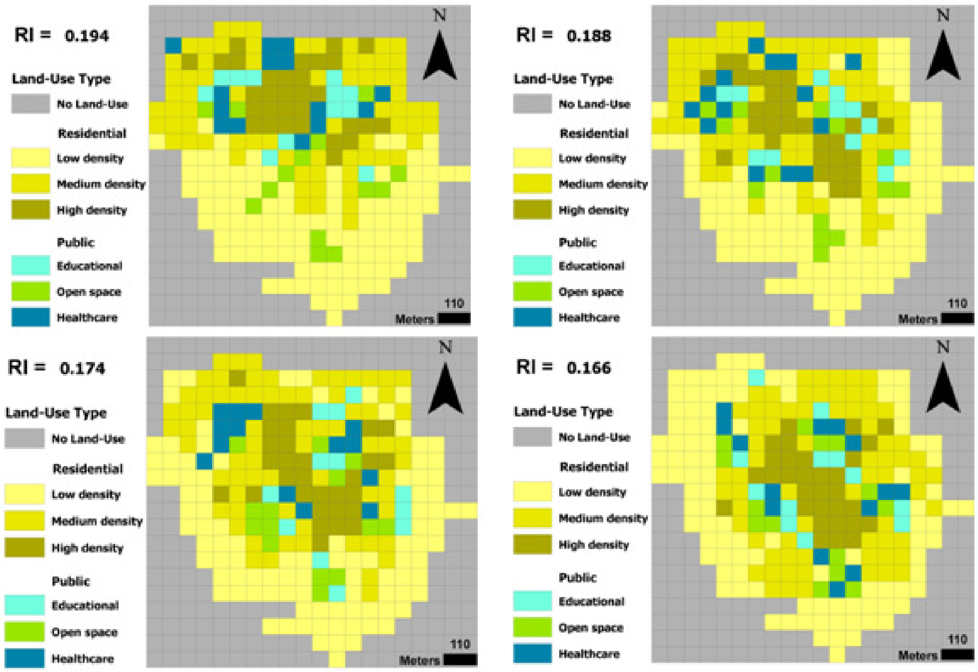


Fig (3): changes in land-use pattern due to variation of hazard and accessibility importance factors (the importance factor for accessibility increases from left to right and up to down)

4. CONCLUSION

This paper starts with an index-based model to identify the most influential seismic risk factors and indicators for the Tehran city, Iran. Engineering judgement and expert opinion have been collected to determine the importance of each risk component. The second part of the research, attempts to approach the earthquake risk management from a more general point of view: seismic hazard-sensitive land-use allocation. An optimization model developed to facilitate the process of land-use planning in earthquake prone urban areas. The performance of the models have been examined by applying them to a vulnerable urban area in Tehran, Iran. The results show an acceptable degree of fulfilling the problem objectives.

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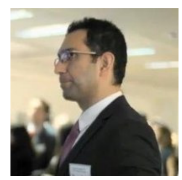

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