Migration Letters

Volume: 20, No: S10(2023), pp. 928-934

ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)

www.migrationletters.com

Conceptual Model for Managing Sources of Danger in the Event of an Earthquake

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Abstract

Safety is a state of human activity in which the realization of a potential danger is excluded with a certain probability. However, there is an axiom: any human activity is potentially dangerous. The criterion, i.e. a quantitative assessment of the danger, is the risk.

Practice shows that the previously applied concept of safety, which excluded any manifestations of danger (the concept of zero risk) turned out to be untenable. Currently, the basic concept of security is the concept of justified risk, i.e. risk that, given the available economic opportunities and social relations, is considered acceptable for ordinary citizens. This study presents the results of a conceptual model - a model of communication channels obtained as a result of system analysis and reflecting the dynamics of information flows about the state of sources of danger in the zone of a possible earthquake. The conceptual model consists of functional operators B1, B2, B3, B4, B5, B6, B7. This study is an important direction for improving the effectiveness of protective measures is the mathematical modeling of emergencies and forecasting their consequences.

Keywords: *Conceptual model; earthquake; Risk evaluation; Seismic risk; Urban risk.*

Introduction

For management purposes, risk can be characterized as the potential outcomes, which include economic, social, and environmental dimensions, that stem from hazardous events that could transpire within a defined time frame. Nevertheless, historically, the concept of risk has frequently been tackled in a disjointed manner, with each scientific discipline involved in risk assessment offering its distinct definition (Cardona 2004). In recent decades, a multitude of methodologies for evaluating risk have arisen from various viewpoints, expanding on the concept of disaster risk established by UNDRO (1980). Taking a holistic perspective, understanding risk requires a multifaceted evaluation that encompasses not just the expected physical harm, the quantity and varieties of casualties, or financial losses (referred to as primary impacts) but also the factors associated with societal vulnerability and the lack of resilience conditions. These factors contribute to

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secondary consequences (indirect impacts) when a seismic hazard event affects an urban area (Cardona and Hurtado 2000; Masure 2003; Carreño et al. 2007a, b).

Traditionally, risk has been predominantly assessed in physical terms, mainly because quantitatively evaluating social vulnerability is challenging. Nevertheless, this does not mean that it is infeasible to analyze vulnerability relatively or through indicators and indices, allowing for a concept of "relative risk." This approach enables informed decision-making and the establishment of priorities concerning prevention and mitigation. Risk indices should encompass both physical aspects of risk and non-physical aspects, such as the economic capacity of the community, the population's ability to self-protect, social structures, organizational levels, governance, among others (Cardona et al. 2003).

Various methods exist for integrating data and modeling risk and vulnerability. Nonetheless, approaches grounded in fuzzy logic and expert systems offer the distinct advantage of assigning quantitative values.

A comprehensive risk assessment, drawing from a range of disciplines that encompass geophysical, structural, economic, social, institutional variables, and more, is often referred to as a holistic, integral, or comprehensive approach. This approach addresses all aspects of risk. It's important to emphasize that scenarios detailing potential physical damage, known as scenarios of the physical aspects of risk, are crucial because they result from the interplay of hazards and the physical vulnerability of buildings and infrastructure.

The holistic approach to risk assessment might spark debate when seen from specialized and narrow perspectives. Nevertheless, given the intricacies of the socio-technical systems needed for modeling urban risk, it is preferable to offer an approximate solution to a properly framed problem rather than a precise solution to a poorly formulated one. The level of uncertainty associated with the holistic approach is favored over a singular, point-focused perspective, typically linked to higher precision (Cardona 2001).

In conclusion, although both reductionist and holistic approaches hold merit, the preference lies with the latter in this context. The aim of these analyses is to advance comprehensive risk management, which means taking into account not only physical vulnerability but also other vulnerabilities across urban planning, education, emergency preparedness, and related domains.

Cardona (2001) devised a conceptual framework and a model for comprehensively analyzing the risk of a city. This model takes a holistic view and characterizes seismic risk using indices. It encompasses both "hard" and "soft" risk factors within the urban environment, taking into account aspects such as exposure, the socio-economic attributes of different areas or neighborhoods, and their ability to cope with disasters or their degree of resilience.

A key objective of this model is to provide guidance for decision-making in risk management. It achieves this by pinpointing critical areas within the city and assessing their vulnerabilities across a range of professional disciplines. The model hinges on a relative normalization of the indicators involved, ensuring a standardized and comparable basis for risk assessment.

Carreño (2006) introduced an alternative approach to Urban Risk Evaluation, building upon the foundations laid by Cardona's model (Cardona 2001; Barbat and Cardona 2003). This method evaluates urban risk by utilizing composite indicators or indices in a unique manner. It assesses the physical risk index for each unit of analysis based on expected building damage and infrastructure losses resulting from loss scenarios (Carreño et al. 2007a).

Moreover, this method enhances the normalization process and calculates final risk indices in an absolute, rather than relative, manner. This adjustment facilitates risk comparisons among different urban centers. Notably, exposure and seismic hazard are no longer part of the evaluation process, as they are now included in the computation of physical risk variables. The descriptor of population density, previously considered an exposure component in Cardona's model, has been repurposed to serve as an indicator of social fragility. This fresh approach still employs indicators and fuzzy sets or membership functions, as originally proposed by Cardona (2001), albeit with some modifications. Furthermore, certain descriptors are now normalized with respect to the population rather than the area of the study area in certain cases (Carreño et al. 2007a).

Subsequently, Marulanda et al. (2009) evaluated the robustness of the methodology proposed by Carreño (2006) and (Carreño et al. 2007a).

In addition, this paper proposes another alternative method that leverages fuzzy sets theory to provide a more flexible tool for situations where information is either unavailable or incomplete. This approach maintains the conceptual framework of previous methodologies while offering increased adaptability in handling incomplete data.

Results and Discussion

The conceptual model is a model of communication channels obtained as a result of system analysis and reflecting the dynamics of information flows about the state of sources of danger in the zone of a possible earthquake. The conceptual model consists of functional operators B1, B2, B3, B4, B5, B6, B7.

Operator B1 describes the procedure for collecting and analyzing information about a production facility and an industrial area in an earthquake zone:

$$B_1 : T \times X \times \Pi \times \theta_1 \rightarrow U_1$$

T is the set characterizing the operating time of the operators;

X is a set that characterizes the state of the sources of danger;

Π – monitoring regulations;

θ_1 – staff errors;

U_1 – generalized characteristics of the state of sources of danger at the production facility and industrial territory.

Operator B2 makes a forecast of the technical safety of the state of the production facility and industrial territory in the earthquake zone:

$$B_2 : T \times U_1 \times K_2 \times \psi \times \theta_2 \rightarrow U_2$$

K2 – criteria and restrictions for monitoring a production facility and an industrial area;

ψ - forecast horizon;

θ_2 - forecast errors;

U_2 – the state of technical safety of the production facility and industrial territory in the earthquake zone for the selected forecast horizon.

Operator B3 forms management decisions:

$$B_3 : T \times U_1 \times U_2 \times K_3 \times \psi \times \theta_3 \rightarrow U$$

K3 – limitations in making managerial decisions;

θ_3 - mistakes in making managerial decisions;

U – management decisions.

Operator B4 describes the forecast of the state of the production facility and industrial territory in the earthquake zone after making a management decision:

$$B_4 : T \times U \times X \times \psi \times \theta_4 \rightarrow P$$

Θ_4- staff errors;

P – the state of the production facility and industrial territory after the adoption of a management decision on the accepted forecast horizon.

Operator B5 describes the assessment of the forecast of the state of the production facility and industrial territory in the earthquake zone:

$$B_5 : T \times P \times U_2 \times \psi \times \theta_5 \rightarrow M$$

Θ_5- errors in the analysis of the situation;

M – characteristics and assessment of the forecast of the state of the production facility and industrial territory in the earthquake zone.

Operator B6 describes the safety assessment at the production facility and industrial area in the earthquake zone:

$$B_6 : T \times U \times P \times M \times \psi \times \theta_6 \rightarrow B$$

θ_6 - errors in risk assessment;

C – safety assessment at the production facility and industrial territory;

Operator B7 describes the procedure for forming a management decision, taking into account the safety assessment at this production facility in the earthquake zone:

$$B_7 : T \times P \times M \times B \times \psi \times \theta_7 \rightarrow U'$$

θ_7 - mistakes in making managerial decisions;

U' – management decision;

In the comprehensive assessment of risk using indices, the risk outcomes are determined by incorporating contextual factors such as socio-economic fragility and lack of resilience, which exacerbate the physical risk. To apply this method, it is essential to have input data concerning these conditions at the urban level. This approach enhances the effectiveness of risk management by identifying weaknesses within the urban center and prompting proactive measures.

Socio-economic fragility and lack of resilience are characterized by a set of indicators that amplify the physical risk, which represents potential direct effects. Consequently, the overall risk is influenced by both the direct effects, or physical risk, and the indirect effects, which are expressed as a multiplier of the direct effects.

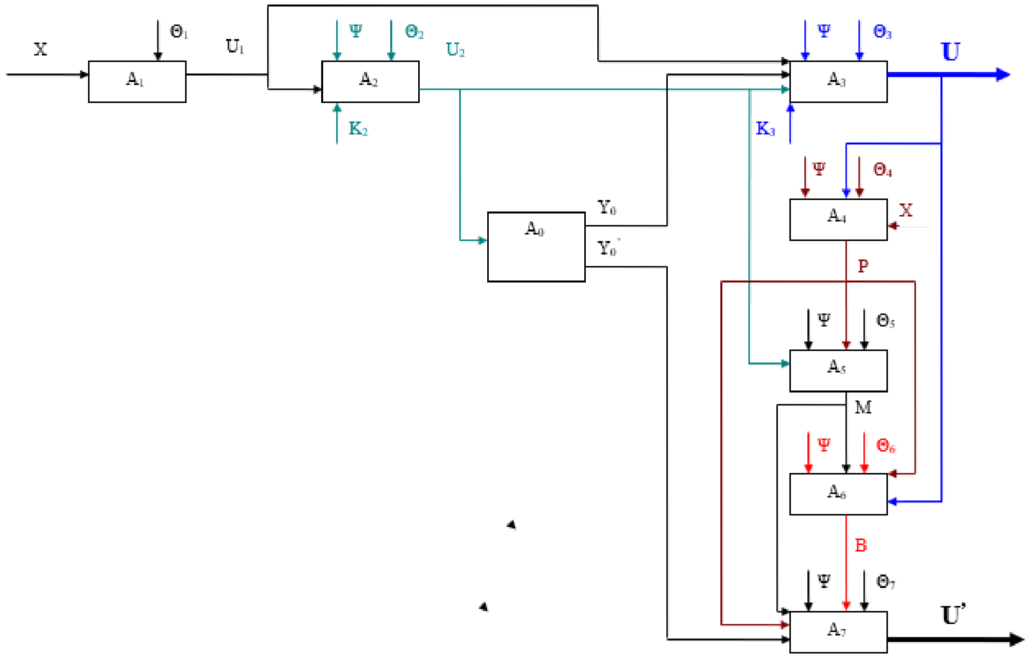

Figure 1. is a diagram of a conceptual model for managing sources of danger.

Operator B1: This operator describes the process of collecting and analyzing information about the state of a production facility and an industrial area in a potential earthquake zone. It takes into account time (T), the state of the sources of danger (X), monitoring regulations (N) and personnel errors (E). The result of this operator is a generalized characteristic of the state of hazard sources (U1) on these objects.

Operator B2: This operator is responsible for predicting the technical safety of the state of the production facility and the territory in the earthquake zone. It takes into account the criteria and limitations in monitoring (K2), forecast horizon, forecast errors and the state of technical safety (U2) for a certain forecast horizon.

Operator B3: This operator forms management decisions and takes into account limitations when making them (K3), errors when making decisions and issues management decisions (U).

Operator B4: After making management decisions, this operator describes the forecast of the state of the production facility and the territory in the earthquake zone. It takes into account staff errors (Θ4) and the state of the object after the implementation of solutions (P) for the selected forecast horizon.

Operator B5: This operator evaluates the forecast of the condition of the production facility and the territory in the earthquake zone. It takes into account errors in the analysis of the situation (Θ5) and gives a characteristic and an estimate of this forecast (M).

Operator B6: Operator B6 evaluates the safety of the production facility and the territory in the earthquake zone. It takes into account errors in risk assessment (Θ6) and issues a safety assessment (B).

Operator B7: This operator describes the process of forming a management decision taking into account the safety assessment at the production facility in the earthquake zone. It takes into account mistakes when making managerial decisions (Θ7) and issues the final managerial decision (U').

This conceptual model makes it possible to systematize information and processes in risk management in the earthquake zone. Each operator performs certain functions and takes into account various aspects, such as monitoring, forecasting, decision-making and safety assessment. The model provides a tool for more effective risk management in this area.

Conclusions

A simplified yet conceptual model for the management of earthquake-related hazards is proposed here, employing parametric variables to capture various aspects of this risk. This model is designed to be highly adaptable and realistic, utilizing fuzzy sets to allow for continuous adjustments and alternative configurations. By considering physical aspects, it enables the construction of a physical risk index. This index is based on information regarding seismic scenarios, specifically physical damage (direct effects), while another index is derived from estimating the exacerbating conditions (indirect effects). These indirect effects are determined by descriptors and factors associated with social fragility and the lack of resilience of exposed elements. The application of fuzzy sets is particularly valuable when complete information is lacking, as it can be substituted with expert opinions. This novel fuzzy model for holistic risk assessment simplifies the process of integrated risk management, facilitating decision-making for various stakeholders involved in risk reduction. The case studies illustrate how the aggravating coefficient is calculated. These coefficients help identify key factors that significantly influence the results, providing valuable guidance and potential prioritization of measures to enhance socio-economic conditions within the studied area. In both case studies, identical weights and aggravation coefficient values are utilized for different reasons. It is worth noting that future research can explore variations in the membership functions and variable weights, which may not significantly impact the results due to their foundation in the transformation functions of the original methodology.

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