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A Framework for Web Integrated Information System for Risk Management of Natural Disasters

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Abstract. The paper tackles with the possibility to propose a framework for Web Integrated Information System for risk management of miscellaneous natural disasters. Different methods and tools for risk analysis and estimation are discussed when different types of disasters may occur. The system ability to serve as a unified platform for interdisciplinary research is considered with regard to consolidating researchers with different specialists and individual users that will be able freely to offer information and knowledge exchange through a Web 2.0 dedicated online social network. The proposed framework aims at making efficient management decisions for risk prevention and reduction in emergency situations due to natural disasters.

Keywords: risk, risk management, natural disaster, framework, Web, information system

1. Introduction

In recent years Europe and its immediate neighbours experienced a series of particularly severe disasters, ranging from flash floods and severe storms in Western Europe, large-scale floods in Central Europe, volcanic ash clouds after the eruption in Iceland, to unprecedented forest fires in Russia. The world also witnessed two of the worst natural disasters in recent decades - the Haiti earthquake and the Pakistan floods, both of which resulted in considerable loss of life and widespread destruction. The March 2011 earthquake in Japan has lead to severe natural and technological damages directly affecting not only the country itself, but the consequences of its negative effect have spread all over type rest of the world [1].

The geographic location, the natural peculiarities and the economic conditions define the high vulnerability of Bulgaria, SE Europe, to different types of disaster that could lead to significant human, ecological and material losses. Hence enhanced R&D efforts are necessary, as well as analysis and assessment of possible risks in order to avoid or reduce the consequences due to the negative impact of numerous natural hazards.

The established in Bulgaria "National Program for Disaster Defence 2009 – 2013" defines the goals, priorities and tasks for disaster defence for a 5-year period. The program represents a major document for government policy in the field of prevention, seizure and overcoming the consequences of possible disasters and it draws the tendencies for the development of effective, resource and technological backed national integrated system for disaster prevention and response. One of the major tasks is the "introduction and systematic use in practice the methodologies for analysis, estimation and forecasting the disaster emergency risks". The National Program states that a necessary condition for its fulfillment is "the use of modern scientific methods in solving all problems related with disaster defence" and the scientific potential development. The need for the development of Web-based knowledge portal for action in emergency conditions is indicated.

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2. Problem Statement

In recent years a vast scientific and scientific-application research is conducted on specific disaster types and their consequences for the people's health and property, the environment, cultural and material assets. The major part of the research is conducted in the specialized higher education organizations and the institutes of the Bulgarian Academy of Sciences. These activities are related with the development and application of modern methods and tools for analysis and estimation of risk processes and events with a natural and an anthropogenic origin; development of models for risk control in emergency situations; development and maintenance of dedicated databases and information systems.

It is important to note the results of that scientific and applied scientific research mostly concern particular natural disasters. Most often the interdependence of natural disasters and their joint impact on society and infrastructure are not sufficiently taken into account. Major results are related to the study of mutual influence between the various elements of the critical infrastructure in emergency situations. Different research groups use different tools (methods, databases, programming languages, software environments, etc.). Due to this reason it is difficult to compare, reconcile and mutual use the results, risk assessment, analysis and forecasts for the overall consequences due to a certain disaster emergency. Therefore, the research, risk analysis and estimation of disaster emergency are a complex, multidisciplinary process, which demands for the unification of the efforts of specialist from different scientific areas.

Hence the development of Integrated Information System which should include different methods and tools for risk analysis and estimation when different types of disasters occur is required and it will serve as a unified platform for interdisciplinary research. The system should be a Web-based one in order to consolidate researchers with different specialists and individual users that will be able freely to offer data and exchange information. The system will help making efficient managerial decisions for risk prevention and reduction in emergency situations due to different disasters.

In recent years research interdisciplinary teams from different countries work on the development of Web-based information systems for emergency situation control, including modules for research, risk analysis and estimation of occurring disasters.

The purpose of the current work is to propose a Web integrated information system which implements an innovative methodology for research, analysis and assessment of risks from natural disasters. The designed integrated information system should be implemented as a Web-based research software platform which should include individual and logically connected subsystems.

3. An Integrated Approach for Risk Management of Natural Disasters

In this work the risk of natural disasters for different objects is considered as a function of two variables:

$$Risk = F\,(Consequences, Probability).$$

The consequences cost (losses) depend on the degree of vulnerability of monitored objects (buildings, roads, municipalities, etc.) and the specific characteristics of disasters (strength, intensity, duration, etc.):

$$Consequences = f\,(Vulnerability,\ Hazard),$$

The vulnerability is related to the objects ability to resist the negative effects of any natural disaster;

The hazard reflects the potential threat due to the occurrence of a disaster with certain characteristics

The risk management of natural disasters is usually performed in conditions of the subjectivity and incomplete certainty. This requires application of innovative methods of risk assessment and development of sophisticated web information integrated system for emergency management.

The proposed web information system will implement an integrated approach for risk management of natural disasters based on ISO 31000:2009 "Risk management - principles and guidelines". The integrated approach includes following major activities that will be designed as elements of the information system [2].

3.1. Comprehensive description of the monitored objects

Each monitored object can be described by the different characteristics, for example:

- Geographical location, boundaries and area where the object is located;

- Natural conditions (landscape, geological-tectonic structures and seismicity, water resources, soils, flora and fauna, etc.) and potential natural disasters (threats);
- Municipality economics, demographic situation and technical infrastructure;

3.2. Risk Identification - description of the possible disasters and assessment of the vulnerability of the monitored objects

Risk identification requires detailed studies of the characteristics of the sources of risk (possible natural disasters) and elements of risk (monitored objects). The risk is generated by the opportunity for natural disasters interaction, both among themselves and also with elements of risk.

Information for the natural hazards and disasters is accessible through the different national and international sources, like:

- different databases with research information and scientific results;
- electronic databases, electronic and printed catalogs, maps, scientific results, etc.;
- archive records of past hazardous natural events and statistical information;
- chronological information on different weather, climate, hydrological and other parameters;

In the proposed Web integrated information system the descriptions of the risk sources will be stored in a database, called “Natural disasters”. The disasters will be classified according to the following features:

- intensity (small, medium, strong и catastrophic);
- probability of occurrence (frequency of occurrence, without considering the influence degree);
- distribution - range (zone/area that can be influenced by the considered risks);
- time range (warning time, duration, time occurrence during the day, week, and year);
- observerability and manageability (what can be done about this environmental disaster).

Identification of the interaction between the risk resources and components requires the application of systematic approach. The risk matrix is formed. The matrix includes various quantitative and qualitative data as well as expert knowledge provided by specialists and emergency management offices.

3.3. Risk Analysis of the monitored objects

The risk analysis includes consideration of sources of risk, the consequences for the monitored objects of their manifestation and the probability of occurrence of exactly these consequences. This is a conditional probability, which defines the probability of occurrence of harmful consequences due to a natural disaster, rather than the probability of occurrence of the source of risk. The risk analysis results depend on the available data and research resources. Usually the information is incomplete and inadequately defined which requires the use of specialized methods and tools. A qualitative or/and quantitative risk analysis is performed.

The estimation of the effects is not limited to assessment of potential financial losses by determining the market value of destroyed physical resources (infrastructure / systems identified as critical), since in financial analysis those effects which are not market value cannot be measured quantitatively.

The economic losses evaluation allows analyzing both the material and intangible losses due to disasters. In this sense, the economic analysis for assessing potential losses leads to extension of the assessment range. According to the classification adopted losses are tangible and intangible, which are grouped further direct and indirect (implicit). Classification applied in the integrated information system is based on current research and developments in the risk assessment of natural disasters.Advanced modern economic and financial analysis and evaluation of potential losses due to disasters are used.

3.4. Risk Assessment of the monitored objects

The proposed approach allows for a risk assessment using of various probability and intelligent methods, enabling integration of diverse types of data and expertise in terms of subjectivity and incomplete certainty. The comprehensive risk assessment aims to classify the objects in order of disaster severity and formulate recommendations for activities to minimize risk in terms of limited funds and resources.

The risk assessment methods that will be used in the integrated information system can be viewed as:

- Inductive methods for risk assessment

The inductive methods for risk assessment start with the definition of potential scenarios describing

different risks for a given system. Further they identify the risks and the consequences of previously defined scenarios. The major limitation of these methods is related to the fact that the scenarios can be defined only at the beginning and definition of new once is no allowed during the analytical stage. Methods for analysis of failure modes and their consequences (as FMEA, FMECA, HAZOP) and event tree analysis will be used.

- Deductive methods for risk assessment

The deductive methods of risk assessment begin with the definition of possible consequences of given risks for the monitored object. Fault tree analysis is one of them. A logical diagram is constructed in order to investigate cause-consequence relations between faulted normal functioning of the system as a whole and the logical order of failures in its different parts. It is appropriate for multi-object interaction representation.

- Probabilistic methods for risk assessment

The insurance mathematics methods and actuarial techniques usually apply probability theory methods.

- Intelligent risk assessment methods

The intelligent methods are applied for uncertainty handling tasks. Fuzzy logic, neural networks, genetic algorithms etc. are effectively applied in different systems for risk assessment by expert knowledge. The expert knowledge is used because the information about risk's estimation is obtained by questioning number of experts. The answer could be qualitative or quantitative assessment depending on the chosen scale. The expert knowledge method is subjective and it contains an uncertainty. There are numerous factors that influence the quality of the obtained information: qualification and loyalty of experts, time, resources etc.

The methods for risk assessment based on fuzzy logic have an wide and a successive practical application. This is mainly due to their attractive characteristics: representation of experts' knowledge by "if-then"; universal approximating linguistic variables; ability to account for information's uncertainties. The fuzzy logic methods are appropriated for processing of uncertain expert information in risk's estimation.

The neural networks have different applications due to their ability to approximate almost every function using training data and to classify samples. They use training data set with known class's belonging and after the training they are able to assign to a new sample its corresponding class. Neural networks are widely applied for different purposes as: estimation, identification, prediction and optimization.

4. A Framework for Web Integrated Information System

The proposed framework of the integrated information system must be regarded as a Web based research software platform which includes the following individual and logically connected parts:

- Subsystem for risk source identification; risk component analysis, economic assessment of consequences; complex risk analysis and assessment.
- Subsystem for integrating various databases in GIS environment through developed models;
- Dedicated online social network for helping the monitoring and control of emergency situations.

The framework for a Web Integrated Information System (WIIS) will attempt to provide software tools for modelling and analysis for the targets and systems of the monitored objects as a result of miscellaneous natural hazards, an assessment of the mutual impact and negative consequences, as well as the provision of a complex information for the facilitating the process of making managerial decisions.

The implementation of the WIIS comprises three main areas – the Risk Management (instruments and studies for risk identification and management), the Presentation Area and Online Social Network (OSN). All these three areas are brought all together with the database.

The Presentation Area consists of two elements – Web presence and information management applications. The Web site is responsible for the presentation of the activities and results.

Online social networks are most useful in the context of preparedness and training [3]. During acute emergencies their usefulness is limited by their inherent multiple vulnerabilities, including disruptions of communications, overload, lack of security, questionable quality of information from unknown sources. The Online Social Network will include governmental, non-governmental, research and other related to accident prevention organizations. It is oriented toward explanation and information dissemination for possible threats,

as well as for avoiding accidents or management activities. The OSN assures close connection with all interested organizations and citizens, thus providing day-to-day work management and co-ordination.

The OSN should solve common problems and implement features, which are needed to obtain and store data from/to different physical locations, to verify and filter the data, to avoid information overload, to use ready models for disaster management, to enable collaboration, to provide for reliability and accessibility, to attract experts and users in particular emergency managers [4, 5].

The database will focus on the OSN and user requirements. The database model requirements will be set-up according to the specific defined information inputs and outputs. The database user requests for specific information (areas/domains of risk and risk management, law, responsibilities, activities for prevention, etc.) will be included in the database structure. In order to keep integrity of the three areas of the WIIS a core team of moderators will be established. The databases will contain heterogeneous information for the targets of the objects and characteristics of the natural hazards for the country's territory. Thus a unification of the input-output information is necessary, which will be fed to the analysis and assessment modules of the integrated information system. Each separate module will be connected with different databases, in which the following items will be stored:

- Chronological information from current observations (temperature, rainfalls, river flows, etc.), conducted over the country's territory form station networks (climatic, hydrological, geodesic, etc.);
- Results from specialized scientific and scientific application research, related with the risk assessment due to a particular natural disaster in a given geographic region (floods, sea storms, earthquakes, etc.);
- Information about the geographic particularities of the region – geological (composition of the rocks, types of soil, etc.) geomorphologic (relief, terrain slop, etc.), vegetation**,** etc.
- Algorithms and models for risk analysis and assessment, including for accounting the mutual impact and interrelation between the individual components of the objects, for example as statistical, intelligent – with fuzzy logic, neural networks, genetic algorithms, etc.

The proposed framework should have the corresponding GIS functionality since the targets of the monitored objects are spatially determined and geo-referred objects. A spatial data interpretation will be provided and the relation of the output results with specified geographic locations will be warranted. The risk analysis quality for the monitored objects and the efficiency of the made decisions for the crisis control due to natural hazards is increased.

5. Conclusions

The proposed framework for Web integrated information system for risk management of natural disasters will include different methods and tools for risk analysis and assessment when disasters occur and it will serve as a unified platform for interdisciplinary research. The system will consolidate researchers with different specialists and individual users that will be able freely to offer information and knowledge exchange through a Web 2.0 dedicated online social network. The proposed system will help make efficient management decisions for risk prevention and reduction in emergency situations due to natural disasters. Research on the possibility for designing and using the proposed framework by application of the Cloud Computing technology is being investigated currently as a next step of its implementation and enhancement.

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