

An Innovative Approach for Designing an Emergency Risk Management System for Natural Disasters

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Abstract—The paper discusses an innovative approach for designing an emergency risk management system for natural disasters. Different methods and tools for risk analysis and evaluation are given. The system's 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. The system is regarded as a Web-based integrated information system that includes a social network site (SNS). The components of the proposed system are defined. Special attention is given to the principles and peculiarities of SNS application to emergency management. General recommendations and the steps for establishing SNS for emergency management are proposed.

Index Terms—Emergency Management, Information System, Natural Disasters, Risk, Social Network Site.

I. INTRODUCTION

In recent years a worldwide tendency of increasing negative impact due to different types of natural disasters on the living environment and quality of life is being observed. For instance, 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 led to severe natural and technological damages directly affecting not only the country itself, but the consequences of its negative effect have spread all over the rest of the world [1].

Effective emergency management can be achieved by reducing the uncertainty in the information about possible states of affected objects, external influences, as well as the interdependence within the system.

Therefore enhanced R&D efforts are necessary, as well as analysis and evaluation of possible risks in order to avoid or reduce the consequences due to the negative impact of numerous natural hazards [2], [3].

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 [4], [5]. 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 [6].

In the conditions of global climatic changes the role of information and communications technologies (ICT) increases as a building component in the systems safeguarding the people's health and life, securing the environment, the infrastructure and property in case of natural disasters [7]-[9].

In the course of last 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 [3]-[5], [10].

Hence the development of an 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.

According to new research from the American Red Cross, the Congressional Management Foundation and other organizations, social media could stand to play a larger and more formal role in emergency response. In fact, almost half the respondents in a recent survey said they would use social media in the event of a disaster to let relatives and friends know they were safe [9], [11].

It is necessary to point that design and implementation of social network site can help the control of emergency situations.

The Social Network Sites (SNS) for emergency management usually includes not only governmental, non-governmental, research and other related to accident prevention organizations, but also individual users.

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The aim of the paper to propose an innovative approach for designing an emergency risk management system, which is a Web-based integrated information system that includes a social network site. The principles and peculiarities of SNS application to emergency management are discussed. The technology main components and their features are given. General recommendations and the steps for establishing SNS for emergency management are proposed.

II. AN INOVATIVE APPROACH FOR RISK MANAGEMENT OF NATURAL DISASTERS

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

$$\text{Risk} = F(\text{Consequences}, \text{Probability}).$$

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.):

$$\text{Consequences} = f(\text{Vulnerability}, \text{Hazard}),$$

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 integrated information system will implement an innovation approach for risk management of natural disasters based on ISO 31000:2009 "Risk management - principles and guidelines" [6]. The integrated approach includes following major activities that will be designed as elements of the information system.

A. Comprehensive Description of the Monitored Objects

The first activity of the risk management process according to the standart is establishing the context. In particular, each monitored object is 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.

B. 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.

C. Risk Analysis of the monitored objects

Risk analysis provides an input to risk evaluation and to decisions on whether risks need to be treated, and on the most appropriate risk treatment strategies and methods. Risk analysis can also provide an input into making decisions where choices must be made and the options involve different types and levels of risk.

The risk analysis involves consideration of the causes and sources of risk, the consequences for the monitored objects 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.

Factors that affect consequences and likelihood should be identified. Risk is analyzed by determining consequences and their probability, and other attributes of the risk. An event can have multiple consequences and can affect multiple objectives. Existing controls and their effectiveness and efficiency should also be taken into account.

The risk analysis results depend on the available data, expert knowledge and research resources. Usually the information is incomplete and inadequately defined which requires the use of specialized methods and tools. Analysis can be qualitative, semi-quantitative or quantitative, or a combination of these, depending on the circumstances.

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 Web 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.

D. Risk Evaluation of the monitored objects

According to the standard the purpose of risk evaluation is to assist in making decisions, based on the outcomes of risk analysis, about which risks need treatment and the priority for treatment implementation. Decisions should be made in accordance with legal, regulatory and other requirements.

The proposed approach allows for a risk evaluation 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 evaluation 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 evaluation methods that will be used in the integrated information system can be viewed as:

- *Inductive methods*

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, 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*

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

- *Intelligent risk*

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 a 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.

III. COMPONENTS OF THE WEB BASED INTEGRATED INFORMATION SYSTEM

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

- 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 social network site (SNS) for helping the monitoring and control of emergency situations.

The idea for a Web based 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 Social Network Site. 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.

SNSs are most useful in the context of preparedness and training [11], [13], [14]. 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 SNS 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 SNS assures close connection with all interested organizations and citizens, thus providing day-to-day work management and

co-ordination.

The SNS 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 [3], [15].

The database will focus on the SNS 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 from 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 system 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.

IV. SOCIAL NETWORK SITES

Nowadays the terms Social Media, Social Software and Social Network Site are quite often used, sometimes mistakenly, in Internet interaction between different users.

Social network sites are defined as web-based services that allow individuals to [12], [16]:

- 1) Construct a public or semi-public profile within a bounded system,

- 2) Articulate a list of other users with whom they share a connection,
- 3) View and traverse their list of connections and those made by others within the system. The nature of these connections may vary from between sites.

The SNS main component consists of visible profiles that display list of friends who are also users of the system. The visibility of a profile varies by site. Most SNSs provide a mechanism for users to leave messages on their profiles of their friends.

There are hundreds of social network sites such as Facebook, MySpace that support a wide range of interests and practices. Most sites support existing networks, but others help people connect on the basis of their shared interests, political views or activities. SNS also vary in the extent to which they use new information and communication tools, such as mobile connectivity, blogging and photo/ video-sharing.

The term Social Software is used for software systems that are utilized for group communication and collaboration which thus foster building and managing social networks or publishing information and its dissemination [3], [15]. Blogs, discussion groups, Wikis, music streams with rating features, social networking platforms or picture sharing are examples of Social Software. SNS emulate real social networks in a virtual environment. Each member is encouraged to expand the current network by inviting others to join and connecting with others. Each member also creates a personal profile, which may be very detailed. This information can be shared with all or restricted to a number of members within the network. Links that are made with existing users of platforms and added to ones network can also be controlled. Besides these functions, SNS might offer newsgroups around one or more sets of topics usually managed by members of the community, a personal blog, calendar, RSS, chat, classifieds and picture sharing functionality.

The term Social Media is content creation and distribution. The ability to create, post and share content is a major component of many SNS [16], [21]:

- Social media helps to inform people and allows the news media to get instant responses from around the world. Reporters can now use social networking sites to break news almost immediately. The direct links from reporters to their followers allow them to model their stories in a new way. Now they can connect directly to those in the center of the disaster and describe the devastation picture.
 - When a natural disaster occurs, it can severely cut the lines of communication. Social network sites allow survivors and relatives to locate one another quickly.
 - When disaster occurs, many people want to help victims but often there are no evident means for this. During natural disasters charity organisations are able to turn their social network friends into helpers. The beneficial thing about social media is that it normally attracts an audience who is genuinely interested in what you have to say. In such a way social media allows people to donate and allows to feel connected to victims suffering through natural disasters.
- There are various types of social media [11], [13], [14]:
- Blogs - A blog is a dynamic, regularly updated portion of a website used to communicate news and opinions in a daily

way. Through blogs new posts and pages can be added to blog websites without needing to know complex design code.

- Microblogging - Twitter is a microblogging tool that allows users to post messages of 140 characters or fewer. This feature allows users to follow and read the posts of other users, reply to them and forward them to other users.
- Video - Videos captured with camcorders, digital cameras or smartphones and posted to SNS are social media. They represent content, created, captured and posted with minimal planning and work.
- Podcasting - A podcast is an audio or video program optimized for delivery and listening on a smartphone, MP3 player or computer.

V. SOCIAL NETWORK SITES AND EMERGENCY MANAGEMENT

Crisis events generate a huge volume of communication and interaction among organizations and individual participants that stimulates collective action. The purpose of an emergency SNS is to be a common meeting place for organizations and people to come together to share information and find potential collaborators with needed expertise. Online services become increasingly important as useful tools to obtain information faster than traditional media, to provide timely information sources and to reconnect people affected directly or indirectly in crisis.

A complex pattern of interacting parties can be found in an emergency situations. This pattern could be regarded as a social network involving different participants [11], [17]. Understanding interactions and various relations between the participants, who are engaged in an emergency response operation seems vital in order to understand the dynamics of such an operation. Most of the results by which the success of an emergency response operation is measured can be regarded as emergent properties of a complex adaptive system consisting among other things of the agents of the involved organizations. Thus, the measures used to judge whether a particular emergency response operation is successful can seldom be attributed to a single agent or a small group of agents but are instead emergent properties of the system as a whole.

It is reasonable to expect hundreds of involved participants in some of the more severe emergencies and since one participant easily can have connections to many other participants, it can be expected that a great amount of information needs to be collected.

For information to be useful to it must be clear, comprehensive and delivered in a timely fashion. For the implementation a translation process must be developed that interprets the critical information and breaks it down into actionable steps. Emergencies require compressed information collection, processing, decision making and dissemination efforts.

SNS in emergencies can play an important role in facilitating the flow of information across multiple boundaries [3], [16]:

- Social networks increase interaction among organizations that can lead to development of trust which reduce transaction costs;
- Social networks spread risk by providing individual members with sources of support during times of trouble, and allow the group as a whole to engage in overall higher levels of risk-taking;
- Social networks facilitate the rapid dissemination of information among members and reduce the asymmetries of information that can otherwise discourage profitable transactions;
- Social capital improves access to resources among network members;
- SNS allow members to solve collective action problems more easily.

Emergency communications in regard to a social network site context serve as a channel for communication responsive to the disaster event as well as providing a platform for an emergent community of responders and victims, and facilitating the maintenance of the ties of pre-emergency community. At a local level, emergency communications are embedded in community, and community in turn is embedded in the emergency communication network and infrastructure. Communities provide the foundation for emergency preparedness and planning. Part of the work of the social network is to restore community. Communities are a special case of social networks bounded by identification with a place, group or interest and a sense of belonging.

Social network sites can be used for mass notifications on topics like [3], [18], [19]:

- Evacuation routes;
- Locations of evacuation shelters;
- Contact numbers for friends and families of victims;
- Anticipated numbers of casualties;
- Their potential severity;
- Patient transport initiation and conclusion times;
- Times and locations of press briefings;
- Images of the incident, responders and rescue actions in progress.

Therefore, social network sites have positive impacts on the ability to disseminate emergency notifications, the potential pitfalls that exist and steps for creating an effective social media presence to be used in an emergency situations.

The reasons SNSs are important for emergency management may include [11], [15], [16], [20]:

- High usage rates - users are turning to SNS as a primary source of breaking news and up to the minute information.
- Spread of Information - in a crisis situation, people are constantly looking for the newest and most up-to-date information. SNS allow for nearly instant delivery of such information. Users share information with other users when they determine that it is of value or interest to those they are connected with via social media.
- Repeated delivery of messages - When a message is of value or importance, social media users will share that information with their followers, almost instantly.
- Unified notification - Integration with many IP-based and legacy notification systems, to provide easy and effective

- emergency notification from a single Web-based console.
- Rapid and pervasive reach - Distributing emergency alerts to hundreds of thousands of people through network-connected devices in minutes.
- Richer message delivery - Delivering detailed communications based on the threat or scenario (such as evacuation instructions, more data requested, call backs).
- Multiple credible information resources - users will get the necessary information from a source they trust and will listen to.
- Ability to measure attitude - users often add commentary to messages when they share them, which allows the agency responsible for the spreading the information the ability to see instant public reaction to the information and know if the people are complying with directions.
- Ongoing contact which can improve preparedness prior to a crisis - In order to be an effective channel in a crisis, agencies responsible for issuing emergency notifications will need to establish effective SNS profiles prior to the crisis.

However, there certain threats and challenges which exist in SNS:

- Message manipulation - While having other users repeat information is one of the key benefits of social media, it also presents the risk of users clouding the message with incorrect information.
- Possibility of incomplete information - Some channels limit the length of message, which might not be enough room to effectively deliver the message.
- Potential for network overload during a crisis as networks are being upgraded.

VI. RECOMMENDATIONS FOR ESTABLISHING SOCIAL NETWORK SITES FOR EMERGENCY MANAGEMENT

On these assumptions a general strategy for creating a SNS presence can be developed. First of all the strategy must include determination of the conditions regarding time and location for the creation of social media content and participation in social network, as well as a policy, describing the corresponding organization's official social networking presence. Another important aspect of the future SNS is building connections by defining possible participants and their requests.

Notification system for new content added to the website is a critical social networking strategy. The first step is to make sure your organization's blog/website has an RSS feed and allows visitors to subscribe to receive content updates from it. An RSS feed allows users to subscribe to a website's feed and have new content on that site automatically loaded into an RSS feed reader or subscription device.

The general strategy must include the following steps for establishing a SNS for emergency management [12], [18]:

- Creating a blog or another website where content can be frequently updated. Topics for content will include emergency preparedness, planning for a crisis or other relevant information. The site will act as concentration point of all social media activity, and traffic from the social media profiles will be directed here.

- Creation of participant profiles on Facebook, Twitter, LinkedIn and other social networking sites.
- Sharing links to the specific blog content by these channels.
- Sharing links to other relevant information from other websites.
- Engaging other users by posting to their profiles.
- Responding to any queries posted to the profile.

Researchers from a variety of fields have demonstrated the importance of communication in the management of emergencies [11]-[13].

Communication is a core function that can significantly enhance preparedness, improve coordination and cooperation, empower the public, facilitate logistics, reduce public anxiety and generally limit and mitigate harm. Hence certain rules and practices must be defined that should be taken into account regarding participants in social network sites for emergency management [22], [23]:

- Participant access – definition of the possible users of the SNS that can provide useful data and information.
- Account management – definition of acceptable usage policy for the participants in the SNS.
- Participant conduct – definition of the way participants present themselves in the SNS.
- Acceptable content – definition of the allowed sharable content between the participants in the SNS.
- Security – definition of identifiable information and establishing rules that prevent information violation and security breach.
- Legal Issues – definition of terms and conditions regarding applicable privacy of information and content, as well as rules for information storage, retrieval and manipulation.

Disaster response has always been a challenge during and after major natural disasters due to the impact of disaster itself, the number of organizations and individuals participating in the response and the lack of rapid social networking to support immediate response.

Therefore the establishment of SNS for emergency management is a must.

VII. CONCLUSION

The proposed innovative Web based 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 social network site.

SNS can help communicate with the public in emergencies, build situational awareness, and provide for recovery. There is an wide range of social software tools and miscellaneous social media types. Their proper integration into dedicated social network sites for emergency management could lead to significant results in relief attempts and practices when dealing with different types of crisis.

However, there is almost no or little research on the design of social media and knowledge management technologies for emergency management, including how they differ from other organizational systems with respect to usability, portability, open standards and durability in a post-disaster environment. It is not known how these systems influence the decision-making processes of organizations would provide the opportunity to extend understanding of the decision-making models in crisis environments. These topics are important and they must be investigated as soon as possible in order to achieve an efficient utilisation of SNS for emergency management.

The proposed innovative information system will help make efficient management decisions for risk prevention and reduction in emergency situations due to natural disasters.

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