An Approach to Support Decision-Making in Disaster Management based on Volunteer Geographic Information (VGI) and Spatial Decision Support Systems (SDSS)

Flávio E. A. Horita and João P. de Albuquerque
Department of Computer Systems, ICMC
University of São Paulo, São Carlos/SP, Brazil
horita, jporto@icmc.usp.br

ABSTRACT

The damage caused by recent events in Japan in 2011 and USA in 2012 highlighted the need to adopt measures to increase the resilience of communities against extreme events and disasters. In addition to the conventional and official information that is necessary for adaptation to disasters, recently, common citizens residents in the affected areas also began contributing with voluntary qualified and updated information. In this context, this work-in-progress presents an approach that uses voluntary information - also known by VGI (Volunteered Geographic Information) - as a data source for Spatial Decision Support Systems (SDSS) in order to assist the decision-making in disaster management. Our approach consists of a framework that integrates voluntary and conventional data, a SDSS and processes and methods for decision-making. As a result, it is expected that this approach will assist official organizations in disaster management by providing mechanisms and information.

Keywords

Spatial Decision Support Systems, Volunteered Geographic Information, VGI, Disaster Management.

INTRODUCTION

Recent catastrophic events in Haiti, Chile and Pakistan in 2010, Queensland between 2010-11, Christchurch and Japan in 2011 caused severe economic damage and shattered the daily life of their communities. These events highlighted the increasing need to develop activities that support Disaster Management (DM). These approaches should help to enhance the power of community resilience, i.e., improving the community's capacity to resist, adapt or change in order to achieve a new level of functioning or structure in the occurrence of extreme events and disasters (Norris et al., 2008). Thus, DM acquires importance as a measure of adaptation to climate change and the resulting increase in the frequency of occurrence of extreme events and disasters (Mediondo, 2010). In a disaster, two major problems are found: (1) their response time should necessarily be fast and reliable, because a slow response based on incorrect data can lead to serious consequences such as the loss of life and (2) the damage caused implicate on several elements necessary for the work of Emergency Agencies (EA) (Goodchild, 2007; Ostermann and Spinsanti, 2011).

For this, Spatial Decision Support Systems (SDSS) can combine geographic information - obtained from official organizations or sensor networks – with a mathematical model that helps in predicting outcomes and support the decision-making process for DM (Densham, 1991). More recently, Volunteered Geographic Information (VGI), contributed by local people is being considered an important alternative information source (Goodchild, 2007; Gill and Bunker, 2012). Against this backdrop, this work-in-progress proposes an approach that uses VGI as a data source for SDDS to assist in decision making for disaster management.

BACKGROUND

Disaster Management (DM)

Disaster management is an alternative to improve resilience and therefore avoid or reduce the impact of natural disasters (Baharin et al., 2009). Thus, DM is defined as an ongoing process composed of a set of activities before, during and after an event, separated into four main phases: mitigation, preparedness, response and recovery.

In all these phases, information used by Emergency Agencies (EAs) plays a key role in ensuring the reduction of impacts. Because of this, it is important that there are accurate, timely and complete information about the current state of environmental variables, as well as on the scientific predictions about the upcoming changes and their associated impacts.

Volunteered Geographic Information (VGI)

During the last years, tsunamis, earthquakes and hurricanes have hit various countries and shaken the day-to-day of their societies. This largely irreversible damage, affects the coexistence of people, brings difficulties to the EAs, and delay the response processes. This must necessarily be fast and reliable, because a slow response based on incorrect data can lead to serious consequences, such as loss of lives (Ostermann and Spinsanti, 2011; Erkine and Gregg, 2012).

In these cases, data obtained by volunteers from the local population, who are familiar with the area and equipped with suitable and qualified tools, presents itself as an alternative to provide updated and rich information, so as to aid the performance of EAs and facilitate community's organization for response and disaster recovery (Goodchild, 2007; Gill and Bunker, 2012; De Longueville et al., 2010; Elwood, 2008).

Goodchild (2007) coined the term Volunteered Geographic Information (VGI) to name this phenomenon, which was defined as a collection of digital spatial data produced by individuals and non-formal institutions, i.e. by ordinary citizens using appropriate tools to gather and disseminate their views and geographical knowledge on the web. According to Coleman et al. (2009), this volunteerism has a high potential to expand and qualify the amount of information available about the events and experiences of the community members.

This approach is adopted by Erkine and Gregg (2012). Using cell phones, people can contribute with data to a centralized system that transmits relevant and accurate maps of the disaster area for EAs. According to the authors, the research results showed the effectiveness of the VGI mapping to develop effective and reliable real-time information, which is, in many cases, more effective than the traditional systems of disaster response.

Spatial Decision Support System (SDSS)

Disaster Management is closely related to the application of techniques and use of spatial data for emergency planning (escape routes, for example), land use, monitoring, alerting and prevention. In this context, many works and studies have applied SDSSs in order to improve and help in its implementation.

The SDSSs emerged from the combination of the functionality of Geographic Information Systems (GIS) with the processes and methods of Decision Support Systems (DSS) (Rushton, 2001). This integration happened on the one hand, from the limitation of researchers using spatial data on SSD and on the other hand, the efficiency of GIS to store and manage geographic data, however, without help in decision making (Hosack et al., 2012).

For this, SDSSs are typically composed of (1) an enabled database system for managing spatial data, (2) a mathematical model or the expertise to assist in predicting the outcomes of decisions and (3) a graphical user interface to display tabular reports to assist in decision making (Densham, 1991; Chang et al., 2010).

RELATED WORK

Existing work by Yongsong et al. (2012) presents a GIS to support the evacuation of the population after the outbreak of a disaster. The system architecture consists of four layers: the data processing system, data service, application and service core. The layer of data processing system is responsible for managing data and supporting calculations. The data service layer provides information needed for the service layer of the core. This layer, in turn, uses the data to feed models of evacuation and sends the results to the application layer, which then presents the results to the disaster managers. Thus, the model is useful for displaying evacuation routes and estimating the evacuation time. The experimental instance shows that the proposed model is effective to help government officials identify a strategy for evacuation.

Appropriate management of available resources plays an important role in the response to a disaster. In his work, Chen et al. (2011) present a GIS-based framework that integrates all the elements to do it effectively: a web portal to store information and distribute geographically the available resources, a mobile application that allows the requisition of resources, and a system for automated resource management. His trial was held in Champaign, IL, Chicago, IL and New York, NY and the results show its effectiveness in the allocation of resources, in an environment presenting geographical layout of available resources, the local request, access routes and the points where there is traffic blockage.

In the aftermath of a disaster, estimates about its damage must also be obtained in an agile manner and with the highest possible accuracy. Damage caused by floods can be estimated by the analysis of its depth (Poser and Dransch, 2010). Based on this fact, Poser and Dransch (2010) used voluntary information obtained through telephone contacts with victims of the flood that hit the city of Eilenburg, Germany in 2002. This study was aimed at evaluating the feasibility of their application and analyzing the appropriateness of using VGI data for empirical modeling of damage caused by flooding. The results presented show the effectiveness of the approach, but also reveal the need for more detailed studies on the following points: validation of the results for other floods, use of automated methods for quality control and integration with remote sensors.

Closer to this work, Brown (2012) presents a study that evaluates the accuracy of spatial data collected for the mapping of two regions of conservation in New Zealand in 2011 using a public participation geographic information system (PPGIS). This system refers to methods that seek to integrate the knowledge of the local public to inform the planning of land use and support decision-making. The results indicate a competitive economy, the trade-off relationship between participation rates and spatial precision PPGIS, and propose future work to identify processes with the ability to simultaneously increase participation and spatial precision.

As can be seen, SDSSs have been used to assist in the management of disasters. In parallel, VGI has emerged as an important potential source of data and information to mainly assist phases of response and recovery, in the aftermath of disasters. However, to the best of our knowledge, the available literature still lacks studies and research that address the effective integration of these VGI and SDSS to support decision-making in the management of disasters and crisis events.

PROPOSED APPROACH

The proposed approach in this work-in-progress aims at integrating conventional and official sources, qualified and structured data coming from VGI, in order to provide updated and accurate information to optimize and enhance a SDSS to support decision-making processes in the context of disasters. Fig.1 shows the conceptual architecture of the proposed approach.

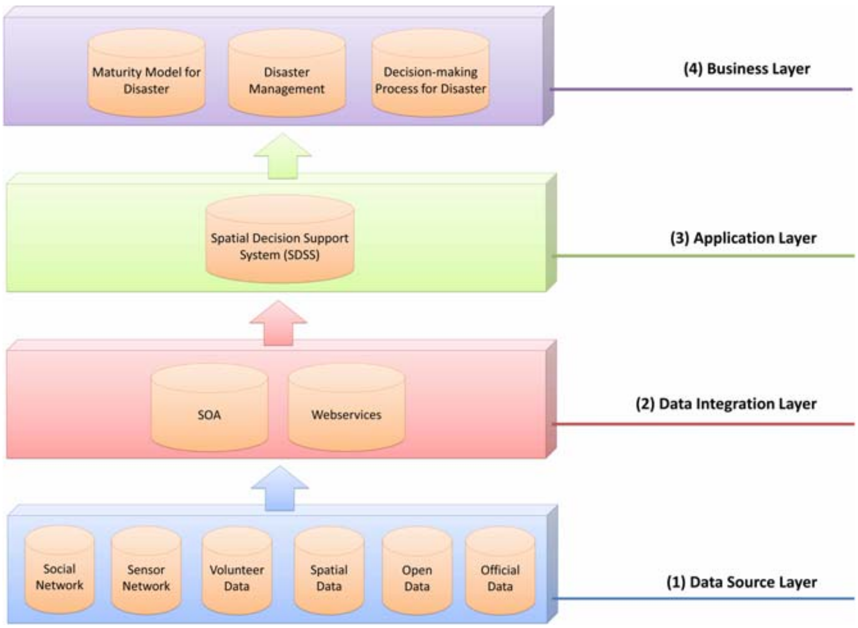

Figure 1. Conceptual architecture of the proposed approach

As shown in Figure 1, the proposed approach consists of four layers. In the base, there is (1) the layer formed by the data sources and information from databases available for access on the Internet. The second layer is the (2) data processing layer, responsible for extracting the data, integrating and making them available for service-based systems placed in the layer above, i.e. the (3) application layer. With these data, the SDSSs offer qualified information to assist the models, methods and processes of the (4) the business layer.

Several tasks must still be completed to develop the proposed approach. These include:

- Develop several processes focused on address the objective of each layers using Business Process Management (BPM), through its language notation, BPMN (Business Process Modeling and Notation);
- A Spatial Data Infrastructure (SDI), with the objective to organize, integrate and deliver data coming from the VGI, will be developed at the data processing layer. This step will be employed techniques, tools and instruments for the development Service Oriented Architectures (SOA).
- An approach for evaluating the quality of VGI data will be developed based on the work of **Fehler! Verweisquelle konnte nicht gefunden werden.**) and **Fehler! Verweisquelle konnte nicht gefunden werden.**). This approach includes the development of new techniques and processes to qualify the volunteer data;
- At the application layer, a collaborative software platform that integrates participatory environmental monitoring and vulnerability communication (Albuquerque and Zipf, 2012) will be used together with a SDSS prototype using a web GIS, a mathematical model to predict the results and a graphical interface to help visualize the results;
- A similar approach adopted by Horita and Barros (2012) will be used in the business layer to develop a maturity model focused in integrating the processes with the disaster management phases to build resilience. In addition, these models may also serve as a strategy to help identify the current state of the resource after the occurrence of an event, and allow the selection of the necessary improvements to the affected society with the goal of recovering a functional state.

Among these activities, the SDI is undergoing final development and validation. The other tasks are presently in early stages of research, analysis, planning and definition.

CONCLUSION AND FUTURE WORK

In recent years, there is an increased attention given to issues related to disaster management, which aims to adopt measures to prevent and reduce the risks of extreme events to become catastrophes. In this context, the processes used to create, store and share information is a key factor to facilitate decision-making. Added to this, the availability and quality of information should also receive special attention because obtaining them with the right people and send them in the right way and at the right time contributes to the effectiveness of the services performed by Emergency Agencies (EA) (Gill and Bunker, 2012).

Thus, the EAs or official agencies must have a mechanism that provides resources to support decision-making. Using a multi-layered architecture, the proposed approach is expected to act broadly in all phases of disaster management building resilience against disasters in the pre-disaster and minimizing the damage on the affected communities in post-disaster phases. For this, the volunteer data integrated with conventional data will serve as data source for the upper architecture layers to provide information for the EAs. The utilization of the volunteer data will be the main contribution of our approach in comparison to existing work (Yongsong et al., 2012; Chen et al., 2011; Poser and Dransch, 2010; Brown, 2012).

Future lines of work will include the development of methods, techniques and processes for decision-making in disaster management, development of methods for structuring and integrating data coming from the VGI to conventional sources, the preparation and development of SDSS and development and validation of a maturity model for the decision-making process in disaster management with the SDSS support.

ACKNOWLEDGMENTS

We would also like to acknowledge the financial support from FAPESP (processes no. 2008/58161-1, 2011/23274-3, and 2012/18675-1), and Prof. Dr. Alexander Zipf for his insightful suggestions and comments.

REFERENCES

1. Albuquerque, J. P. and Zipf, A. (2012). Collaborative information systems for disaster management: Building resilience against disasters by combining participatory environmental monitoring and vulnerability communication. *Alumi seminar natural hazards - researching on natural disasters, civil defense, disaster prevention, and aid*, pages 71–74.

2. Bishr, M. and Janowicz, K. (2010). Can we Trust Information? - The Case of Volunteered Geographic Information. In Workshop at Future Internet Symposium Towards Digital Earth: Search, Discover and Share Geospatial Data.

3. Baharin, S., Shibghatullah, A., and Othman, Z. (2009). Disaster management in malaysia: An application framework of integrated routing application for emergency response management system. In *International Conference of Soft Computing and Pattern Recognition (SOCPAR).*, pages 716 –719.

4. Brown, G. (2012). An empirical evaluation of the spatial accuracy of public participation GIS (PPGIS) data. *Applied Geography*, 34(0):289–294.

5. Chang, K.-T., Wan, S., and Lei, T.-C. (2010). Development of a spatial decision support system for monitoring earthquake-induced landslides based on aerial photographs and the finite element method. *International Journal of Applied Earth Observation and Geoinformation*, 12(6):448–456.

6. Chen, A. Y., Peña Mora, F., and Ouyang, Y. (2011). A collaborative GIS framework to support equipment distribution for civil engineering disaster response operations. *Automation in Construction*, 20(5):637–648.

7. Coleman, D. J., Georgiadou, Y., Labonte, J., Observation, E., and Canada, N. R. (2009). Volunteered Geographic Information: the nature and motivation of producers —. *International Journal of Spatial Data Infrastructures*.

8. De Longueville, B., Luraschi, G., Smits, P., Peedell, S., and De Groeve, T. (2010). Citezens as sensors for natural hazards: a vgi integration workflow. *Geomatica*, 1.

9. Densham, P. J. (1991). Spatial Decision Support System. In *Geographical information systems: principles and applications*, pages 403–412.

10. Elwood, S. (2008). Volunteered geographic information: future research directions motivated by critical, participatory, and feminist GIS. *GeoJournal*, 72(3-4):173–183.

11. Erskine, M. and Gregg, D. (2012). Utilizing Volunteered Geographic Information to Develop a Real-Time Disaster Mapping Tool: A Prototype and Research Framework. In *CONFIRM 2012 Proceedings*.

12. Gill, A. and Bunker, D. (2012). Crowd Sourcing Challenges Assessment Index for Disaster Management. In *AMCIS 2012 Proceedings*.

13. Goodchild, M. F. (2007). Citizens as sensors: the world of volunteered geography. In *Geojournal*, pages 1–12.

14. Goodchild, M. F. and Li, L. (2012). Assuring the quality of volunteered geographic information. Spatial Statistics, 1(0):110–120.

15. Horita, F. E. A. and Barros, R. M. (2012). GAIA Human Resources - An approach to integrate ITIL and Maturity Levels focused on improving the Human Resource Management in Software Development. In *25th International Conference on Computer Applications in Industry and Engineering (CAINE)*, New Orleans, USA.

16. Hosack, B., Hall, D., Paradice, D., and Courtney, J. (2012). A Look Toward the Future: Decision Support Systems Research is Alive and Well. *Journal of the Association for Information Systems*, 13(5).

17. Mediondo, E. M. (2010). Reducing vulnerability ti water-related disasters in urban areas of the humid tropics. In *Integrated Urban Water Management Humid Tropics, Paris, France*, pages 109–127.

18. Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., and Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, se of capacities and strategy for disaster. *American Journal of Community Psychology*.

19. Ostermann, F. O. and Spinsanti, L. (2011). A Conceptual Workflow For Automatically Assessing The Quality Of Volunteered Geographic Information For Crisis Management. In *The 14th AGILE*

International Conference on Geographic Information Science.

20. Poser, K. and Dransch, D. (2010). Volunteered geographic information for disaster management with application to rapid flood damage estimation. *Geomatica*, 64(1):89–98.

21. Rushton, G. (2001). Spatial Decision Support Systems. In Smelser, E.-i.-C. N. J. and Baltes, P. B., editors, *International Encyclopedia of the Social & Behavioral Sciences*, pages 14785–14788. Pergamon, Oxford.

22. Yongsong, Z., Siuming, L., and Kwokkit, Y. (2010). GIS Based Urban Emergency Decision Support Model. In *2010 International Conference on Management and Service Science (MASS)*, pages 1–4.