Use of Cadastral Data for the Development of Spatial Decision Support Systems for Coping with the Consequences of Natural Disasters

Panos Lolonis, Demetrious Rokos and Maria Maragou
Ktimatologio S.A. (Hellenic Cadastre)
288 Mesogion Ave
GR-15562 Holargos-Athens
Greece

ABSTRACT

This paper investigates the potential usefulness of cadastral data to form the core part of databases of Spatial Decision Support Systems [SDSS] that are capable to support decision-makers in dealing with emergency situations, such as earthquakes, floods and fires. Particular emphasis is given on how those data can be used to generate information that is necessary to planners and decision-makers when they cope with natural disasters at every stage of the development of the disaster: before the occurrence (planning and preventive measures), immediately after occurrence (short term measures), and well-after occurrence (medium and long term measures). This investigation is conducted using the Municipality of Magoula, Attica, Greece, as a case study area. This municipality is situated in the greater Athens area and was struck by the earthquake that occurred there in September 1999. Within the scope of the project, we have used cadastral data about the study area and data recorded by the inspection teams in order to set-up a prototype SDSS database that could facilitate planning and decision-making in such a situation. Then, we have used that prototype to generate scenarios and information about typical tasks that are performed during emergency situations. The advantages that are realized from the integration of such data and information technologies are described and assessed, particularly, in comparison with the traditional approaches that are used in such situations.

1 INTRODUCTION

The key to successful management of the consequences of a natural disaster, such as an earthquake, flood, or fire, is the availability of timely and reliable information about: the phenomenon that takes place, the human and natural environment within which it occurs, the demand for emergency services and assistance, and the means that are available for dealing with the emergency situation. Such information, when it is readily available, is taken into consideration by authorities which, depending on the situation, choose the most appropriate actions to respond each time. The value of timely, updated, and reliable information has been widely recognized in the academic circles and constitutes a subject of continuous and rapidly expanding literature (Nishakumari de Silva et al. 1993; Carrara and Guzzetti 1995; Cova and Church 1997; McMaster et al. 1997; Nyerges et al. 1997; National Institute of Building Sciences 1999).

The generation and utilization of the appropriate information for managing natural disasters is not an easy task. Instead, it requires, first of all, availability of an infrastructure for the collection and updating of the appropriate data. In addition, it requires the appropriate technological and institutional infrastructure that is necessary to transfer information to decision-makers and emergency response units. In a large number of cases, of course, such an infrastructure does not exist, and consequently, the authorities in charge do not have the necessary information handy and are not capable of dealing effectively with an emergency situation.

An answer to the above problem of lack of timely information may be provided by spatial decision support systems [SDSS] (Armstrong et al. 1986; Densham and Goodchild 1989; Armstrong et al. 1991). Indeed, those systems are developed to support decision-makers to comprehend the problems that they have to deal with, to generate alternative scenarios for solving them, and evaluate those scenarios. The abundance of information that such systems can provide to decision-makers has already attracted the attention of a significant number of scientists who are interested in the domain of natural disaster management. In fact, there are several proposals in the literature to use such systems in the emergency management (Nishakumari de Silva et al. 1993; French et al. 1999; Miles et al. 1999).

The development of an SDSS for the management of natural disasters requires, first of all, the development of a database containing the data that are necessary to describe the geographical space within which the phenomenon takes place. In addition, it requires availability of software that is necessary for the management and processing of the above data. In this article, we would focus our attention on the database of such a system and, particularly, on how the cadastral data can form the core part of a database of such an SDSS that is suitable for managing the consequences of an earthquake. The data that will be used for illustrating the various concepts refer to the Municipality of Magoula, Athens, Greece, which was struck by an earthquake on September 9, 1999.

This paper is organized in six sections. In the next section, we describe the framework within which decision-making takes place when a natural disaster, such as an earthquake, occurs, at least for the case of Greece. In the third section, we specify the general architecture of an SDSS for managing the consequences of an earthquake. In the fourth section, we describe a number of emergency response activities that take place after the occurrence of an earthquake and how those activities could be supported by an SDSS. In the fifth section, we assess the advantages and disadvantages of using an SDSS in managing such a situation. Finally, in the sixth section, we summarize the conclusions of the work and describe the prospects of incorporating such a system into the decision-making procedure of the natural disaster management.

2 DECISION-MAKING FRAMEWORK FOR EMERGENCY RESPONSE IN GREECE

2.1 **Organizational framework**

In Greece, decision-making for natural disaster management takes place in three distinct levels: national, prefectural, and local. At the national level, the authorities that are responsible for the response to an emergency situation, such as an earthquake, are the central government agencies (e.g. Ministries). At that level, the representatives of various ministries, governmental agencies and organizations convene, assess the situation, activate emergency plans, and determine the activities that would be undertaken by the emergency response units to cope with that situation. In addition, they give directions to authorities at the prefectural and local levels on how to respond, decide about the political measures that would be adopted in the short, medium and long-term, provide highly specialized personnel and equipment to the areas that have been struck, and monitor continuously the progress of the response activities. At the middle (or prefectural) level, the authorities that are in charge, normally, supply personnel and equipment for the management of natural disasters that affect their jurisdiction. Finally, at the local or municipal level, the authorities in charge have a responsibility to provide relief services to those affected by the natural disaster. Such services may include registration of damages, location of settlement facilities for those who cannot reside at their homes, distribution of food and clothing, restriction of access to buildings that are susceptible to collapse and to areas around them that are dangerous to approach.

2.2 **Dis-functionalities of the existing decision-making framework for emergency response**

One of the most important problems that are encountered in the procedures of activating and implementing the emergency response plans within the traditional decision-making framework is that there is no smooth flow of information from the field, where the natural disaster takes place, to the authorities responsible for its management and then back to the field where the emergency response units try to cope with the situation. This difficulty becomes more evident due to the fact that, during the occurrence of a natural disaster, there is an extraordinary demand for emergency services, there is a need for intervention in multiple places simultaneously, there is a disruption of normal activities of the society and, often, there is an overloading of or even damage to the transportation, telecommunications, and utility networks infrastructure. As a result, there is often a social unrest, a large number of complaints from people that have been struck by the disaster, an ineffective distribution of assistance to those in need, and a high social and economic cost for the society. In the earthquake that occurred in Athens, Greece, in 1999, for example, one of the most unpleasant phenomena that was observed was the uneven distribution of the tents to the people who could not stay safely in their homes. Another was the delay in identifying the appropriate temporary settlements where people could stay until better facilities were found. A third problem was the inefficient performance of the inspection teams because of difficulties in their formation, coordination, and logistical support. Finally, another problem was the formation of long lines of people who had been waiting for prolonged periods of time in the municipality halls to submit petitions and obtain relief assistance. Many of the above problems, which had created many intense complaints by people, could be ameliorated, if there was an SDSS that would incorporate cadastral data and would have the capability to register incoming data, process them, and generate the necessary information for decision-makers.

3 AN SDSS APPROACH FOR MANAGING THE CONSEQUENSES OF AN EARTHQUAKE

3.1 **Structure of the SDSS**

The basic components of the architecture of an SDSS for managing the consequences of an earthquake can be the same as those of a typical SDSS (Armstrong et al. 1986; Armstrong et al. 1991). Indeed, an SDSS for emergency response may consist of a database component having relational database management and GIS capabilities, an analytical modeling component for the implementation of models that are relevant to the domain at hand and a user interface for interaction and reporting (tabular, cartographic, textual). The database of such a system, for example, could contain data about the topographic features of the area of interest (e.g. relief, buildings, other human made structures, transportation network, hydrologic network), the geologic characteristics of the area, the cadastral data of the area (land parcels, owners), the population characteristics of the area, and the resources that are available for the emergency response (personnel, equipment). For the case of Greece, for example, the data about the topographic features and land properties are being collected within the scope of the development of the Hellenic Cadastre. The other kinds of data may be provided by the appropriate sources, such as Statistical Service or the emergency response agencies.

The analytical modelling component could contain modules for the determination of the seismic risk of an area (National Institute of Building Sciences 1999), simulation of the expected damages of an earthquake of a given focus and magnitude (National Institute of Building Sciences 1999; Whitman and Lagorio 1999), determination of the areas that are susceptible to landslides (Miles and Keefer 1999), performance of statistical analyses of an earthquake's consequences (O' Rourke and Toprak 1997), and development of plans for the work of the units that are in charge for providing relief assistance.

3.2 **Networking and operation of the system**

In order for the above-described system to operate smoothly during and after the occurrence of an earthquake, it must have been installed in a safe place and be networked in a robust way with all places that need to interact with it (e.g. data entry places, decision-making places, emergency response centers) (Figure 1). The goal of this set-up is to ensure that, immediately after the occurrence of an earthquake, the operators of the system would be able to keep the database always updated by registering the incoming data about demand for services, damages, casualties, and other developments that take place in the struck area.

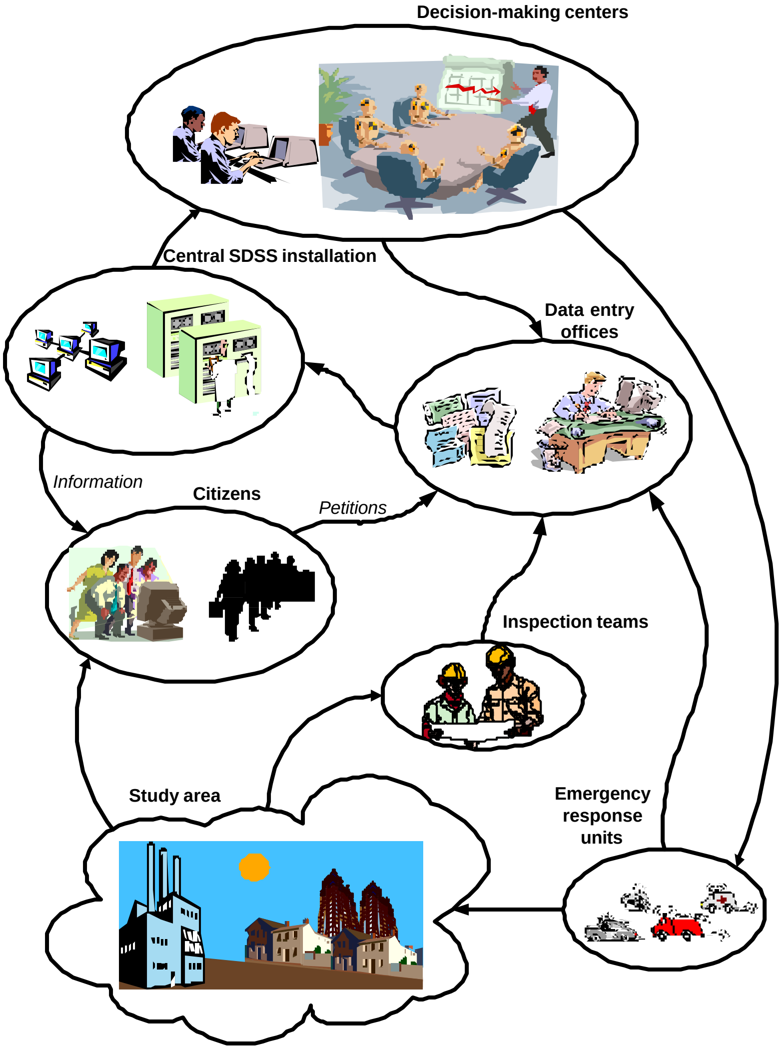

Figure 1: **Conceptual framework for the operation of an SDSS for emergency response**

Thus, the database would contain a comprehensive and reliable picture of the real situation in the field, as the phenomenon evolves and the relief activities progress. The kinds of information that are transferred to each level of the emergency planning and response hierarchy depend on the mission, duties, and responsibilities assigned to authorities of that level. Thus, decision-makers at the high levels of the hierarchy are interested primarily for aggregate information about the damages and demands in order to be able to take all necessary policy measures and mobilize all emergency response units that have a wide area jurisdiction. At the local level, on the other hand, authorities responsible for dealing with the situation are interested primarily for detailed information that would enable them to dispatch inspection teams, teams for securing areas that are dangerous to access, teams that would stop water and electricity supply, if there is a danger for leaks, and personnel that would distribute food and water supplies to those in need. Such information, when the appropriate data are stored in the database of the SDSS, would be available to decision-makers at each level of hierarchy for use.

4 TYPICAL ACTIVITIES THAT WOULD BE SUPPORTED BY THE SDSS

A comprehensive SDSS could support planning and decision-making in all stages of a natural disaster management. Indeed, the system could be used before the occurrence of an event to analyze the risks and potential damages that could happen, if such an event took place. Also, it could be used to develop plans of actions that would be ready for implementation in the event of the occurrence of such a disaster. Secondly, the system could be used immediately after the occurrence of the disaster to enable authorities to activate emergency response plans and coordinate activities of emergency response units. Finally, the system could be used for coordinating, implementing and monitoring all short, medium and long-term relief activities for the population affected.

It must be noted that each of the above areas can be a subject of detailed and comprehensive research. In this paper, however, we would focus our attention primarily on the second stage and we would demonstrate the usefulness of using cadastral data and the SDSS approach in recording and assessing damages caused by an earthquake.

4.1 **Activities for recording damages**

An SDSS that incorporates cadastral data has a great potential to be used for a wide spectrum of activities that are associated with recording the damages from an earthquake.

4.1.1 *Registering petitions for on-site building inspections*

An SDSS can be used to record, in a unified database, the citizen calls and petitions for on-site inspection of their buildings. This part of the database can then be used by those in charge to plan for the work of the primary level inspection teams. In fact, it would be possible to record data, such as date and time of the request, the phone number of the calling person etc., that, are not always recorded within the traditional framework. Yet, these data are very useful in performing inspections and monitoring the progress of the work of the inspection teams. Also, if there is an on-line connection to a cadastral database, it would be possible for the service personnel to connect with that database and cross-reference the correctness of data provided to them by the calling persons (e.g. building addresses, building floors, and building uses). That way, service personnel would have a more accurate picture of the situation at hand.

4.1.2 *Compiling the schedules of the inspection teams*

The availability of an SDSS is extremely useful in planning the work of the inspection teams. Such planning is made, at least for the Greek context, by the supervisors of the teams, who, normally, are engineers employed at the Ministry of Environment, Physical Planning and Public Works and, during emergency situations, are appointed to the local levels that have the need. In the case of the September 1999 earthquake that took place in Athens, Greece, the engineers who were assigned to the technical departments of the affected municipalities were giving lists of buildings to be inspected to the members of the inspection teams. Those lists were sorted either alphabetically by building address, as it was the case with the municipality of New Ionia, or by petition number, as it was the case with the municipality of Magoula. The result of this procedure, however, was that, on the one hand, the inspection teams were wasting time wandering from one place to the other, since the locations of two consecutive buildings on the list were not necessarily close to each other geographically (Figure 2), and, on the other, the team supervisors could not have an accurate perception of the workload that they were assigning to each team each day. Moreover, they did not have a clear idea about the approximate location at which each team was working at a given time and, thus, they could not provide information to citizens who had been waiting for such a team to visit and inspect their building.

Another problem caused by this situation was that the lists given to the teams often contained overlaps and, consequently, two or more different teams were visiting the same location for inspection, wasting, thus, valuable time and energy. Such overlaps in the courses of the teams have been observed even for the work of the teams on the same day (Figures 2 and 3).

The above problems could be solved, if an SDSS that could provide functions for planning the routes to be followed by the teams were used. The criteria that could be used to delineate such routes could be, for example, minimization of total distance traveled by each team and balanced workload among teams. The SDSS capabilities for handling cartographic information through the GIS functions, as well as, and the procedures that those systems incorporate for solving Operations Research problems (e.g. "the traveling salesman" problem) could assist substantially in that direction.

Also, the SDSS could be used to create maps depicting precisely the buildings that must be inspected by a team (Figure 4). Those maps could, then, be given to the members of the inspection teams and to their supervisors in order to facilitate their work.

4.1.3 *Monitoring the progress of the works of recording damages*
The use of an SDSS can have a positive contribution in the area of monitoring the progress in the work of the inspection teams. Indeed, municipal and ministerial officers responsible for coping with an emergency, if they have access to such a system, can have always a comprehensive picture of the progress of the works and the magnitude of the damages (Figure 5). Thus, using reliable data, they could direct more effectively the work of the inspection teams, revise work plans and schedules of the teams, and launch activities that would solve problems. For example, by doing relatively simple spatial analyses (Figure 6), those in charge could identify varying degrees of damage in various neighborhoods and, consequently, give priority to those neighborhoods that have been struck severely and have the largest need for immediate inspections. Similarly, the authorities in charge, could analyze maps depicting buildings that are prone to collapse and order security crews to go there and restrict access not only to those buildings but also to the dangerous areas around them (Figure 7).

4.4 **Supporting the provision of services to the public**

The availability of an SDSS could facilitate greatly the demand for informing efficiently the people affected by an earthquake. Indeed, by entering the results of the inspection in the SDSS database and having the proper communications network, authorities could reduce bureaucracy and monitor better the distribution of the relief assistance to those in need. In addition, having such a system operational, it is possible to inform the public about the schedules of the inspection teams. Thus, people who have asked for an inspection to be made at their houses would be able to better schedule their activities and would not be forced to stay at their homes waiting, in vain many times, for the arrival of the inspection teams. During the Athens earthquake in September 1999, for example, these problems, that is, the inability of authorities to provide effective emergency assistance to people, as well as, to inform them about the schedule of the inspection teams, were observed and caused a series of complains.

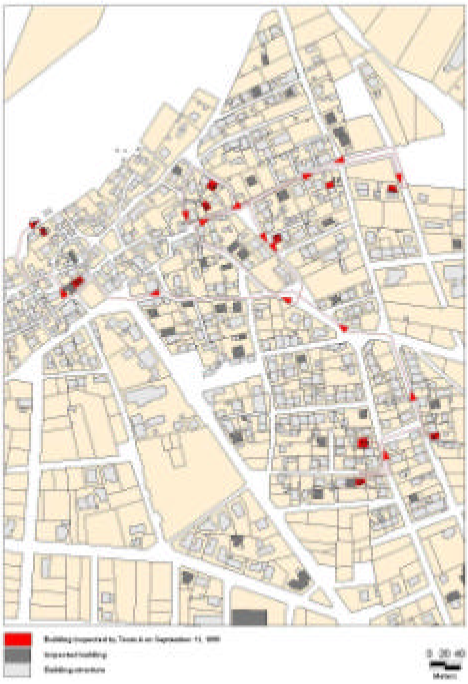

Figure 2: **Route of Inspection Team 1, Magoula, Athens, Greece**

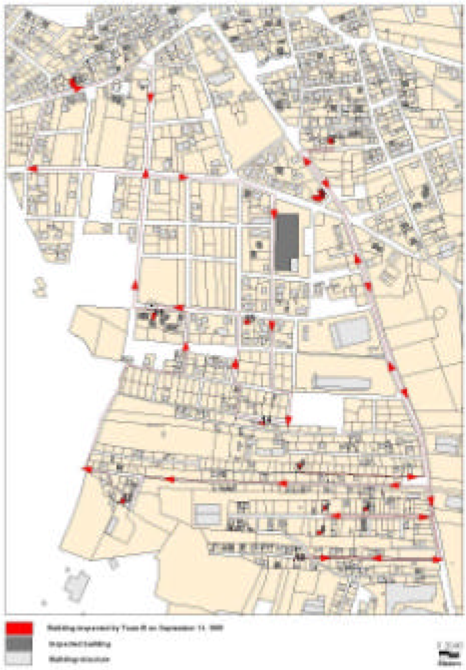

Figure 3: **Route of Inspection Team 2, Magoula, Athens, Greece**

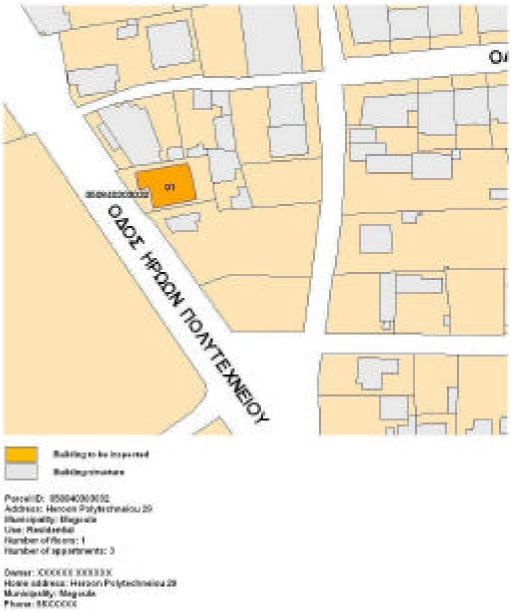

Figure 4: **Cadastral diagram of a building to be inspected for potential damages**

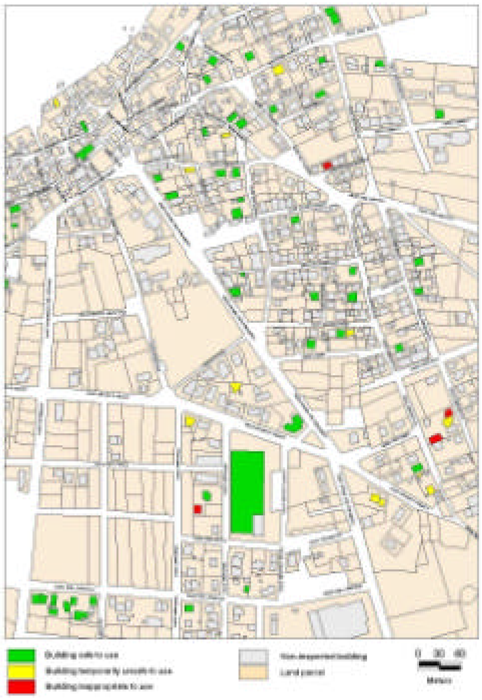

Figure 5: **Results of the Inspection**

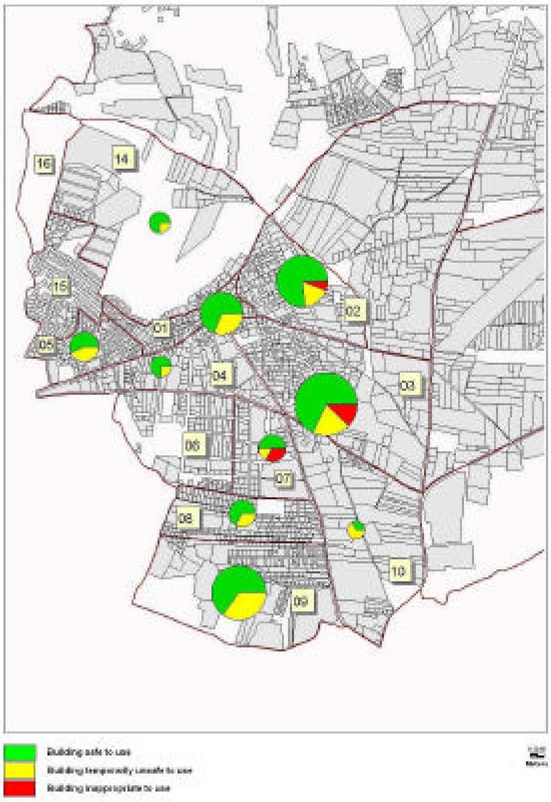

Figure 6: **Percentage of inspected buildings classified according to the outcome of the first inspection**

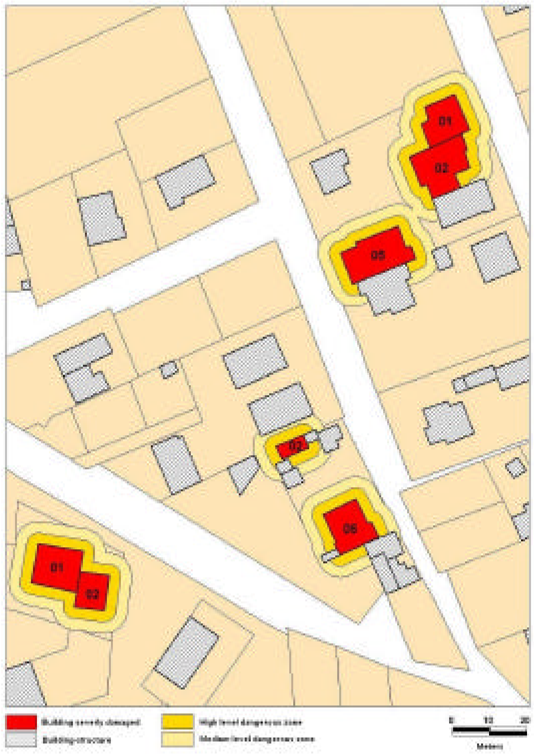

Figure 7: **Buffer zones around buildings damaged by the earthquake**

5 COMPARISON OF THE SDSS APPROACH WITH TRADITIONAL APPROACHES

The main advantages of using SDSS in managing the consequences of earthquakes are: their flexibility in recording and processing data, their computing power, and their ability to forward data and information to the various levels of the decision-making hierarchy. Indeed, an SDSS, which is based on cadastral data, can provide a substantial portion of the informational background that decision-makers need, without the need to collect, organize, and certify additional data. The digital map that contains properties and buildings, for example, as well as, the datasets that contain information about owners and rights, contain a substantial portion of the information that is necessary to deal with earthquake management. Without this kind of information, such management becomes cumbersome and, as a result, there is lack of coordination of activities among the involved agencies and ineffective implementation of relief measures and policies.

In addition to their capability to provide timely and reliable information, SDSS are characterized by their capability to be used in the generation of alternative scenarios for coping with a natural disaster, not only before the occurrence of the phenomenon but also afterwards. These scenarios could be used, on the one hand, to take preventive measures in order to minimize loses from an upcoming disaster and, on the other, to take the necessary measures to reconstruct the affected areas after the occurrence of the disaster. Those scenarios have the characteristic that are based on reliable data and explicit assumptions and, consequently, can provide decision-makers with a clear picture of the expected consequences in case of the occurrence of a natural disaster. This specificity in analysing the consequences of a natural disaster and the adopted policy measures differentiates greatly the decision-making model that emerges within the SDSS approach, as opposed to models that emerge within traditional approaches. Indeed, in the latter case, decision-makers rely primarily on the unclear, subjective, and, often, difficult to document opinions of experts to make decisions.

Of course, the use of SDSS in decision-making is not a straightforward act because it requires modern technological infrastructure (computers, telecommunications networks, and software), specialized personnel, and financial resources. However, with the rapid decline in the prices of computer technologies, the continuous adoption of those technologies in various domains of the society, and the increasing availability of data make the vision of developing and operating such SDSS more and more feasible.

6 CONCLUSIONS AND PERSPECTIVES

In this paper, we have explored the possibility of using cadastral data, as a spatial data infrastructure for managing, within the SDSS framework, the consequences of natural disasters, such as earthquakes. Specifically, we have demonstrated various activities that could be supported using such data and such systems. Particular emphasis was given on supporting activities that take place immediately after the occurrence of an earthquake and aim at recording damages and providing relief of those struck by the disaster. The main concepts of the paper were illustrated using real data from the municipality of Magoula, Athens, Greece, which was struck by an earthquake in September 1999.

It must be noted, however, that the operational implementation of an SDSS in a real life environment requires several steps to be taken. These steps are related to the development of an appropriate decision-making framework, the installation of the appropriate IT infrastructure, the collection of the appropriate data, and the securing of the necessary scientific personnel for the operation of the system. All these prerequisites currently are inhibiting factors to the development of such an operational system.

Of course, in a more general context, such a system, could be used not only for managing the consequences of an earthquake but also the consequences caused by other kinds of natural disasters, such as floods and fires. Those phenomena have similar characteristics with the earthquakes and, in addition, occur more frequently. This way, authorities, having such tools at their disposal, could plan better their activities, implement the policy measures more effectively, distribute the development and operating costs over a wider range of applications, and serve better the public.

7 DISCLAIMERS

The views presented here are those of the authors and do not reflect necessarily the official views of their employer.

8 REFERENCES

Armstrong, M., P. Densham, and G. Rushton (1986), Architecture for a microcomputer based spatial decision support system, *Proceedings of the Second International Symposium on Spatial Data Handling,* Williamsville, NY, USA, pp. 120-131.

Armstrong, M., G. Rushton, R. Honey, et al. (1991) Decision support for regionalization: a spatial decision support system for regionalizing service delivery systems, *Computers, Environment and Urban Systems* **15** pp. 37-53.

Carrara A. and F. Guzzetti (1995) *Geographical Information Systems in Assessing Natural Hazards.* Kluwer Academic Publishers, Boston, USA.

Cova, T. and R. Church (1997) Modeling community evacuation vulnerability using GIS, *International Journal of Geographical Information Science* **11** pp. 763-784.

Densham, P. and M. Goodchild (1989) Spatial decision support systems: a research agenda, *Proceedings, GIS/LIS'89,* Bethesda, MD, USA, pp. 707-716.

French, S., K. Papamichail, J. Ehrhardt, et al. (1999) RODOS: Decision support for nuclear emergencies. A demonstration, *Proceedings of the 5th International Conference of the Decision Science Institute,* Athens, Greece, pp. 434-438.

Mc Master, R., H. Leitner, and E. Sheppard (1997) GIS-based environmental equity and risk assessment: Methodological problems and prospects, *Cartography and GIS* **24**, pp. 172-189.

Miles, S., D. Keefer, and C. Ho (1999) Seismic Slope-Performance Analysis: From Hazard Map to Decision Support System, Paper presented in the 5th U.S. Conf. Lifeline Earthquake Engineering, Seattle, WA, USA.

National Institute of Building Sciences (1999) *HAZUS-Natural Hazard Loss Estimation Methodology,* National Institute of Building Sciences, Washington, DC, USA) (http://www.nibs.org/nibshome.htm).

Nishakumari de Silva, F., M. Pidd, and R. Eglese (1993) Spatial Decision Support Systems for Emergency Planning: An Operational Research / Geographical

Information Systems Approach to evacuation planning, *Proceedings of the 1993 Simulation Multiconference on the International Emergency Management and Engineering Conference*, San Diego, USA.

Nyerges, T., M. Robkin, and T. Moore (1997) Geographic Information Systems for risk evaluation: Perspectives on applications to environmental health, *Cartography and GIS* **24**, pp. 123-144.

O' Rourke, T. and S. Toprak (1997) Using GIS to assess water supply damage from the Northridge earthquake, *Proceedings from the NCEER-INCEDE Workshop on Earthquake Engineering Frontiers in Transportation Facilities* Buffalo, NY, USA (http://nceer.eng.buffalo.edu/bulletin/97/jul97n3.html).

Whitman, R. and H. Lagorio (1999) The FEMA-NIBS methodology for earthquake loss estimation, National Institute of Building Sciences-NIBS, Washington, DC, USA) (http://www.nibs.org/hazus4a.htm).