SDI CONCEPTUAL MODELING FOR DISASTER MANAGEMENT

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ABSTRACT:

One of the main challenges of disaster management concerns to proper management of information. In more details, while most of the information required for disaster management has spatial component or location, current studies show that there are different problems with collection, dissemination, access and usage of spatial data/information for disaster management. The mentioned problems become more serious during disaster response with its time-sensitive and dynamic nature where reliable and up-to-date information must be available to decision-makers and managers.
It is suggested that Spatial Data Infrastructure (SDI) as an initiative in spatial data management can facilitate disaster management by providing a better way for managing spatial data. In order to investigate this suggestion, a research project was conducted in Iran. In this research, an SDI conceptual model and a web-based system were developed for disaster management. The developed model and system were tested in an earthquake disaster response manoeuvre with collaboration of different organizations from disaster management community. The results of the manoeuvre showed that a web-based system using an SDI framework facilitates disaster management and also improves its quality. This paper aims to describe the outcomes of the research project.

1. INTRODUCTION

Disasters have long been presented a tragic disruption to the humans' lives, properties, infrastructure, economy, capital investment and development process. As a result, different nations around the world have had particular attention to managing disasters as part of their activities. The recent huge and unexpected disasters such as the earthquake and Tsunami in the Eastern Asia (2004) or the attack to World Trade Center and Pentagon on September 11, 2001 have increased worldwide attention to disaster management. Disaster management is a cycle of activities beginning with *mitigating* the vulnerability and negative impacts of disasters; *preparedness* for responding operations; *responding* and providing relief in emergency situations such as search and rescue, fire fighting, etc.; and aiding in *recovery* which can includes physical reconstruction and the ability to return quality of life to a community after a disaster.

Information is fundamental requirement for managing disasters, while most of the information required for disaster management has spatial component or location (Amdahel 2002 and Cutter et. al 2003). However, current studies show that there are considerable problems with managing spatial information/data required for disaster management with respect to data collection, dissemination, access and usage (SNDR 2002 and Jain and McLean 2003).

Such problems become more serious during disaster response phase with its dynamic and time-sensitive nature.
Disaster response is dynamic and decision-makers need to be updated on the latest emergency situation. Disaster response is also time-sensitive with little allowance on delay in decision-making and response operations. Therefore, any problem or delay in data collection, access, usage and dissemination has negative impacts on the quality of decision-making and hence the quality of disaster response. With this in mind, it is necessary to utilize appropriate frameworks and technologies to resolve current spatial data problems for disaster management.

It is suggested that Spatial Data Infrastructure (SDI) as an initiative in spatial data management, along with appropriate web-based tools, can be used as an integrated framework for resolving current problems with spatial data.
This paper aims to describe the development of an SDI conceptual model and a prototype web-based system that facilitates spatial data collection, access, dissemination, management and usage for proper disaster management. This is based on an ongoing research and case study in Iran which investigates the role of SDI and web-based GIS in disaster management with emphasis on the response phase.

2. COLLABORATION IN SPATIAL DATA MANAGEMENT

Different organizations (such as Fire, Medical and police departments; Red Cross Society; and Utility Companies) collaborate in disaster management due to the diversity of activities during a disaster, particularly in the response phase. Inter-organizational coordination of disaster response operations and controlling the emergency situation is generally conducted through an Emergency Operation Centre (EOC) where the representatives of involved organizations are gathered. To achieve coordination, each of the representatives in the EOC is in touch with its own organization in order to update itself and other EOC members about emergency situations.

As mentioned earlier, decision-makers in involved organizations and the EOC together with emergency workers need reliable and up-to-date spatial data for proper disaster response. Road networks, buildings, hospitals, fire stations, medical emergency stations, utility networks, damaged areas, closed roads, permit controls, burning areas, and damaged facilities and their associated attribute data are some examples of required datasets for disaster response. Some of these datasets need to be collected and kept up-to-date before the occurrence of a disaster (such as topographic maps, urban base maps and utility network maps) and some parts of datasets need to be regularly collected and updated after the occurrence of a disaster in aftermath of emergency situations (such as damaged areas, closed roads and burning areas).

However, because of the variety of required datasets for disaster response, no individual organization can collect and keep up-to-date all of its required spatial datasets before and particularly after occurrence of disasters. Also, just one organization (being assigned as responsible for data collection) cannot collect and update all of the required datasets for all involved organizations. Therefore, collecting and updating datasets for disaster response should be done jointly, through a collaborative effort and partnership of organizations in spatial data collection/production and sharing.

Organizations involved in disaster management community are the main stakeholders for producing, updating and maintaining required spatial datasets for disaster response. If each of the involved organizations collects some part of the required spatial datasets for disaster response (relevant to its tasks) during everyday business and disaster response, required spatial datasets can always be available to decision-makers. If this data is shared and exchanged, then datasets are accessible to the wider disaster management community.

Although a collaborative effort for spatial data collection and sharing can resolve the problem with collection, access and dissemination of required spatial data for disaster response, however, different researches on collaborative efforts for data collection and sharing (Rajabifard and Williamson 2003; McDougall et al. 2002; Nedovic-Budic and Pinto 1999) show that there are different technical, institutional, political, and social issues that create barriers for such participation to occur. With this in mind, by creating an environment in which such issues are taken into consideration and resolved and consequently the access of decision-makers to spatial data is facilitated, the concept of partnership in data production and sharing can become a reality. In this respect, Spatial Data Infrastructure (SDI), as an initiative in spatial data management with related concepts and models, can be used as a framework for creating such an environment and consequently, facilitating disaster response.

3. SDI AND ITS ROLE IN DISASTER MANAGEMENT

The need to spatial data in different applications particularly for knowledge-based sustainable development on one side and various problems with production, dissemination, access and usage of these kind of data on the other side have resulted Spatial Data Infrastructure (SDI) initiatives around the world.

SDI can be defined as initiative intent to create an environment in which all stakeholders can cooperate with each other and interact with technology to better achieve their objectives at different political/administrative levels (Chan *et* al. 2001). SDI is fundamentally about facilitation and coordination of the exchange and sharing of spatial data between stakeholders in the spatial data community.

SDI initiatives have evolved in response to the need for cooperation between users and producers of spatial data to nurture the means and environment for spatial data sharing and development (Coleman and McLaughlin, 1998).

An SDI encompasses the policies, access networks and data handling facilities (based on the available technologies), standards, and human resources necessary for the effective collection, management, access, delivery and utilization of spatial data for a specific jurisdiction or community (Rajabifard et al 2002). Based on these components, Figure 1 illustrates a basic SDI model. As the model shows (Figure 1), appropriate accessing network, policies and standards (which are known as technological components) are required for facilitating the relation between people (data providers, value-adders and decision-makers in disaster management community) and data.

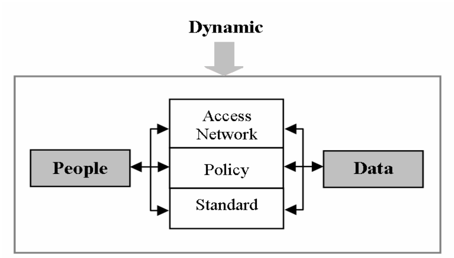

Figure 1. SDI Components (Rajabifard et. al 2002)

By clarifying each of these core components, an SDI conceptual model can be developed which can contribute to facilitating the availability, access and usage of spatial data (Davies, 2003 and Mansourian, 2005).

With respect to above description, by clarifying and expanding SDI core components with respect to disaster management requirements, an SDI conceptual model can be developed for resolving current problems with spatial data during disaster management.

Considering Geographical Information System (GIS) as underpinning technology for SDI and its role in facilitating data collection and storage as well as facilitating decision-making based on spatial data processing and analysis, GIS is a good tool for improving decision-making for disaster management. In this respect, a web-based GIS can be a good tool for facilitating disaster management due to need to high interaction between decision-makers in disaster management community, particularly during disaster response.

Therefore, a web-based GIS using SDI can facilitate disaster management by providing a better way of spatial data collection, access, management and usage.

4. CASE STUDY

In order to investigate the role of SDI and web-based GIS in facilitating and improving disaster management, a case study was conducted in Iran. Two main outputs of this case study were development of an SDI conceptual model and web-based GIS for disaster management.

Main steps of this research included:

- Assessing disaster management community from different technical and non-technical perspectives with respect to spatial data,
- Development of an SDI conceptual model, based on the results of the assessment,
- Development of a web-based GIS based on the SDI conceptual model,
- Conduction of a pilot project to test the developed SDI conceptual model and prototype web-based GIS and
- Refinement of the SDI conceptual model and the developed prototype web-based system.

At the first stage disaster management community was assessed with respect to spatial data and those technical and non-technical factors that affect development of SDI. Results of organizational assessment showed that development of SDI for disaster management in Iran is a matter of *social*, *technical and technological*, *political*, *institutional* and *economical* challenges. Based on the results of organizational assessment, at the second step, the SDI conceptual model was developed by examining and expanding each of the components of SDI within the context of disaster response. This model is a framework that can create an appropriate environment for participation of organizations in collection, sharing and usage of spatial data for disaster management.

At the third step, based on the SDI conceptual model, a prototype web-based system using GIS engine with a user-friendly interface was developed as a tool for spatial data collection, sharing and analysis.

At the fourth step, a pilot project was conducted. This pilot was conducted in Tehran, the capital of Iran with collaboration of different organizations from disaster management community in order to test the web-based system and developed SDI conceptual model. Considering the important role of awareness for SDI development, increasing the awareness of disaster management community on advantages of developed system that works using SDI, was another aim of this pilot project. This pilot project was about responding to an assumed earthquake in Tehran.

At the last step, based on the results of the pilot project, the developed prototype web-based system and the developed SDI conceptual model were refined. Following the developed SDI conceptual model and the developed web-based GIS for disaster management as well as the results of the pilot project are described in brief.

4.1 Development of an SDI Conceptual Model for Disaster Management

As was described earlier the five core components of SDI establish the relation between people and data through technological components (standards, policy and access network) (Figure 1). In light of standards and policy components, producers can produce data free of duplication of efforts and share them to be accessible and applicable for users (including value-adders and end-users). Value-adders can access and enrich data for end-users, other value-adders, and their own use; and end-users can easily access and use data during their business. This is done through the access network component, which provides a physical environment for dissemination of data and access for use.

Figure 2 shows the schematic presentation of the developed SDI conceptual model for disaster response that is resulted by expanding SDI core components. This SDI conceptual model is a framework that defines a clear regime for partnership of organizations in spatial data production and sharing.

As Figure 2 shows, with respect to people, three categories were identified including data providers, value-adders, and end-users (decision-makers and emergency workers) and for each category responsible organizations and their responsibilities were clarified.
Two important subjects that can be described in this context are:

- Mapping agencies, particularly National Mapping Agencies that are not currently a member of the disaster management community, should be considered as a member and appropriate Standard Operation Procedures (an organizational directive that establishes a standard course of action for disaster response) should be prepared for them and
- Training and employing volunteer bodies for data collection and analysis is essential and very beneficial as similar bodies are trained for search and rescue operations.

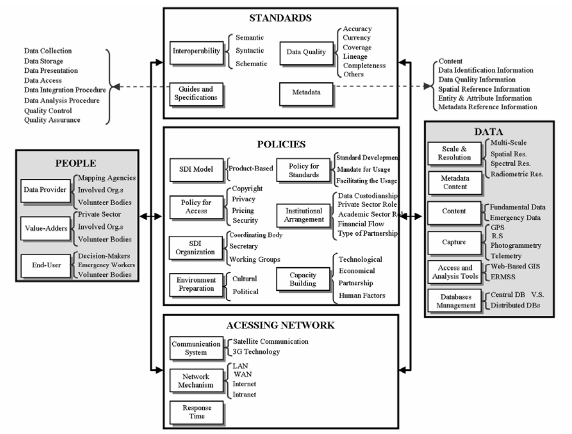

Figure2. Schematic presentation of the developed SDI conceptual model for disaster response

With respect to standards component, interoperability, metadata standards, data quality standards, and guides and specifications were identified as four important requirements. Interoperability is an important subject that needs to be emphasized in the context of standard component. Due to the time-sensitive nature of disaster response, produced data should be easily applicable in data analyzers system and also integratable with each other for real-time use. No time should be wasted by data analyzers in preparing data (such as transferring format, structuring, and referencing data) to be applicable in their systems. Therefore, there should be no heterogeneity between data providers', value-adders' and end-users' systems. In this respect, there are three sources of heterogeneity that should be brought into consideration during standardization including semantic, syntactic and schematic heterogeneities. Semantic heterogeneity is relevant to differences in definition, primitives, structure and coordinate system of data layers. Syntactic heterogeneity relates to difference in software, hardware, DBMS, and data format which is used by data provider and analyzer. Schematic heterogeneity relates to differences in data model, data coding, and topology.

Metadata, which is data about available and accessible data layers, is another important component of standards particularly for data analyzers. Metadata needs to exist so value-adders and end-users can easily identify access and utilize those data layers that best match their requirements and also understand the quality and reliability of datasets. Having quality standards (as another standards requirement) and producing data based on them, available data are reliable for disaster response. Guides and specifications that describe how to do a task and make the procedures standard are also essential for different tasks related to spatial data. Figure 2, describes different subsets that are identified to be required for each of the standards components.

Policy is a very important component as it can facilitate participation of organizations in SDI initiative. These are appropriate SDI policies that can create incentive and willingness in organizations and encourage them to keep their long-term partnerships. SDI development model, institutional arrangements, policy for standards, policy for access, environment preparation, capacity building, and SDI organization were identified as seven important requirements in the context of policies.

As Figure 2 shows, regarding the SDI development model, a product-based approach (Rajabifard, et al., 2002) was selected for SDI development because of current technological capacity of disaster management community and current status of required spatial data for disaster management with respect to availability. In order for organizations to participate in the SDI initiative, a formal mandate is essential. However, beside formal mandate, policies are required to facilitate participation of organizations in data production and sharing by removing barriers and also increasing the incentive and willingness of organizations to form partnerships. In this respect policy for access, environment preparation, capacity building and institutional arrangements are four categories of required policies that can facilitate participation of organizations in SDI initiative.

Clarifying and approving copyright and privacy laws and related concerns for spatial data are important tasks with respect to policy for access that should be considered. Clarifying data pricing and security concerns for data access are other factors in this category should also be emphasized.

Capacity building should be conducted at all three levels of the disaster management community. In this respect, economical and technological capacity building at the group and organizational levels and skill formation and increasing awareness at the individual level are important subjects that should be emphasized. In addition there is a need to increase the capacity of partnerships between private, academic and governmental organizations.
Cultural aspects of data sharing and providing an appropriate political environment are important tasks that should be noted in the context of environmental preparation. Institutional arrangements with respect to data custodianship, financial flow, type of partnership, and role of private and academic sectors need to be considered to facilitate partnerships by removing institutional barriers.

Having policies with respect to the practical utilization of standards by data providers and value-adders in order to meet interoperability of systems and integration of datasets with accepted quality is another important item that should be noted.

An appropriate organization for SDI is required to coordinate and follow SDI activities. A coordinating body, secretary and working groups are three tires which are recommended for this organization. The SDI coordinating body should have a peak position to be able to mandate relevant SDI approvals to other participants.

Sharing data relies on the physical relocation of data from providers and value-adders to users. Three major factors that need to be considered with respect to the accessing network are communication system, network mechanism and response time.
With respect to data, scale and resolution, content, capture (tools and mechanisms), access and analysis tools, database management, and metadata were identified as important factors and each one has been clarified (Figure 2).

Multi-scale datasets are required for disaster management due to the need for different details of information for different kinds of decisions. Satellite and aerial imageries with different spatial, spectral (e.g. Visible, thermal and infrared) and radiometric resolutions are required for collecting different kinds of data. With respect to database, considering current capacity and cultural situation for disaster management community, designing the system based on a central database has been recommended. Having a central database, better control (with respect to participation situation and progress of database establishment) can be applied on production of datasets by organizations and hence creation of a database. Utilizing diffusion of SDI in disaster management communities and using a distributed database and GIS system can be a better alternative to the current recommended central database structure.

4.2 Development of a Prototype Web-based System for Disaster Management

A prototype web-based system using GIS engine with a user-friendly interface was also developed as a tool for spatial data collection, sharing and analysis (Mansourian 2005). It was designed based on a combined model of thick-client and thin-client architectural models (two different architectural models for developing web-based GIS; Peng and Tsou, 2003).

Figure 3 shows the overall structure of this system. As Figure 3 shows the web-based system is based on five core components including user interface for clients to enter, update, access and analyze data, web server and application server for getting the clients' request and sending it to map server, map server for data analysis and query based on clients' request, data server for retrieving data from a database and serving them to map server for analysis, and database that includes spatial data. Based on the developed SDI conceptual model, different technical specifications were considered for the developed web-based system (Mansourian 2005).

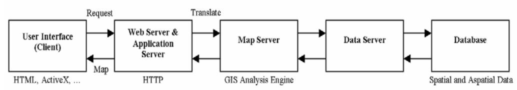

Figure 3. Core components of web-based System and their relations

4.3 Pilot Project

The pilot project was conducted in Tehran, the capital of Iran, based on the developed SDI conceptual model and the developed web-based system. This pilot project was about responding to an assumed earthquake in Tehran.

In this pilot, a manoeuvre scenario was defined with which involved organizations could experience a coordinated disaster response based on spatial data sharing and analysis. During the manoeuvre, each organization updated its own spatial datasets within responding operations, and shared them with the disaster response community. Therefore each individual responding organization had access to required spatial datasets to integrate and analyze their datasets using GIS functionalities to support their own decision-making for disaster response.

The results of the pilot project also showed that a web-based GIS using an SDI framework:

- Facilitates and improves decision-making process,
- Facilitates and improves coordination of activities and
- Reduces the response time span to at least 40% of the currents situation.

5. CONCLUSION

The results of the case study and its pilot project showed how useful a web-based system that works using SDI can be for effective and efficient disaster response management. Using SDI framework, reliable and up-to-date spatial data for disaster response is always available and accessible for decision-makers. A web-based system is also an appropriate tool which can be used for data sharing and data analysis and consequently coordinating and controlling emergency situation.

The effectiveness and efficiency of the system can be interpreted by different elements, however, in this research facilitating decision-making process, facilitating coordination of activities and reducing the response time duration were chosen as three evaluating factors.

It should be noted that such SDI conceptual model and web-based system facilitates and improves not only disaster response, but also other phases of disaster management including mitigation, preparedness and recovery.

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