GEO-INFORMATION SUPPORT IN MANAGEMENT OF URBAN DISASTERS

Sisi Zlatanova, Peter van Oosterom & Edward Verbree

Abstract

Within the management of urban disasters, geo-information systems (GIS) are used in any of the phases of mitigation, preparedness, response and recovery as most of the required data have a spatial component. Examples of GIS-based decision support systems on mitigation are found in simulation models of floods and earthquakes. In the preparation phase all kinds of spatial observations and models can be used to predict which areas will be threatened. To prepare for adequately responding in case of an actual disaster, these systems are capable of developing realistic scenarios that are used within training and virtual reality (VR) systems. During the actual response phase geo-information is used intensively: for getting an impression of the environment, for routing, for obtaining up-to-date information about the actual situation, etc. In the recovery phase, there is often a high public and political interest to judge the situation - comparing the pre- and post-disaster situation - and to set priorities for the rebuilding.

Despite this potential of GIS-based support for urban disaster management, the use of these systems or even the utilisation of geo-information itself is still very limited in countries in Africa, Asia and Latin America. The emergency management is usually done with paper maps that are seldom up-to-date. Useful systems to support decision makers in any of the phases of disaster management are nearly completely lacking. To improve the work of decision makers and rescue teams, different premises have to be archived in relation to: meta-information to provide insight on the availability and usefulness of the geo-information itself, the technical equipment of the rescue teams (i.e. communication devices and field computers), and the up-to-date information from the affected areas (images, observations, reports). This paper suggests a framework for "urban and urgent" disaster management to facilitate the work of police forces, fire departments, ambulances and government coordinators in disaster situations by extending and improving the utilisation of geo-information. Within a pre-disaster situation, geo-information support management further can assist planning for prevention and mitigation.

Keywords: *Geo-Information, Geo-DBMS, Interoperability, Positioning, Urban Disasters*

1. INTRODUCTION

The tsunami in South Asia at the end of 2004 has again demonstrated that the emergency response sector needs to be extended, and more sophisticated means for facing natural, but also man-made and industrial risks are needed. This issue has gained a high priority on the political agenda in many governments, e.g. in Europe (FABBRI and WEETS, 2005), North America (AMBROSE, 2005), Australia (HUNTER, 2005), but still insufficient attention is paid in developing countries. For many countries in Africa, Asia, and Latin America, the cost is the major impediment. Therefore, new cost-effective systems have to be developed that allow different service units to operate together (using open source and standards based systems[1]) in any critical situation. The cooperation across different sectors involved in disaster management - such as the health sector, police and fire brigade, civil protection and development - has to be extended toward cross-sector systems and cross-sector services. The final goal is limiting the number of casualties by a) facilitating the work of the emergency services, making it safer and more efficient; b) ensuring citizens (in the disaster affected area and the surrounding area) the receipt of high-quality care, on-time information and instructions; and c) preventive urban planning.

Amongst all the possibilities, geo-information is becoming a key issue in the achievement of these

[1] Please see: http://www.refractions.net/white_papers/oss_briefing/2005-02-OSS-Briefing.pdf, accessed May 2005, for a neat discussion on open source and standard based GIS where the source code is available for modification and redistribution by the general public.

goals. Geo-information collections consisting of maps, images, plans, and a variety of schemas are already widely used in many of the disaster management phases, e.g. mitigation, preparedness, recovery (ZLATANOVA and HOLWEG 2004; PUNDT, 2005). However, the use of geo-information in the urgent response phase is still limited and this is the case not only in developing countries. Several major problems can be identified[2]:

- Much of the information in developing countries is outdated or insufficient.
- Most of the data available are stored, and managed by organisations that normally have distinct authorisations. In normal circumstances these organisations operate independently of each other. They are not designed to work in a multidisciplinary environment, and their systems are hardly interoperable.
- Geo-data is managed by different systems (mostly GIS) with specific details, resolutions, object definition, schemas and formats. Exchange of data is based on creating a copy of data sets in a specific format that is readable by the systems of the other party. Preparations of such files may require days and storage space of several hundreds megabytes. The complexity is increasing if geo-data have to be integrated with other graphic information such as construction plans (usually in CAD format).
- Technology for ground field update is completely missing. The countries rely on satellite images (VOIGT et al., 2005) of which the scale is often too small for certain details (conditions of houses, people and environments).
- Often, the hardware equipment in developing countries is old, with limited memory and storage capacity. Telecommunication and Internet networks are of narrow bandwidth and not available everywhere.

It should be mentioned that the resolution of satellite data is ever increasing and through international agreements, such as "The Charter on Space and Major Disasters"[3], the derived information can be used free of charge in case of natural or man-made disasters (VON DER DUNK, 2005). This increases the potential of satellite data in the case of disaster management in urban areas of developing countries. However, this is a topic in itself and in this paper the focus will be more on the use of geo-information.

Insufficient technical capabilities create difficulties in developing countries, but the general problem is the information. The current development of Geo-Information Infrastructures (GIIs) at several levels based on open standards is expected to drastically improve this situation. In addition to lack of data, the limitations are often (as all over the world) related to the meta-information or the "information" about the information, i.e. finding the most appropriate data and making these data available. There is also lack of interoperability, i.e. the ability of systems to operate together effectively, which in existing situations delays systems being connected and updated without massive investments (often unaffordable for organisations). This results into a partial automation capable of dealing with dedicated tasks, but unable to deliver needed information to multi-user groups.

This paper addresses the developments in open source, open standards based, low cost geo-management solutions with the focus on the response phase in disaster management.

2. THE USERS AND THE SYSTEM

Disaster management is a discipline that involves a wide group of users. Two general categories of users can be distinguished, i.e. teams working in wireless environments in the field (indoor or outdoor), and users working in wired environments (indoor) in management centres and related institutions (ZLATANOVA and HOLWEG, 2004). The users in wired environments can be subdivided further into users working in Virtual Reality (VR) environments (training, simulation, controlling, analysing and managing), Desktop environments (advising on particular situations and occasions) and accessing information through the Web (wide audience, press, etc.), see figure 1.

In coordination centres various pieces of information have to be assembled for decision-making.

[2] The information presented in this publication is the result of a research programme called "Sustainable Urban Areas" carried out by Delft University of Technology.

[3] Please see: http://www.disasterscharter.org, accessed May 2005

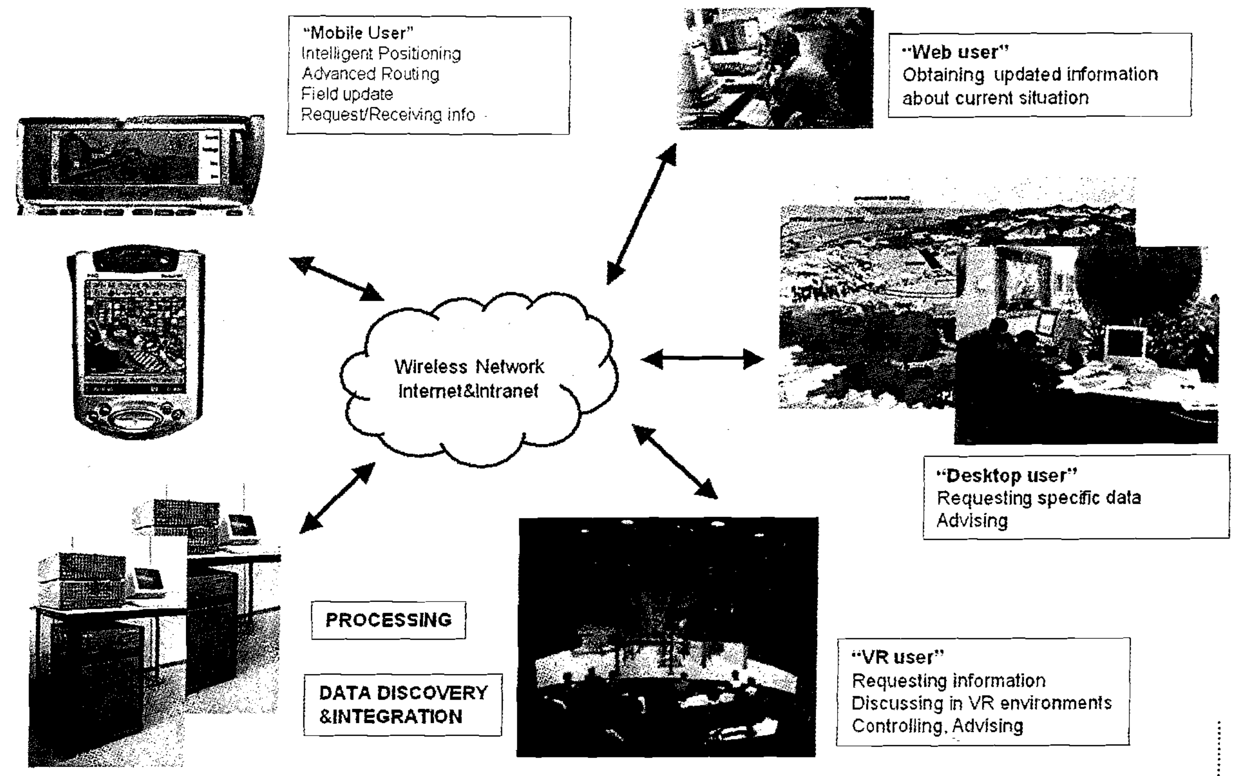


Fig 1. The users in a disaster management situation

In the field, the workers need information about the current situation and the prognosis for the immediate developments in their area. Moreover the field workers can collect information to be returned to the management centre for analysis and redistribution. These generalised activities impose a variety of requirements, such as: consistent information in any environment; search, analysis and processing of information on the Internet and distributed databases; real-time data update; positioning; routing outdoor working teams; and individual and intuitive visualisation on different devices to support decision-taking.

Most of the important data and information necessary for the support of such a system are spatially related; a geo-component is of special relevance. Amongst all the systems dealing with geo-information, Database Management Systems (DBMS) are the fundamental component as these are the software tools responsible for the data management.

DBMS have been used for years to manage administrative data. In the last decade, a strong tendency was observed towards managing spatial data by DBMS. Therefore, a DBMS with spatial support is often referred to as a geo-DBMS. The integrated architecture of storing geometric data and relationships together with administrative data in DBMS is now maturing. The importance of the integrated architecture was recognised by the industry and they participate in an organisation: the Open Geospatial Consortium (OGC). In addition to commercial DBMS vendors, several heavily used non-commercial DBMS have geo-information support: PostgreSQL (PostGIS) and MySQL (since the most recent version in 2004)[4]. These databases are of great importance for developing countries since they are freely available for downloading from Internet.

Despite the progress shown within DBMSs developments, a number of generic issues still need to be addressed in order to provide service to multi-risk management (ZLATANOVA et al 2004):

- Methods for describing multidimensional spatial relationships, structures for maintenance of multi-resolution or multi-scale (or even scaleless) data, and 2D and 3D and temporal geo-data need further research. Multidimensional and multimedia data models for efficient organisation of large urban models (since urban models may easily grow to Gibabytes of data) need to be developed.
- Data update with newly collected data from the field can be very critical for both a)

[4] Please see http://www.opengeospatial.org, accessed May 2005.

monitoring the disaster event and b) giving instructions to the involved people. From a database point of view, this process requires strict consistency rules for integration with existing data and immediate propagation of the information to all the users. In this respect, extended models for maintenance of spatio-temporal information (to be used also for prognosis and future scenarios) are becoming especially desirable and have to be developed.

- Semantic domain models and translators between data from different sources and domains are to be supported within the DBMS, at least for the part that is reasonable supported by the implementation at DBMS level.
- The DBMS has to be prepared to function within distributed environments, which are composed of autonomous and heterogeneous components based on agreed interface specifications, using the Extensible Mark-up Language (XML) for structured data exchange on the Internet.

To realise this service in multi-risk management, a number of problems have to be solved (VAN OOSTEROM et al., 2005). The first one is bridging the semantic gap between these different worlds (i.e. representations from different sensors and systems). The meaning (semantic) of one object in two different organisations may drastically differ (e.g., "house" and "building"). Once an agreed model (covering aspects of the different worlds) is created, different views on this representation may be defined. The integrated model is managed in such a way that consistency is maintained (during updates or addition of new data). The result will be that different applications may be used to perform specialised tasks. This outcome also implies that different users may be working, at the same time, in different environments (or at different locations) with the same model, but potentially with different views tailored to their specific task. As all users then work with the same data this provides the required consistency.

3. MULTI-SOURCE DATA INTEGRATION

The integration of multiple systems and databases is a common necessity in large organisations dealing with spatial data, including planning and housing organisations. For disaster management it is becoming a critical issue as the data sources are always distributed in a heterogeneous environment and especially in the response phase there is not much time available.

There are two main cases in which information may be lost when communicating between different professionals:

- In the first case, definitions and concepts are shared but there is no common language between the two groups. For instance, if professionals A and B want to talk about logistics and the overland transportation of goods, and A refers to this activity as trucking while B knows the large vehicles as lorries, they can agree that the mapping of "truck" = "lorry" will be used to communicate this concept. Note that this example may seam a bit strange as both terms are from the English language (but different dialects) and not from two complete different languages. This problem is corrected through simple translation between the two languages.
- In the second case, definitions are not shared between the communities. This could be caused by the fact that the two communities have starkly different worldviews. For example, consider the real world features "snow" and "transportation systems". Suppose one Information Community recognizes only the first, and the second recognizes only the second. Attempting to address the effects of snow on transportation systems would be difficult or impossible in either community.

The discussion above clearly shows that an important key for solving the problems is capturing the semantics included in the different models. Implicit knowledge or pieces of natural text and tables are not sufficient for this purpose. A more formal approach, as developed in disciplines such as knowledge engineering, ontology and object-oriented modelling, is required. Based on this formal semantic approach it becomes possible to decide whether different domain models (or even models within one domain) are or can be harmonised. Also, spatial information handling by machines will become important especially in time-critical situations such as in the response phase of disaster management, which makes the formal approach even more necessary. In the last decade, important technology progress has been made in the discipline of knowledge engineering (such as Unified Modelling Language, ontology, semantic web), which enables further knowledge formalisation in a practical manner.

Some of the most important issues to be considered in semantic/data discovery domain are:

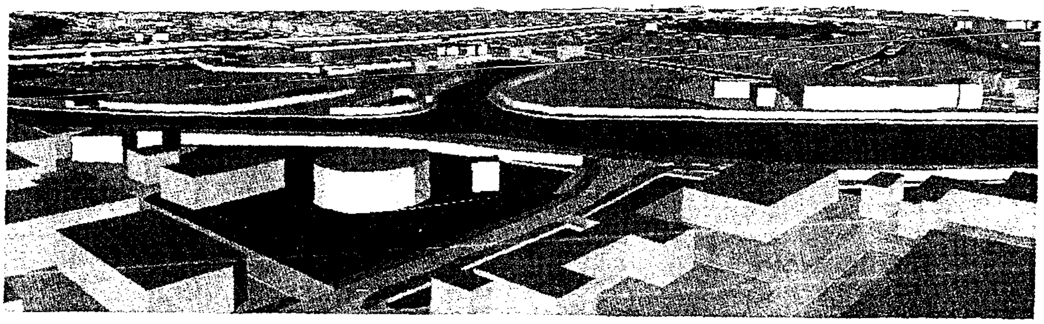
- Integration of thematic, contingency and real-time data in the emergency information processing.
- Developing context-aware engines and agents for query and analysis with respect to the type of the front-end and communication channels used.
- Investigating, adapting and developing of converters to well-known Web standards and formats.
- Developing knowledge-based systems for browsing and analysis in a distributed data environment.
- Investigating and developing intelligent semantic-based engines and corresponding translators for semantic search and analysis.

Once the semantic formalization and the corresponding schemas are created, the data can be obtained from the source where they are stored and maintained (DE VRIES, 2002). The data exchange is then based on an online combination of geo-data from more than one data provider, hosted on different remote servers, in real-time. This could be realised in several ways as:

- an Intranet setting: different departments of the same company or organisation;
- an Extranet setting: "closed" Internet or mobile network, to which only authenticated users have access to the information on different servers;
- an "open" Internet setting: everybody has access, providing a digital library for geographic information.

One of the main principles of the OGC is that, in order to improve data and software interoperability, it is necessary to create standardised interfaces between the different components, possibly of different vendors, of geo-information systems. The Web Map Service (WMS) specification for the request and retrieval of map-portrayals was the first developed in the line of OGC interface specifications.[5] The Web Feature Service[6] supports the retrieval of the vector data, specified by the Geography Markup Language (GML). GML is one of the other important interoperability initiatives of OGC. Since GML does not have limitations on dimension, 3D data can also be exchanged and visualised on the web. Figure 2 shows an example of 3D topographic data transformed from GML to X3D, an open standard 3D file format, to succeed the Virtual Reality Modelling Language (VRML). The use of this kind of communication with real-time 3D data is given in (VRIES and ZLATANOVA, 2004).

Fig 2.
3D visualisation in X3D



[5] OGC Web Map Service Implementation Specification, please see http://www.opengis.org/docs/01-068r2.pdf, accessed May 2005.

[6] Web Feature Service Implementation Specification, please see http://www.opengis.org/docs/02-058.pdf, accessed May 2005.

The advantage of such standardised services for developing countries is the possibility to develop application on a very low (or no) price. Examples of freeware Web-servers are available on the Internet; e.g. the Minnesota MapServer from the University of Minnesota or the GeoServer, an Open Source project with contributions from several different organisation.

4. POSITIONING AND COMMUNICATING

To be able to discover the most appropriate information, the system may need 3D positions of the users. Furthermore the system has to be able to maintain continuous communication related to both rescue forces (police, ambulance, fire brigade) and citizens. The required accuracy of the positioning is depending on certain situations and may vary from 100 meters (locating a hospital) up to 5 meters (locating a safe exit in a building with reduced visibility). The system should be able to analyse the situation and decide on the preferred way of positioning and communicating, depending on the availability of networks.

At the moment, the only available relatively low-cost Global Navigation Satellite System (GNSS) devices offering 3D positioning and navigation capabilities are GPS devices (ZLATANOVA and VERBREE, 2003). Although these devices are designed to track up to 12 satellites simultaneously, in dense build-up areas it is not so easy to receive the minimal four satellite single frequency signals necessary to determine a 3D-position. The advantage of GPS is the (near) global coverage, including the developing countries, and the mass production and miniaturisation of GPS receivers. This makes GPS receivers very cheap and they can be built into all kinds of equipment such as a car, mobile phone, and even a watch.

Due to the obstructed line-of-sight to some satellites, the accuracy can become less than 10 meters, which could be obtained with a clear view. At first sight, both accuracy and availability are not suitable for the rapid and precise positioning necessary for tracing and tracking mobile workers and users within a disaster management application. Furthermore, with a cold start, the receivers need a certain start-up time to acquire the satellite almanac, necessary to know where to look for a certain satellite. Within buildings and other closed spaces, the satellite signal is often too weak to use. All these limitations are not improving the use of GPS in the current practise.

However, all the mentioned limitations are likely to be solved within the near future or by a combination with other equipment. For example, new GPS-satellites will use a stronger signal. The receivers will be assisted in urban environments by terrestrial communication signals providing the satellite almanac data beforehand, which will reduce the start-up time necessary for a first position. It is important to realise the progress in the hand-held devices industry. The GPS/Galileo receivers will be miniaturised and integrated with cell-phones, creating a situation in which the location of these devices is known prior to accessing the disaster management system. This location-awareness will reduce the human input required while specifying a certain location-based query.

The expectations of positioning based on telecom networks are high. One illustrative example is given by the rescue of several people after the tsunami tragedy during Christmas 2004. An article at ABC News online reported the rescue of at least 30 foreigners by trilateration (simultaneous distance measurements) of the mobile phones.[7] This shows the possibilities of the combination of positioning and communication. But where for example GPS is a global navigation system, telecom networks are not. Where GPS offers real 3D positions, a telecom network cannot due to the configuration of the transmitters bounded at the earth's surface. Where GPS offers a global accuracy of 10 meters or better, the accuracy of telecom networks corresponds in principle to the cell-size of the base-station, i.e. it is limited to 100-500 meters.

The developments in global positioning systems will reach a stage to be sufficient within the majority of situations in disaster management, especially when communicating with citizens. In the United States, the mandate called E911[8] demands operators to make available the location of the mobile phone user. For this purpose the telecom and GNSS positioning techniques will be combined. In the near future, a built-in GPS will be as common as the cameras found nowadays within cellular phones. Further developments will be needed to allow receivers to be applied within buildings and other GNSS-hostile environments. A sort of hybrid system will have to be developed that will connect to spe-

[7] Please see http://www.abc.net.au/news/newsitems/200412/s1273800.htm, accessed May 2005.

[8] Please see http://www.fcc.gov/911/enhanced/, accessed May 2005.

cial kinds of transmitters, WLAN and other short distance networks to provide the rescue teams with highly specialised services. As the kind of service needed to help people within buildings is more specific compared to outdoor applications, specialised vendors and operators will drive the development of these short range-positioning tools. In the context of disaster management, this could result in flexible (moveable) temporary systems for positioning and communication, which can be installed very quickly (as one of the first steps in disaster response).

5. CONCLUSIONS

The key constraint in emergency response is the time component. Rapid information delivery will be achieved only after the development of the models and frameworks as discussed in Sections 2 and 3. These models should be able to manage relevant information from the field that will assist coordinating rescue operations. The information about a disaster can be managed in a distributed manner and there is no need for centralised databases. However, metadata, or "information about the information", is definitely required. This can be achieved by knowledge approaches based on information extraction from multiple and distributed databases. These methods provide the emergency sector with all insights that can be realistically obtained in support of life saving and protection of material assets.

An improved utilisation of geo-information will contribute to better monitoring and fighting disasters, leading to shorter response times, focused and efficient emergency operations, and can also assist pro-active planning for prevention and mitigation. Satellite data are important geo-information sources for disaster management systems to be used in developing counties. Through international agreements, the derived information can be used free of charge in case of natural or man-made disasters. The system architecture has to be based on open source technology and standardised interfaces utilizing standards given by the Open Geospatial Consortium. Accurate global positioning, such as GPS signals, will facilitate the logistics of emergency operations by providing 2D/3D navigation capabilities, as this is available all over the world without costs. Further, wireless communication is also likely to be available (or being developed) in the urban areas of developing countries. This will increase the resources for the core emergency tasks and limit the chaotic nature of emergency handling.

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Authors' Addresses:
Sisi Zlatanova, Peter van Oosterom and
Edward Verbree
OTB Research Institute for Housing,
Urban and Mobility Studies
Delft University of Technology
Jaffalaan 9, Delft
the Netherlands
{s.zlatanova | oosterom | e.verbree}@otb.tudelft.nl
http://www.otb.tudelft.nl