Geo-ICT for Risk and Disaster Management

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Abstract
There is no doubt about the importance of Geo-ICT in risk and disaster management. Systems that make use of geo-information are used in all activities before, during and after the occurrence of a disaster. In this chapter we address the use of Geo-ICT before and during disasters. Special attention will be given to the use of geo-information, such as risk maps, topographical maps, etc. A brief analysis of current risk maps and of their limitations sets the stage for research that could overcome some of the present unsatisfactory aspects of risk maps. Access to and provision of spatial information is examined with respect to the needs of emergency response systems and the challenges in the use of geo-information for disaster management are discussed.

1 Introduction

In order to deal with the critical issues in the application of Geo-ITC for disaster management it is important to review the main concepts of risk management and of risk-related information, as shown in Figure 1. Four general phases can be distinguished: prevention & mitigation, preparation, response and recovery. They are currently widely accepted by agencies all over the world, although some institutions work to specific national specifications. The first phase is also referred to as risk management and the last three are also referred to collectively as disaster (or crisis) management.

The terms risk management, hazard management, disaster management, crisis management and emergency management are often used interchangeably. Here, we use 'risk' to denote the probability of a negative, damaging outcome from an incident or a natural event (process). In applying safety/mitigation procedures and actions, planners and decision makers attempt to reduce the risk, limit the damage and reduce the vulnerability of given regions. Therefore, risk management could be regarded as the understanding, managing and reducing of risks. In practice, that should generally result in lowering vulnerability.

A hazard is considered to be a potentially damaging physical event, phenomenon and/or human activity, which may cause loss of life or injury, property damage, social and economical disruption or environmental degradation (UNISDR 2007). Intuitively, hazards are classified according to their origin.

The usual classes are therefore natural hazards (e.g. floods, landslides, earthquakes, tsunamis, volcanoes, etc.) and human-caused hazards (e.g. industrial accidents, fires, terrorist attacks, etc.). However, other classifications are known from the literature (for example, Stingfield 1996). Schneiderbauer (2007) suggests four different groups: pure geogenic (e.g. earthquakes, tsunamis and landslides), geo-anthropogenic (meteorological, oceanographic, hydrological and biological), anthropogenic-technological (explosions, release of toxic materials, structural collapses of transportation systems, constrictions or manufacturing accidents), anthropogenic-conflict (crowd-related, terrorist activity and political conflicts). Disasters can be defined as events triggered by hazards; in effect, they are potentially negative consequences that have become reality due to the occurrence of hazard (Schneiderbauer 2007). The term disaster management is therefore related to managing the consequences of hazardous events.

The four phases of disaster management shown in Figure 1 are interrelated and equally important, but they also have their own specific characteristics. Prevention & mitigation focuses on long-term measures in order to reduce vulnerability or, more rarely, the hazard. Preparation focuses on active preparation in the event of a possible emergency. The rescue services (e.g. police, ambulance and fire brigade) are trained in how to operate and cooperate in emergency situations. Response is an acute phase following the occurrence of an emergency and is the most challenging stage because of the dynamics and unpredictability of these situations. Recovery is the phase after the acute emergency, including all the arrangements for removing damages and the long-term supply of irreversible detriments.

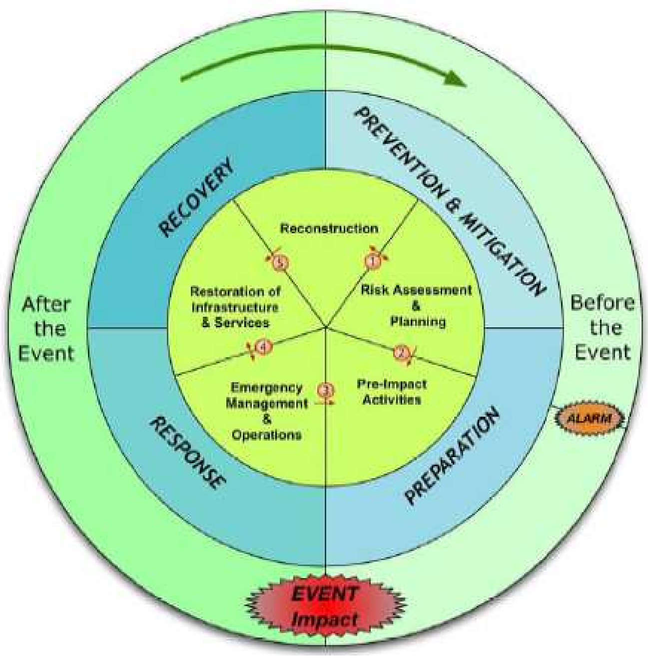

Figure 1. The disaster management cycle (source: PSC Forum, www.publicsafetycommunication.eu).

These specific actions influence the Geo-ICT applications developed in support of the various tasks within a particular phase. For example, risk management relies on large amounts of statistically processed data. The emergency activity depends on fast response, reliable access to existing data, up-to-date field information, integration (for decision makers) and distribution of information (between rescue teams, citizens, etc.).

Furthermore, many risk and disaster management applications are hazard specific and it one hazard often triggers off others. For example, floods near industrial areas may cause technological hazards (explosions, fires, etc.), power failure may result in an explosion and damage to a dike, which consequently may transform it into a flood disaster, and earthquakes may provoke landslides. This means that the chaining of disasters triggered by a primary hazard, which then leads to secondary hazards, must be considered as likely outcomes. This chaining can involve any kind of complexity: an earthquake can cause a tsunami, which can destroy a factory, which may in turn provoke an explosion that releases toxic materials. For this reason, disaster management is often mentioned in a multihazard context.

Location identification and Geo-ICT play a major role in all the phases of disaster management. The first questions asked in call centres after a disaster has been reported is about the location of the incident and its possible ramifications. A variety of systems use maps, models, tracking of rescue personnel and images obtained from various scanners to monitor a disaster, make forecast, estimate damages, predict risks and vulnerability, etc. (Kerle et al. 2008; Li and Chapman 2008; Zhang and Kerle 2008). In some cases, imagery from various sensors can be quickly provided for analysis and estimation of damage caused by recent major disasters, such as the effects of the tsunami in Banda Aceh in January 2005 (see Figure 2). Amdahl (2001) and Green (2002) provide numerous examples of the use of maps and GIS technology in all the phases of risk and disaster management using ESRI® software. Significant progress has also been made by suppliers of CAD/AEC tools and database management systems (DBMS) in providing solutions for managing disasters, predicting risk, training and simulation, and in geovisualisation.

Figure 2. High resolution Quick Bird images provided to the Aceh Region under the International Charter on Space and Major Disasters (Source: ICSMD).

However, the use of Geo-ICT is still rather limited compared with the potential benefits to be gained from its application in managing the many disasters that occur throughout the world. Presently, geodata is stored and used almost daily in many organisations. Geo-ICT is expanding in scope and changing in nature, especially regarding the use of the third and the fourth dimension (time). Many GIS vendors provide extended 3D visualisation tools and new visualisation environments such as Google Earth and Virtual Earth are now available, although spatial analysis is still in the 2D domain. The traditional stand-alone, desktop GIS analyses are evolving into complex system architectures in which DBMS play the critical role of a repository of administrative, geometric and multimedia data. Cell phones now incorporate functionality which used to be restricted to ultraportable computers, which are also updated with communication abilities.

To increase awareness in crisis situations, such Geo-ICT advances will have to be used more extensively as a basis for developing knowledge-based, multi-user and multi-risk disaster management systems, and help decision makers during the entire disaster management cycle. There are various factors which complicate the use of Geo-ICT in disaster management and these are addressed in the following sections of this chapter. The following two sections discuss existing Geo-ICT applied in risk and disaster management and review the challenges and opportunities for wider and better use of the latest technological developments. Section 4 of this chapter examines research and developments issues to be considered in constructing integrated multi-risk, multi-disaster systems, followed by a concluding discussion.

2 Geo-ICT opportunities for risk management: risk maps

Risk visualisation for risk management combines risk analysis and risk evaluation (for a discussion of various risk terms see, for example, Plattner 2004 and http://www.sra.org/resources_glossary.php). In essence, risk is a human condition related to the probability that one or more natural or technological processes take place that negatively affect our daily lives, there where we are more exposed to the damage. In practice it is the spatial distribution of the natural and technological processes and the exposed socioeconomic activities that are critical to risk management.

2.1 Risk maps – the most appealing application of Geo-ICT in risk management

Generally a risk map shows the distribution of risk levels, or of objects representing risk levels, across an area of concern. Such levels are plotted to assist a decision maker in taking action to avoid or mitigate risks and in responding to disasters. For instance, a map of flood risk should show the inundation levels expected as a result of likely events such as exceptionally heavy rainfalls or hurricanes.

The difficulties in generating such risk maps are numerous and multidisciplinary, ranging from the poor availability of consistent data, the need to model the hazardous processes in space and in time, the complexity of valuating human life, assets and activities, and the co-occurrence of more than one risk. Clearly, the risk mapping task involves objective and subjective aspects and representations that have to be directed not only to specialists in the risk areas, but also to non-specialist decision makers and to the general public, whose perception of risks can be an important factor in risk management. As a result, the generation of a risk map places a heavy burden of responsibility on the producer and the local administration that eventually distributes it and explains its usability.

An encouraging view of modern approaches to risk mapping is the one taken by Monmonnier in his extensive analysis of 'cartographies of danger' (Monmonnier 1997, 293). He points to hazard-zone mapping as a recent phenomenon that seems to focus on forecasting and monitoring, while prior cartographies used to be mainly descriptive and explanatory of past hazardous events. This means that "Most risk maps involve statistical models of some sort for estimating the likelihood of rare events such as volcanic eruptions or disastrous floods…and forecasting requires a representative record of the hazard's magnitude and variability". Moreover, "comparatively rare hazards, like volcanic eruptions are inherently uncertain" and "we cannot guarantee a future that uniformly replicates the past" (Monmonnier 1997).

It is instructive to run through a few representative interpretations of risk and risk maps. A naïve search on the internet helps to describe the present general understanding of risk maps. Typing the two keyword phrase 'risk maps' into a search engine immediately leads to over 30 million hits! Clearly the topic happens to be a great concern; however, there is a large variety of interpretations regarding what these maps should look like, their meaning and how they can be used.

For instance, various agencies or consulting groups offer services such as mapping of specific risks for areas selected by customers over regions of competence in a wide range of fields, including the medical field (contagious diseases), economics and industrial activities, traffic, social unrest and terrorism, and technological and natural hazards. At times, what is meant by a risk map is a graphic representation of risk levels within a decision space delimited by a risk significance axis and a risk likelihood axis. Such representation, often rather qualitative, is intended to help with structuring and prioritising actions in logical and convenient terms for an industry (see for instance www.luisepryor.com/showTopic.do?/topic=33; www.riskgrades.com/retail/treemap/treemap.cgi)

In our case, we will consider specifically the distribution of risks in geographical space for disaster management. An example of this are the risk maps made available by a company called Risk Management Solutions http://www.rms.com/Publications/Maps.asp that offers natural hazard risk, terrorism risk, water risk and enterprise risk services and a variety of catastrophe maps of the USA, Latin America, Europe and Japan. They are small scale maps for posters intended to assist catastrophe managers and others at conferences and meetings. Contoured values for entire continents or countries show a common measure of combined relative risk for the most typical insured hazards (termed aggregate average annual loss or

AAL), a ‘Risk Thermometer’ for selected cities and the footprints and industrial losses for historical disasters. Clearly, such products are not meant for a close analytical scrutiny for risk management.

Let us consider a few representative websites that offer specific risk information to citizens. The Government of the Canadian Province of Alberta offers a Flood Risk Map Information System on its website. http://www3.gov.ab.ca/env/water/flood/index.html. Besides introducing flood risk concepts and the Canada-Alberta Flood Damage Reduction Program, it provides flood risk maps for individual municipalities or otherwise delimited areas of concern for which information happens to be available. On another site, http://nolarisk.usace.army.mil/, the US Army Corps of Engineers provide the New Orleans Risk and Reliability Report drawn up after Hurricane Katrina made Gulf Coast landfall on August 2005. Examples of interactive maps are available with risk assessment laid over Google Earth background maps. These can be queried and instructions are given on how to read the risk maps.

Since 2005, the Manila Observatory’s Center of Environmental Geomatics has constructed a website on its Mapping Philippine Vulnerability to Environmental Disasters Project. http://www.observatory.ph/vm/. It provides ample training material to calculate risks (also hazards, exposures and vulnerabilities) and provides an atlas of risk-related maps of climate, weather and geophysical risks. Another more specific site worth mentioning is on tsunami risk in Papua New Guinea: http://map.mineral.gov.pg/tiki/tiki-index.php?Page=Rabaul+Tsunami+Risk+Maps. Among the maps available on this site are the detailed Rabaul Tsunami Risk Maps of East New Britain.

To obtain an impression of how relevant risk has become in many countries, it is indicative to consider that in the last five years it has become common for many local and national administrations, universities and private consultants to construct websites to educate the public at large on natural hazards and risks. In Italy, for instance, searching for *rischio idrogeologico* (hydrological-geological risk) leads to over half a million hits, with many sites providing some types of hazard, vulnerability and risk maps. Naturally, these sites aim to inform the general public; more technically-oriented users looking for scientific information will have to search elsewhere.

More extensive risk map resources are available from the U.S. Geological Survey’s Earthquake Hazards Program (http://earthquake.usgs.gov/) and Landslide Hazard Program (http://landslides.usgs.gov/). In particular, the USGS Geologic Hazards Team provides a list of research projects and staff where articles can be downloaded (http://geohazards.cr.usgs.gov/research.php). An example are maps on landslide recurrence intervals and probabilities in the Seattle area, Washington State (Coe et al. 2004; Schulz 2007). The authors provide maps of landslide densities, mean recurrence intervals and exceedence probabilities for different probability models applied in that study area. However, they are to be used as a general guide to landslide occurrences and not to predict landslide hazard at specific sites.

Clearly, as we can see from these few examples, we can go from general and broad representations of risk to detailed risk maps for specific areas of concern, so that even the characterisation of all types of risk maps available on the World Wide Web would become a research endeavour in itself. As an example, we can consider a project supported by the European Commission that aimed at applied multi-risk mapping of natural hazards for impact assessment: ARMONIA. It applied state-of-the-art methodology in a case study on the Arno River Basin Authority area near Florence, Italy (http://www.armoniaproject.net/, 2004-2007). It assessed most methods and techniques for hazard and risk mapping in Europe and outside the continent.

Nevertheless, one of the problems encountered to date is that none of the risk maps analysed seem to contain measures of the credibility, uncertainty and robustness of the spatial representations. In particular, it is not clear whether the risk is represented as an aggregation of past events or as a prediction of future ones. Because of this, Fabbri et al. (2004), Chung and Fabbri (2004) and Chung et al. (2005) have introduced an analytical strategy to provide such measures for spatial predictions of hazard and risk maps via empirical validation techniques. Their approach will be exemplified by an application in the following subsection that presents some results based on spatial validation strategies for resolving those problems.

2.2 Examples of risk mapping systems

Risk is a condition that is evaluated by combining the presence of exposed vulnerable elements and the probability of occurrence of hazardous processes. Without the former no risk condition can occur. Risk is generally represented either as monetary loss or as a number of human casualties expected. Such values can be represented in map form to express and comprehend the significance of their distribution within a landscape containing static and dynamic human elements and activities. Simple qualitative or semi-quantitative risk maps use classes of risk such as high, medium and low, but more advanced qualitative maps provide many more values, often on a continuous scale.

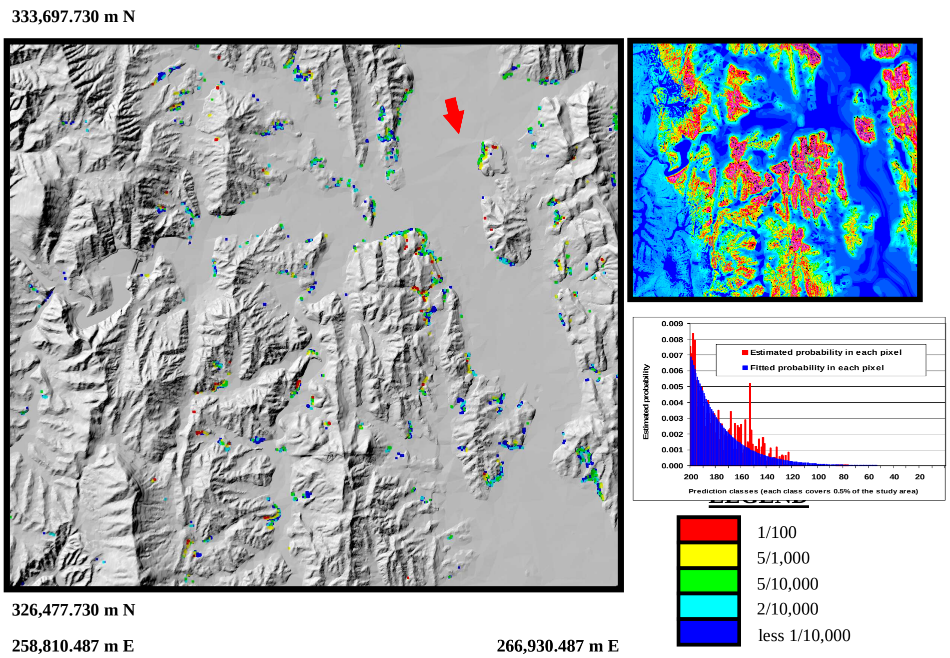

Figure 3. A 5-class population risk map of the Boeun study area (South Korea) affected by landslide processes. The classes have been mapped on a shadow relief enhanced elevation image. The landslide-hazard prediction image and the histogram of probability of occurrence necessary to compute the values for the risk map are shown on the right (after Chung et al. 2005).

An example of a risk map for surficial debris flow landslides in an area of South Korea is shown in **Error! Reference source not found.**3. Most of the map has no risk values due to the absence of urban settlements in those areas. The classes indicate the casualty rates expected per 5 m pixel. To understand the significance of a risk maps, it is necessary to know how it has been constructed using a spatial database, a specific mathematical model and its assumptions and the analytical strategy used for the prediction of the hazard. The Boeun study area is 58.4 km^2 and has about 45,600 inhabitants living in 15,000 households. The spatial database (Fabbri et al. 2004) is a set of digital images of 1624 x 1444 pixels with a resolution of 5m x 5m showing the digital elevation model (DEM), surficial geology, forest coverage, land use, drainage and the distribution of 420 past surficial debris flow landslides that occurred prior to 1997. In addition, several socioeconomic ‘indicator’ images were compiled to represent the vulnerable elements: the distribution of population density, of road networks, buildings of several types and of the drainage features and embankments. For these values in US$ for 5m pixels and the corresponding vulnerability levels (values between 0 = no damage and 1 = total destruction) were also compiled. In addition, information became available on 44 new landslides in the area that occurred in 1998, which occupied 2,000 pixels. They caused about $200,000 of damage to man-made properties and three injuries to persons. The information on the number of pixels affected in 1998 allowed estimation of the risk level distribution in the study area.

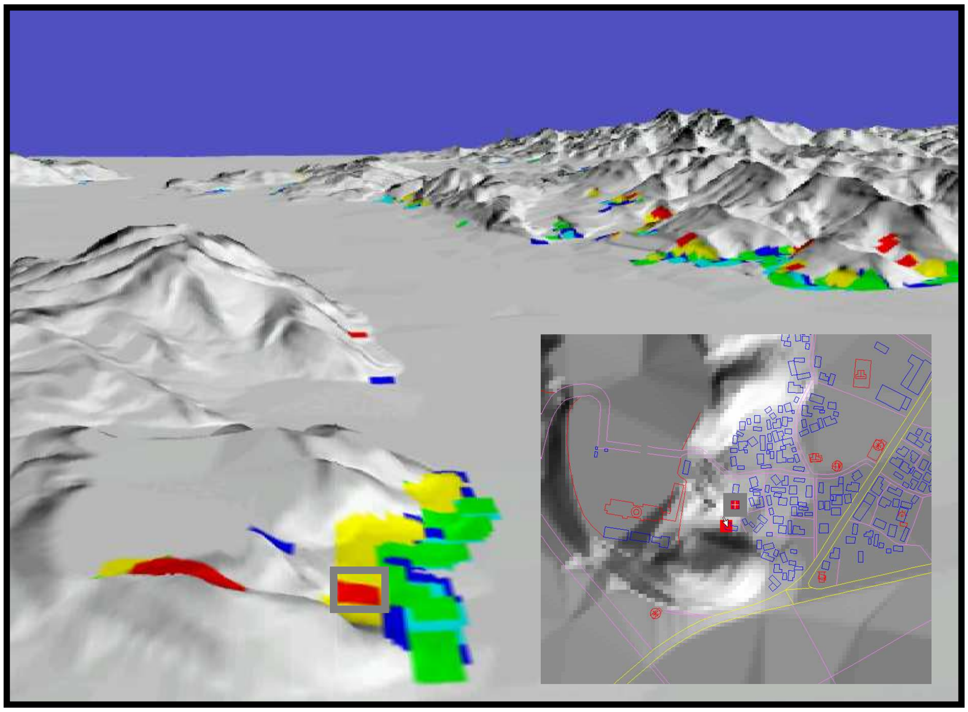

Figure 4. A fly-through is shown of the 3D visualisation of a portion of the risk map in Figure 3, in which the flight direction is indicated by a red arrow. The grey box shows the location of a house where a casualty occurred. The inset on the lower right shows a vertical view of the population density database (after Chung et al. 2005).

What was done, was to apply a three-stage analytical strategy of risk assessment, keeping in mind the actual damages and casualties due to the 1998 landslides, but using only the numbers of pixels affected in 1998 to set up a computational scenario and the distribution of the 420 pre-1997 landslides. In the first stage the distribution of the 420 pre-1997 landslides was used with a fuzzy set prediction model (Chung and Fabbri 2001) to classify the study area from the spatial relationships between the landslide distribution and the digital images of the DEM, surficial geology, forest cover, land use and drainage patterns. The prediction is represented as a 200-value hazard image (using a pseudo-colour look-up table) shown on the upper right in Figure 3. In the second stage, a second hazard prediction was obtained by the same model, but using only the distribution of a random half of the 420 landslides. That of the remaining 210 landslides was compared with the 200 hazard classes obtained in the second prediction to see whether the high hazard classes contain a high proportion of the 'validation' landslides. This was to obtain a prediction-rate table, also visualised as a prediction-rate curve, expressing the predictability of the events given the database and the 200 classes of hazard (200 used as default). Cost-benefit analysis can be applied to the characterisation of the curve into meaningful sections. Finally, in the third stage a realistic scenario assumed that 2,000 pixels would be affected by landslides in 1998, so that the probability of occurrence of future landslides could be estimated at each pixel of each class. The estimated probability histogram is shown to the lower right of Figure 3. Those probability values have to be used to combine the first prediction map from the first stage with the socioeconomic data and images using the risk expression $R = E \cdot V \cdot H$, where E indicates the element exposed, V its vulnerability and H the probability of occurrence of the hazardous event. The combination of digital images of probability values and vulnerability/dollar values allows the risk map in Figure 3 to be computed. To better communicate the risk visually, a fly-through risk map is shown in Figure 4, in which a partial view of the image in Figure 3 is shown.

The risk map is evidently a complex construct whose understanding is not trivial, due to the analytical steps and the necessary assumptions. One critical issue, therefore, is how credible and reliable a risk map is. The three stage strategy used to obtain the risk map in Figure 3 is indeed transparent and repeatable. However, in the above application it only provides the empirical validation of the predicted hazard map using a random half of the events. Thus it does not tell us when to expect the events and it only tells us that, given the data in the database, the expected casualties in the study area are 3.14, in this case almost the same as the 3 casualties observed in 1998. More considerations on this case study can be found in Chung et al. (2005). In this example, empirical validation techniques were used not only to demonstrate and measure the spatial support to the predicted hazard map, but also to estimate the probability of occurrence through a scenario that exploited the notion of the 2,000 pixels affected in 1998. To estimate the risk uncertainty in time and in space, however, more information will be needed in the spatial database containing the distribution of the hazardous events in time intervals and in space subdivisions, and, in addition, a number of different validation experiments. If a time division is not possible because there is no information on the time of occurrence of the past events, they can be randomly subdivided into two or more groups to obtain other validations. All such experiments will generate prediction-rate tables and curves that can be compared to assess the uncertainty of the prediction results in the hazard map that is to be used to generate the risk map from the estimation of the probability of occurrence; in other words, this is the most critical estimation needed in risk mapping. A spatial prediction modelling software intended to be complementary to conventional GIS has been described by Fabbri et al. 2004. The process of generating credible and convincing risk maps must be able to take advantage of the strategy described here if it is to be used to communicate risk to the public at large.

Unfortunately, in many societies it is still unclear who is responsible for producing such risk maps and which stakeholders or actors should contribute to the decision making on such maps! For instance, a study by Bonachea (2006) as part of the EC Research Network Project ALARM (Assessment of Landslide Risk and Mitigation in Mountain Areas) http://ivm10.ivm.vu.nl/webmapping/Alarm_SP_image_maps2 observed that in Europe there is no legal obligation to incorporate consideration of natural risks into land use and management policies. The only reference to such considerations is in a resolution of 16 October 1989 (Official Journal of the EU, 1989) which calls for the preparation of a statement on natural and technological risks. Worldwide, there is clearly a scarcity of hazard maps. In Spain, for instance, there are standards for information on flood hazards, but it is not clear who is responsible for preparing the hazard maps that have to show the return periods of the floods. It can be concluded, therefore, that the challenge is to include quantitative assessments of hazards and risks in future risk maps.

2.3 An example of a risk map for industrial hazards

In contracts to natural hazards, mapping industrial hazards is a subject of European legal enforcement. Article 12 of the Seveso II Directive requires the member states to consider, within their land use planning policies, the need of defining opportune safety distances between dangerous establishments and urban, natural and infrastructural developments. ‘Dangerous’ substances are those which by explosion, fire or release could lead to major accidents involving the external areas of establishments.

The Seveso II Directive is in the process of being transposed into the national legislation of all Members states. In Dutch legislation, the various provisions of the Seveso II Directive are incorporated into the Hazards of Major Accidents Decree (BRZO) and the External Safety (Establishments) Decree (BEVI). The BRZO focuses on the management of hazardous installations. The BEVI regulates the environmental quality requirements for external safety when planning land uses around hazardous installations. Decisions on land use planning and the granting of environmental permits for activities within the area hazardous establishment fall under the BEVI. The Dutch methodological approach to external safety is described extensively in the literature (Ale 2002; Bottelberghs 2000).

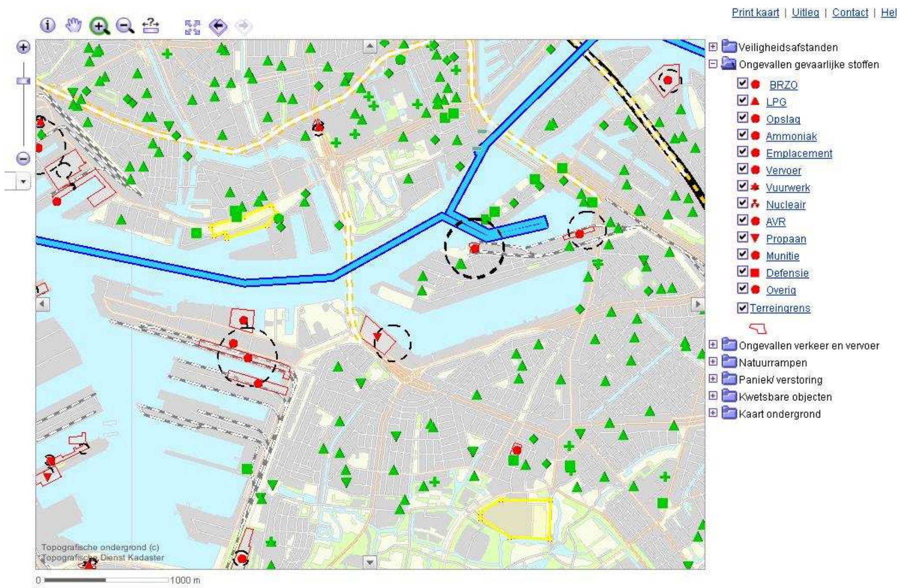

Figure 5 Example of a Risk map:. The symbols in red represent the hazardous establishments with the corresponding risk areas. The symbols in green indicate vulnerable public buildings, such as schools, hospitals, etc.

The Ministry of Housing, Spatial Planning and the Environment (VROM) is the competent authority for establishments of national importance, such as nuclear power plants (NPP) and nuclear waste disposal facilities. Hazardous establishments falling under the provisions of the Seveso II Directive are classified in accordance with threshold values for the quantity of stored/treated hazardous substances. Under this classification, top-tier sites are the responsibility of the provincial authorities and lower-tier sites and small liquid petroleum gas (LPG) stations are the responsibility of the municipal authorities. The urban and environmental objects and sites are classified accordingly to vulnerability categories (high, medium, low). Risks associated with an accident are estimated with respect to the type of accident being considered, its iso-risk contours and the specific territorial context. The preparation of digital risk maps to convey this information about the type of risks affecting specific areas is therefore an obvious, although recent, operational development. (http://www.risicokaart.nl/).

In the Netherlands risk maps are prepared by the provincial authorities. One such map is shown in Figure 5. The Register of High-Risk Situations involving Dangerous Substances (RRGS: Register Risicovolle Situaties Gevaarlijke Stoffen) is used as informative source together with the Information System for Major Disasters (ISOR: Informatie Systeem Overige Rampentypen). ISOR has been set up jointly by the 12 Dutch provinces and contains additional information on risks, such as flood risks and vulnerable objects. Currently, it covers 11 types of disasters: dangerous substances, nuclear incidents, aircraft incidents, accidents on water, roads and in tunnels, collapse of large buildings, fire in buildings, widespread panic (or disturbance of the public order), floods and natural fires. Thanks to these developments, information on risks that was previously dispersed over many sources is being brought together in national, multi-accessible databases.

Mapping potentially hazardous establishments and vulnerable objects is a major step forwards, but it still does not help to make significant improvements in risk management and disaster management. The hazardous situations that are best represented on the risk maps are the sites whose locations or extent can be determined with accuracy, such as buildings, tunnels, stadiums, large exhibition halls, airports, parts of roads and waterways, etc. The maps give little information about the areas and populations at risk. The iso-areas are given only for hazardous establishments and the information they provide is rather limited. Iso-areas represent the individual risk at the given location, which is defined as the statistical probability that a person who is permanently present at a certain location in the vicinity of a hazardous activity will be killed as a consequence of an accident at that hazardous site. Individual risk for residential areas, hospitals, schools and the like may not exceed the legal threshold of 10^{-6} (one in a million per year). The iso-contours indicate only that the risk within the area is larger than outside the area with respect to this threshold. Moreover, current risk maps only represent the chance and magnitude of a possible incident, but do not reflect the controllability of a possible incident. For example, it is not clear whether it would be possible to evacuate an area subject to flooding when the water reaches a near critical level.

2.4 Examples of common pitfalls in risk mapping

There are a number of common pitfalls to using existing natural hazard/risk mapping models in risk and disaster management. Some of these pitfalls, as discussed by Chung and Fabbri (2004), are the absence of statements on the assumptions made in the prediction models, the lack of validation of the prediction results, and the absence of estimations of the conditional probabilities of future events given the characterisations of an area within a study area. Overcoming these deficiencies is a necessary but not sufficient condition. The following points are still major challenges: (1) the need for a spatial database that captures the distribution of hazardous processes, their settings and the socioeconomic elements exposed to risk; (2) the need to use models for estimating the hazard probabilities; (3) the requirements of techniques for estimating the uncertainties associated with the models and for estimating the uncertainties associated with the database; (4) the development of scenarios necessary to compute the risks; and, (5) the different techniques needed for representing the risk maps so that the risk levels and the associated uncertainties can be understood.

Until recently hazard models and risk maps have been prepared mostly for municipalities as aids in urban planning process. As such, the pitfalls listed above have not been considered critical. However, if applied in emergency response situations, hazard models and risk probability estimations have to be adapted to the development of the hazardous event and preventive measures taken during the event. Time therefore becomes a crucial factor for successfully predicting and managing the disaster. The next section concentrates on the use of geo-ICT in emergency response.

3 Geo-ICT for emergency response

Emergency response differs from the other phases in many respects: time is critical, the dynamics of events is higher than in normal circumstances, many people (who normally have different responsibilities) are involved, human emotions (pains, stress, panic) play an important role, infrastructure might be partially or completely destroyed, communication between different actors could be limited and even impossible, access to data and other sources of information might be obstructed, etc. Several studies have investigated factors of major importance for successful emergency response (Cutter et al. 2003; Borkulo et al. 2005; Diehl and van der Heide 2005; Kevany 2005; Zlatanova 2005; Brecht 2006; Zlatanova et al. 2007). Some of the most appealing aspects related to geo-information are addressed below.

3.1 Important factors for emergency response

Information awareness

Studies on past major disasters (Kevany 2005; Brecht 2006) conclude that there is insufficient information about existing resources, types of data and the availability and accessibility of data. Appropriate measures have to be taken prior to a disaster to agree on access to and availability of data. The lack of a spatial data infrastructure has been reported as a major obstacle to quick data availability and transfer. Related to this is the dynamic aspect of the information becoming available after the disaster. Frequently asked questions are: What is the position of rescue teams? Where are the shelters? What are the flood depths? Where are the landing platforms for helicopters? What is the current magnitude of a toxic cloud and how will this cloud develop over time? What is the current capacity of the nearest hospitals? Which roads are accessible and which ones are not? Because the circumstances during an emergency may change at any moment, continuous monitoring of developments and continuous distribution of information on monitored changes is necessary.

Collaboration and exchange of information

As emergency management is a multidisciplinary activity, it should be possible to exchange information between different partners at different administrative levels during the disaster. Command and control systems in dedicated centres should be built prior to the disaster or, alternatively, easily deployable components (open standard) should be developed to allow temporary management centres to be established quickly. For example, following the Hurricane Katrina disaster in the US, several ad hoc centres were created to replace the infrastructure for providing geo-information that had been flooded. Another frequently mentioned bottleneck is the issue of dynamic data management. It has been often unclear who should be responsible for the collection and appropriate organisation of dynamic data. In some cases much 'private' data has been donated by private companies and institutions (Brecht 2006).

Intuitive interfaces
In a crisis response system heavy emphasis is placed by operators on intuitive interfaces with simple methodologies for communication and data access. Much attention has been given to the use of appropriate icons and symbols (Tatomir and Rothkrantz 2005). Little importance is placed on extended functionality, or even artificial intelligence, to support decision making. In situations of stress, system operators place more reliance on their own judgment and the judgment of other human beings than they do on any form of artificial intelligence. What they want is to have a system that can be used in their day-to-day work and which they are comfortable with. The motivation behind this is directly related to the specifics of crisis response. Working with a unfamiliar system will contribute to critical delays and operator stress, which will inevitably lead to 'expensive' errors when mobilising emergency resources in response to life threatening situations.

3.2 Systems in use in emergency response

In recent years many emergency response systems have been developed for different types of disasters or for multi-disaster management that are dedicated to a particular group of responders or users. Special attention is also given to mobile systems and sensor networks for monitoring natural phenomena. All of them are intended to support decision making. In this respect it is difficult to define the scope of Geo-ICT in emergency response. The systems developed are integrated state-of-the-art technologies that include not only GIS technologies, but also computer graphics, human-machine interfaces, communications, gaming, etc. Due to the importance of location, most of the systems use vector digital maps, raster maps, images (aerial, satellite, range, radar, etc.) and 3D models for simulation and forecasting. The diversity of systems is extremely high. There are systems devoted to a particular disaster type (e.g. fire, flood, avalanches, etc.), to a group of responders (e.g. fire brigade, ambulance, police, Red Cross), or to a particular activity (e.g. early warning, evacuation, following patients to hospitals, etc.).

Generally, the systems can be subdivided into two large groups: scenario-based and demand-based (Erlich and Zlatanova 2008). The scenario-based systems concentrate on a particular type of disaster and attempt to consider a sufficient number of factors, which, when incorporated into the models, can provide the best predictions to support the decision-making process. The demand-based systems attempt to provide tools that can help in any kind of emergency. The concepts for these systems are relatively new and take account of the fact that a disaster may change its nature and may require information (or models) that are not available for the programmed disaster type. Several examples are given below.

3.2.1 Scenario-based systems

Numerous recently developed systems (either prototypes or operational tools) in the domain of floods, water pollution, forest fires and other natural hazards use predefined scenarios as a part of the entire architecture for forecasting the results of the monitored process. This approach allows for integrated data management (considering historical records), the creation and integration of modelling and simulation methods, and the development and adaptation (calibration and validation) of scenarios, supported by advanced optimisation tools, for forecast generation. The advantage of the scenario-based approach is the possibility of concentrating on and studying particular phenomena in depth, with the involvement of the relevant specialists, and of carefully selecting tools and components. However, such systems also have to be used by a specialist to run the different scenarios, adjust the simulations and interpret the results.

Bearing in mind the complexity of the scenarios, many of the systems may become too vendor-oriented, making use of proprietary connectors and tools.

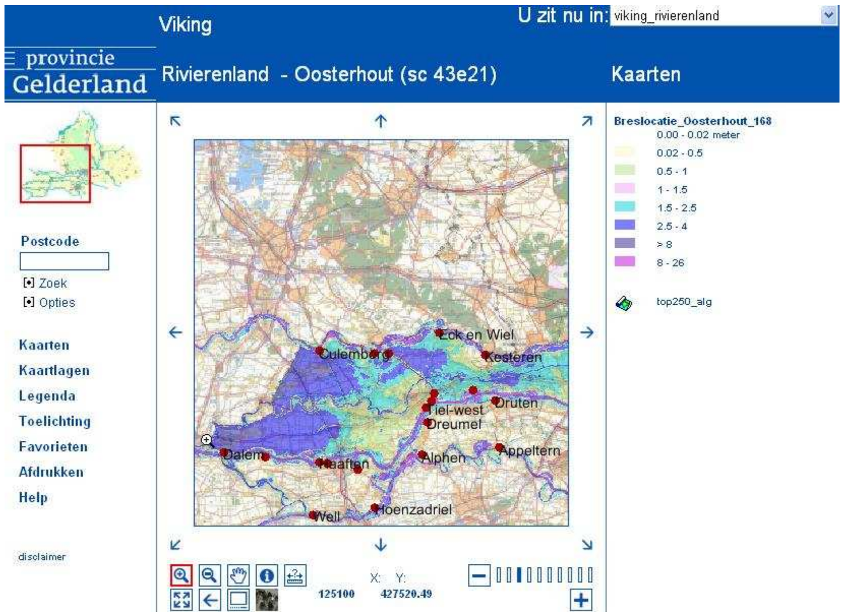

Figure 6. Viking flood warning module.

VIKING

The VIKING project began as a cross-border collaboration between water management organisations and incident management organisation in the province of Gelderland in the Netherlands and the German state of Nordrhein-Westfalen (http://www.programmaviking.nl/). The system that has been developed in the project is a typical example of scenario-based flood disaster management systems. It has many of the functionalities of a traditional GIS. The graphic user interface is based on maps and aerial photographs and the flooded areas are interactively shown on the screen with prediction animation. VIKING enables communication between different systems (that provide the necessary information), interaction between separate procedures and cooperation between different organisations. One of the modules is the Flood Information Warning System (FLIWAS), which contains an evacuation model described by van Zuilekom and Zuidgeest (2008). Training and simulations are provided by the Virtual Cockpit, which is shown in Figure 6.

Delft-FEWS

A very interesting example is the Flood Early Warning System (FEWS) at WL|Delft Hydraulics (http://www.wldelft.nl/soft/fews/int/index.html), which has grown from a simple tool based on the combination of hydrodynamic and hydrological models into a highly functional real-time simulation program. The system uses an open shell flood forecasting system that provides essential generic (GIS) functionality for handling real-time data, data assimilation and managing forecast runs, while also allowing integration of existing forecasting modules through an open 'XML-based' interface. The modular structure of the system and generic forecasting functionality allow natural integration of the system into the flood warning process, without the requirement of extensive migration to a specific modelling environment.

OSIRIS

Developed as one of five prototypes of the OSIRIS project (Operational Solutions for the management of Inundation Risks in the Information Society) is yet another system for flooding (Erlich, 2006). The emphasis in this case is on an interface, which can help citizens to understand official forecasts. The system allows the integration of various data, such as risk maps, flood prevention plans and rescue organisational charts. Detailed information is available at http://www.ist-osiris.org/.

Indian Tsunami Early Warning System

The Indian Tsunami Warning Centre established at the Indian National Centre for Ocean Information Services (INCOIS) in Hyderabad opened in October 2007 (http://ioc3.unesco.org/icg-iii/documents/natreports/Indian%20National%20Report.pdf). It is perhaps the largest centre of its kind and collects information from the Indian national seismic network and other international seismic networks. The system running at the centre detects earthquake events of more than magnitude 6 on the Richter scale, which occur in the Indian Ocean in less than 20 minutes after the event. The dedicated software for the automatic location of earthquakes uses a large database of model scenarios for different earthquakes to estimate the travel time and magnitude of the tsunami. Once an earthquake occurs an appropriate scenario is selected, based on the location and magnitude of the earthquake, to adjust various predefined parameters. The scenario is needed to estimate the travel time and magnitude at various locations. At the same time, all the responsible organisations and individuals are alerted by email, fax, text messages and telephone. The use of geo-information is quite advanced. Different visualisation environments are used to display sensor information, to analyse measurements and to plot results. Areas can be identified where the population should be warned of the approaching disaster. The system makes use of various types of GIS information, including several modes of visualisation (e.g. Google Earth).

Various similar applications have also been developed by large vendors, including ESRI (Amdahl 2001), Bentley (www.bentley.com) and Integraph (www.intergraph.com). Most of these, however, rely on specially prepared datasets and models.

3.2.2 Demand-based systems

Very typical examples of demand-based systems are the command and control systems developed mostly at local and regional levels. These applications concentrate on the communication and sharing of information between different units; they are able to access distributed information and share dynamic data. The tools are available to all the users involved in a particular incident and are not domain-oriented (e.g. not only for police).

CCS (http://www.gdi4dm.nl) and MultiTeam (http://www.multiteam.info) are two systems for coordination and cooperation in the event of an emergency in the Netherlands. In both systems the different responding agencies (fire service, paramedics, police, municipal authorities and other special units) can log in to the system and exchange information about their location and the tasks that they are performing. They can show the location of their mobile units on a map (using special symbols) or mark important areas, such as those not accessible to the public. Each user of the system can select from a number of maps. Some maps can be accessed by other institutions via certain web services. The two systems differ slightly in their functionality and access to the information. While MultiTeam, shown in Figure 8, has a quite large local database with information, the concept of CCS (Diehl and van der Heide 2005), shown in Figure 7, is to provide access to distributed information stored at the individual organisations. In both systems, however, the spatial functionality is limited and extended spatial analyses are not available yet. The only available operation is map overlay for interpretation by visual inspection. Simulations (as discussed in flood risk management, above) are not available. Compatible communication systems are being developed to improve communication when flooding is imminent.

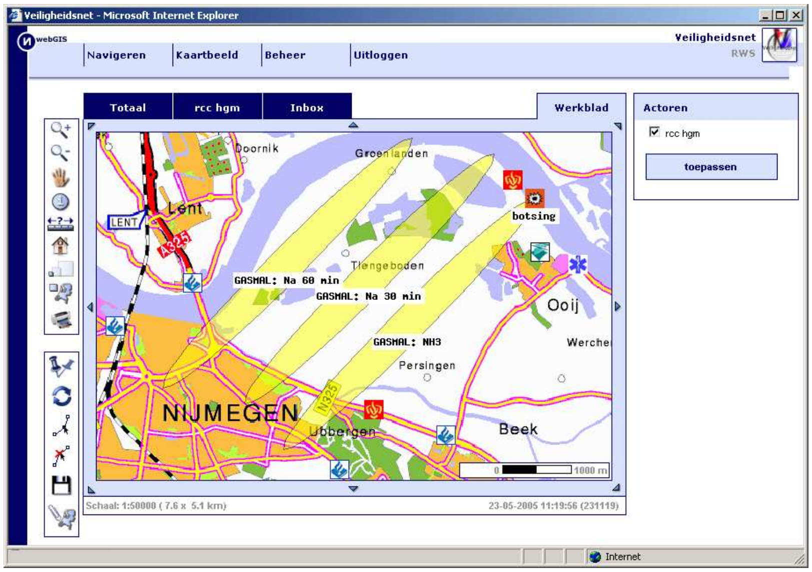

Figure 7. CCS showing predicted plumes.

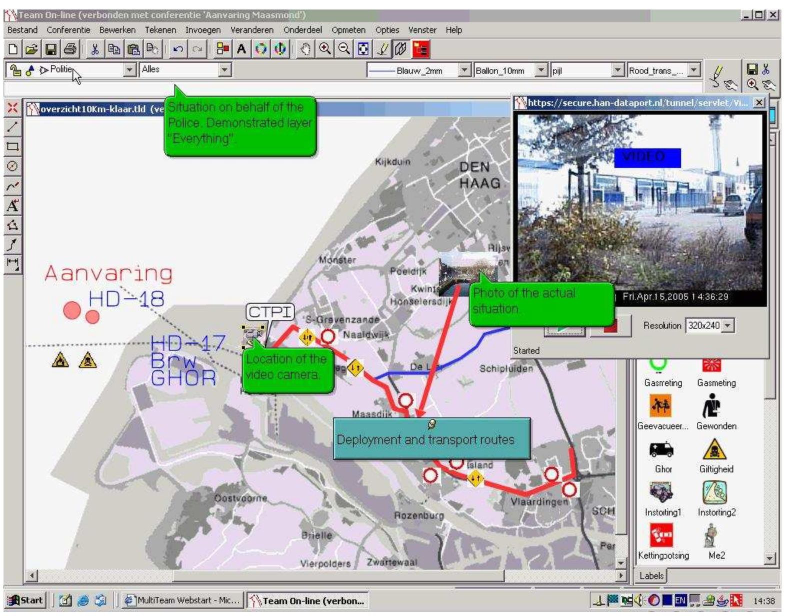

Figure 8. MultiTeam interface.

A remarkable work has been completed within the Open Geospatial Consortium (OGC) Open Web Services (OWS) Phase 4 test bed. Two major demonstrations have been presented, 36 interoperability program reports have been written, and 59 components have been developed in this test bed. One of the demonstrations is devoted to various aspect of emergency response: integrating data from GIS and CAD applications (in a 3D viewer), monitoring dangerous gas dispersion and integrating data from various sources – all based on OGC web services such as WFS (web feature services), WCS (web coverage services), SOS (sensor observation service) (Döllner and Hagedorn 2008; Lapierre and Cote 2008).

3.3 The human perspective

Geo-information is now used in all phases of disaster management in various forms, from paper maps to digital models equipped with elaborated simulation and analysis tools. Many of these systems are still only understandable to the specialists and it should be noted that many professionals involved in risk and disaster management are not familiar with GIS technology, and may even have difficulty reading maps. Several authors (Kevany 2005; Neuvel and Zlatanova 2005; Brecht 2006) have discussed the various challenges in using GIS technology during disasters. Observations and tests have revealed many interesting issues.

In recent years the range of end users has become wider, but actual use of geo-information continues to be restricted primarily to those using Geo-ICT in their day-to-day work. Reports from recent emergencies indicate Geo-ICT use for a wide range of activities, from those managing and combating the emergency and involved in search and rescue operations to support operations in transportation, medical care, evacuation and shelter, security and recovery.

The technical skills of those involved in emergency management are slowly improving, although the majority still lack Geo-ICT knowledge. Most operations that involve the use of geo-information continue to be performed by geo-experts, who generate products for emergency personnel. In many cases hard copy maps are still the primary geo-products used in emergency response. Those using them tend to possess only general map-reading skills and little special emergency training is available (Kevany 2005).

Various organisations have recognised this problem and have formally or informally identified people to provide staffing for emergency response on an ‘all-times’ basis. An example is the GISCorps (http://www.giscorps.org), which was founded in 2003 in the USA to provide a formal mechanism for arranging volunteer information support where disasters overwhelm the capabilities of the local GIS organisations. At the end of 2007 GISCorps had over 1,100 enlisted volunteers spread across 47 countries in five continents. These volunteers include natives of 57 countries and the US volunteers come from all 50 states. GIScorps has implemented 20 missions around the world and clocked up over 5,100 volunteer working hours.

Geo-ICT usage is not identified as a specific emergency response function in most emergency response units. Consequently, most Geo-ICT experts working in disaster management are advisors and very few become emergency managers and decision makers. Little has been done to develop emergency geo-information leadership through training programmes or other mechanisms. As discussed in the literature (e.g. Brecht 2006), strong leadership is critical in emergencies. Lacking emergency training and having little opportunity to gain experience, Geo-ICT experts are therefore generally at a disadvantage compared with emergency managers and responders. The alternative – training managers to become expects in understanding and operating with geo-information – is also hardly applied

Emergency managers are trained to save lives and protect property and infrastructure. The tools of the geospatial professionals are never the first things people think of when a disaster actually strikes. People on the field react according to their experience, training and instincts. In a crisis situation, people are reluctant to take the risk of relying on technology if they are not familiar with it. Recent studies have shown that only after employing a technology in their daily work do people feel confident enough to use it in emergency situations.

A general tendency towards increased interest in Geo-ICT can be observed. A large user investigation performed in early 2007 among fire fighters, police, ambulance and local authority staff in a province in the Netherlands (Snoeren 2007) has clearly revealed a desire for better systems that can provide a good overview of progress with combating disasters. Exhaustive information (from a large numbers of updated maps with locations of responders and in situ sensor data), better hardware (fast servers and communication channels) and improved graphic user interfaces are some of the issues mentioned.

4 Further application of Geo-ITC in disaster management

Utilisation of geo-information in risk and disaster management is rapidly increasing, but a large number of developments in geotechnology can be envisaged. Some emerging areas are listed below.

Spatial data infrastructures, semantics, ontology

A spatial data infrastructure (SDI) is intended to create an environment that will enable users to access and share spatial data in an easy and secure way (van Lonen 2005; Nebert 2004). Practically, it ensures that users save resources, time and effort because it provides access to data via standardised services and protocols. Generally, an SDI is defined as consisting of spatial data, standards, networks and policies. All components play a critical role in establishing an SDI for disaster management, but the technical aspects (spatial data, networks and standards) are especially critical. In this respect two international initiatives are of significant importance: the EU INSPIRE Directive (establishing an Infrastructure for Spatial Information in the European Community) for harmonisation of geo-information, and the European GMES initiative (Global Monitoring for Environment and Security) to bring data information and providers together with users. The European Commission has funded numerous large projects, for example for defining services (ORCHESTRA), developing data models (WIN), monitoring and processing of sensor networks (OSIRIS) and cooperation between different systems (OASIS). Various similar initiatives have been initiated at the national level (e.g. in the Netherlands: www.gdi4dm.nl, http://www.geonovum.nl/ontwikkeling-imoov.html) which pay much attention to client-server architectures that use standardised services. There is growing awareness that the information needed for risk and disaster management should be available for access at the source (which ensures that the information is up to date and reliable) and not managed centrally using replicated information from the original hosts.

Successfully integrating and analysing various types of data and providing appropriate information to the end users requires not only standards, but also a strong formalism to deal with the most difficult problem: the semantics of data. The spatial data used in disaster management are usually collected and managed within specific domains (land register, topography, utilities, water, soil, etc.) using specific representations and notations. These need to be understood by the users in the response sector, in risk management and in land use planning. Moreover, these users have different terminology and use specific language to denote features from the real world. It is expected that formal semantics and ontology will greatly help in providing the right information to the right people (Xu and Zlatanova 2006).

Management of dynamic data

A variety of systems (GIS, CAD, Architecture, Engineering and Construction (AEC) software DBMS and combinations of these) can be employed for managing operational (in situ) data. One of the most critical aspects of a system for emergency response is time. Fast and efficient storage of fresh data into databases, quick search of data, flexible maintenance of time sequences and robustness of the approaches used are among the most important aspects to be addressed. All these processes have to be near real time. The in situ data used in emergency response are usually sensor data delivered by stationary gauges for monitoring particular phenomena (river level, gas dispersion, volcanic activity, etc.) or sensors (cameras, laser scanners, radar), mounded on mobile, aerial or satellite platforms, or information about moving objects (such as ambulances and police cars, fire engines and people) (Zhang et al. 2002).

The second problematic issue is the third dimension. 3D geospatial information has always been a challenge due to the variety of data models, resolutions and details, and representation methods (boundary representations, voxel, constructive solid geometry, CSG). Since the 9/11 disaster in New York, interest in 3D models (of buildings, underground systems) for emergency responses has grown, but there is still no commercial system that can be used easily to manage and analyse 3D data. Obtaining 3D models of indoor environments is a challenging issue, especially when they have to be created in real time. Indoor spaces can be measured (using laser scanning or images) and reconstructed (by 3D modelling software) but this process usually requires much manual intervention (to resolve complex topologies that commonly occur). A promising approach is simplification of 3D design CAD models of buildings represented in the IFC (Industrial Foundation Classes) construction standard (Isikdag 2006). This approach allows a high level of automation, but there is a risk that the building has been modified during the construction.

Spatial analysis

Many tasks in disaster management require the affected area to be delineated with respect to area ofimpact. In GIS technology, this operation is known as the buffer operation. Suppose response units are looking for a water supply near a burning building. The first step in this operation can be to create a buffer object from a feature (such as a building on fire). Sources of water within the buffer object can then be identified using an overlay operation. In 2D, the buffer object is a polygon, while in 3D the buffer object is a 3D solid object. The 3D searching operation should be able to resolve complex geometric computational problems involved in defining topological relationships (inclusion relationships) between the 3D buffer object and well-formed 3D objects representing a microscale urban area (such as spatial units in a building) (Lee and Zlatanova 2008).

Another challenging operation that needs to be performed is a shortest path analysis in 3D space. Several evacuation algorithms have already been reported in the literature (e.g. van Zuilekom and Zuidgeest 2008). Most of the evacuation algorithms are 2D and cover outdoor spaces (the road networks). Scott (1994) implemented a shortest path algorithm for an unindexed three-dimensional voxel space using a cumulative distance cost approach. This approach produces a set of voxels, such that each voxel contains an attribute about the cost of travelling to that voxel from a specified start point, if there is uniform friction of movement throughout the representation. A 3D shortest path algorithm moves through the 'cost volume' along the steepest cost slope from target to origin using a 3 x 3 x 3 search kernel (Raper 2000). Boundary representation approaches are discussed in Kirkby et al. (1997), Kwam and Lee (2004). Zhu et al. (2008) implemented a modified version of the 'Dijkstra' shortest path algorithm in a 3D GIS, in which the gradient over a 2.5D surface was added into the computation. However, much research is still required to address the diversity of problems in evacuation from large buildings.

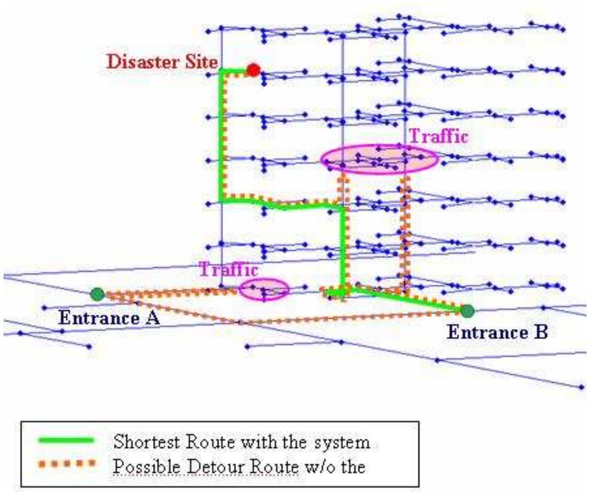

Figure 9. Navigation routes in a building (Source: Kwam and Lee 2004).

Visualisation environments

One of the first possibilities to be considered is the human interaction with the system. New tools have to be constructed to ensure intuitive interfaces and easy-to-use visual environments. Virtual reality environments, such as Google Earth, Visual Earth, Second Life, and even more elaborate environments like CAVE (Cave Automatic Virtual Environment) or augmented reality systems still have to be explored. In this respect, a very interesting tool is the touch table, shown in Figure 10. Users around the table interact with the system directly with their hands, avoiding the use of input devices such as a mouse or keyboard. The information displayed on the table is tangible for the users, allowing them to retrieve information by direct contact with the table (Scotta et al. 2008). The system permits multiple users to work together and in parallel when gathered around the table. This multi-user quality introduces an original and unusual aspect to the system, since the current hardware and software is still based on single user input and as a consequence users are not aware of the advantages that can be derived from a multi-input tool. Such devices can be particularly beneficial in command and control centres, where decision makers analyse incidents and discuss response actions.

Figure 10. Touch table at Geodan B.V, the Netherlands.

5 Discussion

In this chapter we have introduced the disaster cycle and its associated terminology and discussed the importance of location and Geo-ICT in disaster management. This shows how an increase in awareness has led to critical needs for Geo-ICT advances to overcome many of the present pitfalls in disaster management. These include risk maps of both the natural and technological risks and the importance of timely information delivery for effective emergency response. Present and future developments were pointed out in the areas of SDI, dynamic data, spatial analysis and visualisation environments.

The complexity of Geo-ICT systems and models used in risk and disaster management depends on the stage in the disaster management cycle. Maps are largely used as background information for location awareness and decision making, but the functionality of offer is varied. While the risk prevention phase can benefit from elaborate modelling and simulation tools, applications in the response phase are limited to relatively simple communication modules. Apparently, the time restriction and human perception are some of the major bottlenecks for working with complex models and of leaving decisions to be taken by 'machines'. Greater awareness of and trust in Geo-ICT is needed. This can be achieved by more training, but also by developing systems and tools that can be used in daily routine work.

It is increasingly important to allow the sharing and exchange of information within the entire disaster management cycle, from risk prevention and mitigations to response and recovery. As mentioned earlier, risk management have been mostly performed by land use planners who increasingly recognise the need to study disasters so that they can improve the quality of planning decisions, and particularly to arrange for preventative evacuation in the likelihood of a disaster. Armed with the knowledge that some areas are more vulnerable to a disaster than others, including the availability and capacity of escape routes, local and regional authorities could adapt spatial policies and development plans accordingly. The emergency sector is also seriously considering the implications of risk criteria and vulnerable objects used by land use planners. The systems that are used in land use planning contain information on hazardous sites and the location of vulnerable objects that can be extremely useful for emergency services. As this review has shown, hazard modelling systems are evolving to real-time demand-based systems to be used in emergency response. In this respect, building a SDI for disaster management can greatly contribute to connecting different systems and sources of spatial information. The use of web services and obtaining information via internet will play a critical role in the near future. Downloading, copying and storing information on local servers will be reduced drastically. The number of web services in use is growing and many new systems rely on client-server architectures using web services.

Risk and disaster management can be seen as an emerging science in which spatial information plays a significant role. Again, a distinction must be made between risk management and disaster management. While risk management could be referred to as an *explicitly spatial* discipline, disaster management is even more *implicitly spatially-oriented*. In the event off an emergency, the use of spatial information (except location) is not normally seen as the first priority. However, as the technology develops and new tools allow for a better use of spatial information, crisis management will evolve into a typically spatial discipline. The increasing availability of GIS analytical functions such as buffers, within-area, field-of-view, shortest distance and best distance (avoiding blockages and dangerous areas) and the capacity to dynamically monitor and forecast hazards or trajectories of moving vehicles and people during crisis response will help to make disaster management a fully spatially-oriented discipline. In addition, more advanced analytical tools should be developed to move from static to dynamic representations of spatial information. The aim should be to create spatial risk databases in which risk zones can be identified, queried in different manners and supported by reliability and certainty labels for task prioritisation.

Clearly, awareness of the importance of spatial information in both risk management and disaster management is growing. Two general tendencies can be distinguished here. Firstly, an increasing number of different types of spatial data are being used to perform tasks within risk and disaster management. Second, a general understanding is building up about sharing information between the two domains. This tendency is especially strong for spatial information and it is even difficult to determine when spatial information was first used in risk or disaster management. Both natural and man-caused hazards have been studied and modelled as real world phenomena and modelling has always been based on some kind of spatial information. However, practice in recent years has revealed the need for the integration of multiple spatial datasets in order to perform more complex analyses. Progress in Geo-ICT has been contributing to this process by making management, use, analysis and visualisation of various spatial-temporal data possible with easily adaptable and user-friendly interfaces.

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