Geo-ICT for Risk and Disaster Management

S. Zlatanova[1] and A. G. Fabbri[2]

[1]GIS Technology, OTB, Delft University of Technology, Jaffalaan 9, 2628 BX, Delft, The Netherlands, phone +312782715, fax: +312784422
[2] SPIN*lab*, Vrije Universiteit, De Boelelaan 1087, 1081 HV Amsterdam, Netherlands & *DISAT*, Università di Milano-Bicocca, Piazza della Scienza, 1, 20126 Milan, Italy

E-mail: s.zlatanova@tudelft.nl andrea.fabbri@ivm.vu.nl;

Abstract

There is no doubt about the importance of Geo-ICT in risk and disaster management. Systems making use of geo-information are used in all activities before, during, and after the disaster. In this chapter we will address the use of Geo-ICT in two stages of handling disasters before and during occurrence. Special attention will be given on the real utilization of geo-information, e.g., risk maps, topographic maps, etc. A brief analysis of current risk maps and of their limitations sets the stage for a research work that could overcome some of the present unsatisfactory application aspects of risk maps. Access to and provision of spatial information is elaborated with respect to the need of emergency response systems. The last section discusses the challenges in the use of geo-information for disaster management.

Key words: emergency response management

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 all kinds of agencies all over the world, although some institutions have implied specifications at a national basis. The first phase is also referred to as risk management while the second three as to disaster (or crisis) management.

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

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 the classification of hazards is done regarding the hazard's origin. So the usual classes are 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 (e.g., Stingfield, 1996) are known from the literature. Schneiderbauer (2007) suggests the four different groups of: pure geogenic (e.g., earthquakes, tsunamis, and landslides), geo-anthropogenic (meteorological, oceanographic, hydrological, biological), anthropogenic-technological (explosions, release of toxic materials, structural collapses of transportation systems, constrictions or manufacturing accidents), anthropogenic-conflict (crowd-related, terrorist activity, political conflicts). Disasters can be defined as events triggered by hazards. Disasters are actually 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 specifics. Prevention and Mitigation focuses long term measures in order to reduce the vulnerability, or more rarely the hazard. Preparation focuses on the active preparation for an occurring case of emergency. The rescue forces (e.g., police, ambulance, fire brigade) are trained on how to operate and cooperate in emergency situations. Response is an acute phase after the occurrence of a case of emergency. Emergency response is the most challenging part with its dynamics and unpredictability. Recovery is a phase after the acute emergency including all arrangements to remove detriments and long-term supply of irreversible detriments.

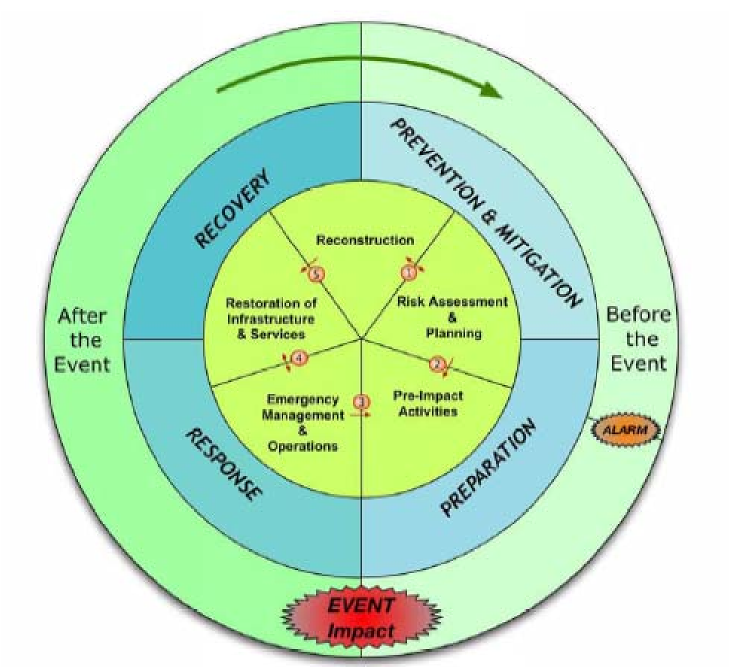

Figure 1: The disaster management cycle (PSC Forum, www.publicsafetycommunication.eu/)

These specifics influence the geo-ICT applications developed in support of the various tasks within a particular phase. For example, risk management relies on large amount 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 applications of risk and disaster management are hazard specific. Also, it is difficult to consider only one type of hazard. Very often one hazard is triggered by another. Floods near industrial areas may cause technological hazards (explosions, fires, etc.); power failure may result in an explosion and damage of a dike, which consequently may transform it into a flood disaster; earthquakes may provoke landslides, etc. Therefore, often it is the chaining of disasters triggered by a primary hazard and developing to secondary hazards that must be considered as likely. The chaining can be of 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 multi-hazard 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 reporting a disaster is about the location of the incident and its possible extensions. A variety of systems use maps, models, tracking of rescue personnel, images obtained from various scanners to monitor a disaster, to make forecast, to estimate damages, to predict risks and vulnerability, etc. (Kerle *et al.*, 2008; Li and Chapman, 2008; Zhang and Kerle, 2008). In some cases, imagery from various sensors was timely provided for analysis and estimation of damages in the latest large disaster devastations, as the one shown in Figure 2. Amdahl (2001) and Green (2002) provide numerous examples of using maps and GIS technology in all the phases of risk and disaster management utilising ESRI® software. Significant progress is observed also in the efforts by CAD/AEC and DBMS vendors in providing solutions in the management of disasters, prediction of risk, training and simulation, and in geo-visualisation.

Figure 2: High resolution Quick Bird images provided to the Aceh Region under the International Charter (courtesy, ICSMD)

However, the use of geo-ICT is still rather limited compared to the opportunities offered by the numerous and continuing disaster occurrences. Presently, geo-data is stored and used almost daily in many organisations. Geo-ICT is in growing expansion and changing in nature. The third and the fourth dimension (time) are getting increasingly familiar. Many GIS vendors provide extended 3D visualisation tools; new visualization 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 incorporate functionality, which was the domain of ultra-portable computers, while later ones are 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. Apparently, there are various factors, which complicate the use of geo-ICT in disaster management and these are going to be discussed in the following sections of this chapter. The rest of the chapter is organised in two general parts devoted to risk management and disaster management. Each of the parts discusses existing geo-ICT applied in DM and addresses challenges in and opportunities for better utilization of the latest technological developments. Section four concludes on research and developments issues to be considered in constructing integrated multi-risk, multi-disaster systems. Section five summarizes the results of this review.

2. Geo-ICT opportunities for risk management: risk maps

Risk visualization for risk management combines risk analysis and risk evaluation (for a discussion of various risk terms see, for instance, Plattner, 2004, and also 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 affecting negatively our daily life, 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 the risk management.

2.1 Risk Maps as most appealing application of Geo-ICT is 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 to assist a decision maker in taking action towards risk avoidance or mitigation, and eventually also in disaster response. 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 implies a strong responsibility for the producer and for the local administration that eventually distributes it and explains its usability.

An encouraging view of modern approaches to risk mapping is the one of Monmonnier's (1997, p. 293) extensive analysis of 'cartographies of danger.' He points at 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 … comparatively rare hazards, like volcanic eruptions are inherently uncertain … we cannot guarantee a future that uniformly replicates the past.'

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. Using the two keyword 'risk maps' 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 of how those maps should look like, and on their meaning and use as well.

For instance, various agencies or consulting groups offer services such as mapping of specific risks for areas selected by customers over regions of competence. Risks may vary from the medical field (contagious diseases), economics and industrial activities, to traffic, social unrest and terrorism, to technologic and natural hazard. 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 directed to help structuring and prioritizing 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 that are the risk maps made available by a company named 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 RMS catastrophe maps of the US, Latin America, Europe and Japan. They are small scale maps for posters intended to assist catastrophe managers and the like at conferences etc. 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 so called 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 the following 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 after the Harricane Katrina made Gulf Coast landfill on August 2005. Examples of interactive maps are available with risk assessment over backgrounds of Google Earth maps. These can be queried and instructions are made available on how to read the risk maps.

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

To obtain an impression on how relevant risk has become in many countries, it is indicative to consider that in the last 5 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' (hydrologic-geologic risk) leads to over half a million hits, with many sites providing some types of hazard, vulnerability and risk maps. Naturally, these sites just considered aim at informing citizens at large, so that scientific insight for more technically oriented users will have to be searched elsewhere.

Alternatively, an extensive risk map production is through the U.S. Geological Survey's Earthquake Hazards Program (http://earthquake.usgs.gov/), or the Landslide Hazard Program (http://landslides.usgs.gov/). In particular, the USGS geo-hazards research work (http://geohazards.cr.usgs.gov/research.php) provides a list of research projects and staff where articles can be downloaded for instance on landslide recurrence intervals and probabilities in the Seattle area, Washington State (Coe *et al.*, 2004; Schulz, 2007). Maps are provided by those authors 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 as a prediction of landslide hazard at specific sites.

Clearly, as seen in those 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 characterization of all types of risk maps 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 is 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), and 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 analyzed seem to contain measures of 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 sub-section 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. It is represented commonly either as monetary loss, i.e., $ or € values, 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.

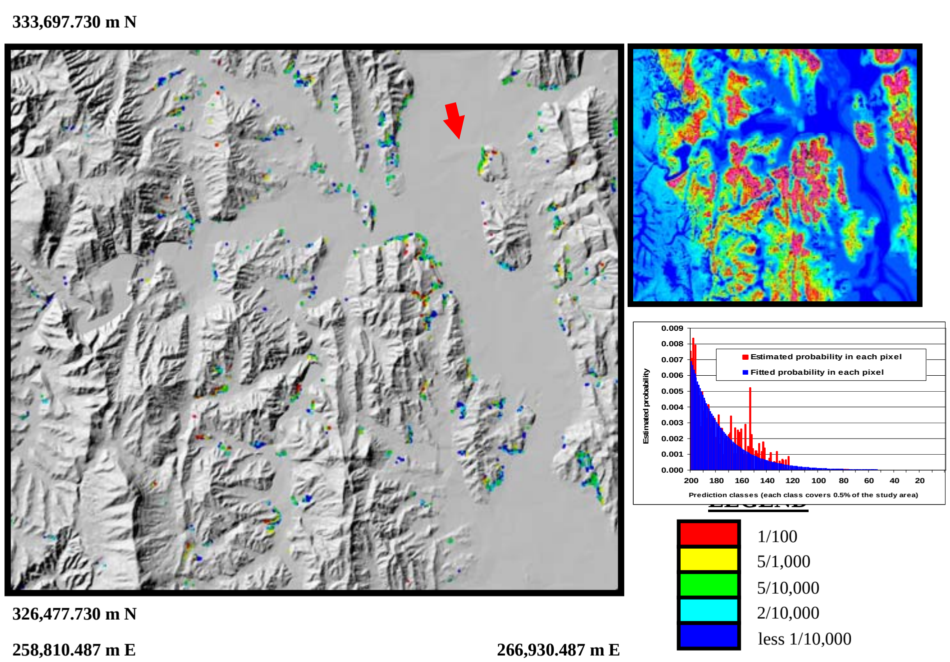

Figure 3: A 5-class population risk map of the Boeun study area located in South Korea, affected by landslide processes. The classes have been warped on a shadow relief enhanced elevation image. On the right side are the landslide-hazard prediction image and the histogram of probability of occurrence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

An example of a risk map for landslides can be seen in Figure 3 that shows a 5-class population risk in South Korea for the Boeun study area that is affected by landslides of surficial debris flow type. Naturally, most of the map has no risk values, which is due to the absence of urban settlements at those locations. The classes indicate the proportions of casualties expected per 5 m pixel. To understand the significance of the risk maps, it is necessary to know how it has been constructed using a spatial database, a specific mathematical model with 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 of 5m x 5m resolution: the 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 $ for 5m pixels and the corresponding vulnerability levels (values between 0, no damage, and 1 total destructions) were also compiled. Furthermore, information became available on 44 new landslides in the area that occurred in 1998 and 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 estimating the risk level distribution in the study area.

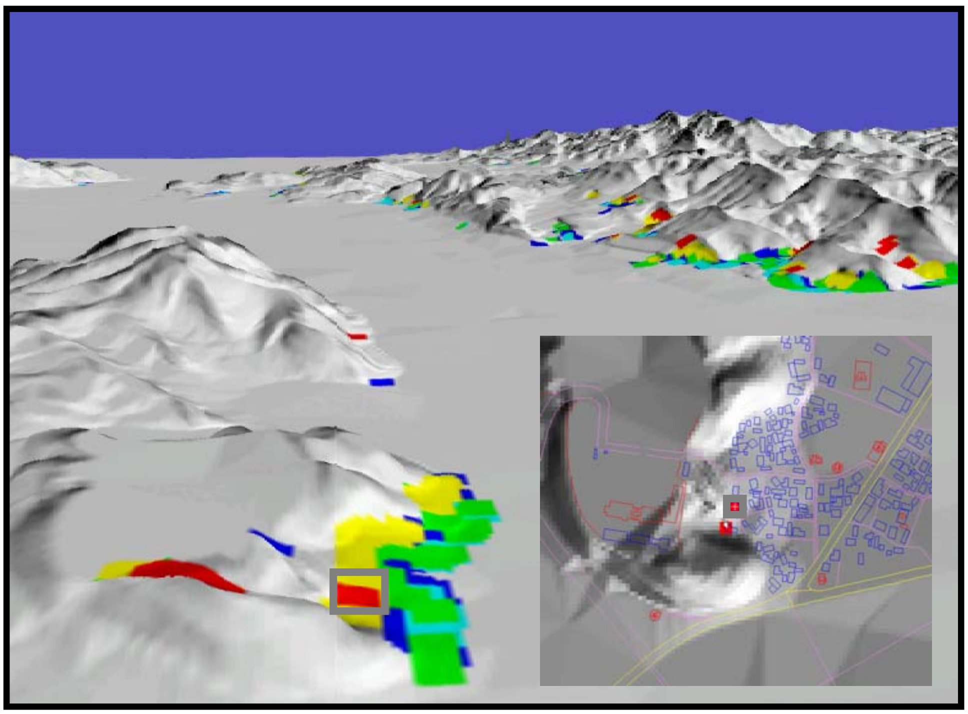

Figure 4. A fly-through is shown of the 3-D visualization of a portion of the risk map in Figure 3 where the flight direction is indicated by a red arrow. The grey box indicates the location of a house where a casualty took place. The inset on the lower right shows a top view of the population density 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 DEM, surficial geology, forest cover, land use and drainage patterns. The prediction is represented as a 200-value hazard image (using a pseudo-color 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 high proportion of the ‘validation’ landslides. This was to obtain a prediction-rate table, also visualized 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 characterization 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 indicate 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 computing the risk map in Figure 3. To better communicate the risk visually, a fly-through risk map is shown in Figure 4 where 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 then is how credible and reliable a risk map is. The three stage strategy in 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, almost coinciding in this case with 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 with the distribution of the hazardous events 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, i.e., the most critical estimation needed in risk mapping. A spatial prediction modelling software intended as 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 to communicate risk with the public at large.

Unfortunately, it is still unclear in many societies who has the role of producing such risk maps and who has the role of stakeholder or actor to contribute in the decision making related to such maps! For instance, a study by Bonachea (2006) that represented a contribution within an EC Research Network Project ALARM, (Assessment of LAndslide Risk and Mitigation in mountain areas ALARM, (contract EVG1-CT-2001-00038, 2001-2005), http://ivm10.ivm.vu.nl/webmapping/Alarm_SP_image_maps2), observed that in Europe there is no law directive to develop a policy to manage the territory in relation with natural risks. Only a resolution of October 16, 1989 (Diario Oficial de la UE., 1989) is referred to for the presentation of natural and technological risks. Worldwide, the scarcity of hazard maps seems evident. In Spain, for instance, flooding hazard has a specific normative, however, it is not clear who has a mandate to provide the hazard maps that have to show the return periods. It can be concluded then that quantitative expressions of hazards and risks are presently the targets of the risk maps still to come!

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 Directive Seveso II requires 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' are considered substances which by explosion, fire or release could lead to major accidents involving the external areas of establishments.

The Seveso II Directive is in process of implementation in all Members states. In the Dutch legislation, the Seveso II Directive is addressed by the Dutch Major Hazards Decree (BRZO) and the Dutch Public Safety Decree (BEVI). The BRZO focuses on the management of hazardous installations. The BEVI regards the regulation of land-uses around hazardous installations, i.e., the external safety regulation. Spatial decisions related to the adaptations, elaborations, modifications, dispensations and revisions of land-use allocation plans within the sphere of influence of a hazardous establishment fall under the BEVI. The Dutch external safety's methodological approach is extensively described in literature (Ale, 2002; Bottelberghs, 2000).

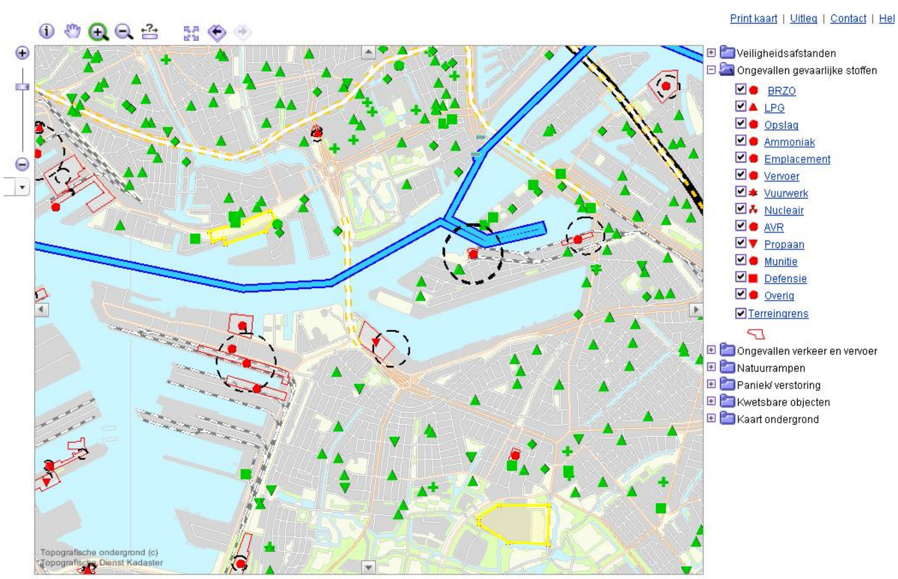

Figure 5: Risk map of province Zuid Holland. The symbols in red represent the dangerous settlements with the corresponding risk areas. The symbols in green indicate vulnerable public buildings such as schools, hospitals, etc.

The Ministry of Housing, Spatial Planning and the Environment (VROM) is competent for facilities of national interest, such as nuclear power plants (NPP) and nuclear waste disposal. Dangerous establishments falling under the Seveso II requirements are classified in accordance to threshold values considering the quantity of stored/treated dangerous substances. According to their classification, top-tier Seveso plants fall under the provincial competence and, in case of lower-tier plants and small liquid petroleum gas (LPG) stations, under the municipal competence. The vulnerability of the involved urban and environmental elements is classified accordingly to vulnerable categories (high, medium, low). Standing to this approach, the visualization of the risk connected to an accident results from the overlap between the selected accidental event, its iso-risk contours and the specific territorial context. Digital risk-maps reporting this overlap are therefore an obvious, although recent, operational development. (http://www.risicokaart.nl/).

Risk-maps are developing under the provincial responsibility in the Netherlands. One such map is shown in Figure 5. The National Installations Handling Dangerous Substances Database (RRGS: Register Risicovolle Situaties Gevaarlijke Stoffen) is used as informative source together with the Information System for Overall Disaster types (ISOR: Informatie Syssteem Overige Rampentypen). ISOR is the result of the cooperation between the 12 Dutch provinces, in which additional risk information such as flood risks and vulnerable objects are collected. The types of disasters currently considered are 11: dangerous substances, nuclear incident, aircraft incidents, accidents on water, roads, tunnels, collapse of large buildings, fire in buildings, panic in large extends (or disturbance of the public order), flood, natural fires. Thanks to these developments, previously spread out risk information is converging towards national, multi-accessible databases.

Mapping potentially dangerous establishments and vulnerable objects is a large step, but still does not help significantly in the risk management and disaster management. The most well represented hazards on the risk maps are the areas, whose locations (or extent) can clearly be determined such as buildings, tunnels, stadiums, large exhibition halls, airports, parts of roads, water ways, etc. The maps hardly give an indication about affected areas and population. The iso-areas are given only for dangerous establishments. Furthermore, 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 within that activity. Individual risk for residential areas, hospitals, schools, etc. may not exceed the legally determined 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 deal with the controllability of a possible incident. It is for example not clear whether it would be possible to evacuate an area when the water reaches a near critical level.

2.4 Examples of Common pitfalls in risk mapping

There are a number of common pitfalls in existing natural hazard/risk mapping models applied in risk and disaster management. As discussed by Chung and Fabbri (2004), some of them are: (a) the absence of statements on the assumptions made in the prediction models, (b) the lack of validation of the prediction results, and (c) the absence of estimations of the conditional probabilities of future events given the characterizations 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) need of spatial database that captures the distribution of hazardous processes, their settings and of the socioeconomic elements exposed to risk; (2) necessity to use models for estimating the hazard probabilities; (3) requirement of techniques for estimating the uncertainties associated with the models and for estimating the uncertainties associated with the database; (4) development of scenarios necessary to compute the risks; and, (5) 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 to serve them in urban planning process. As such the pitfalls listed above have not been considered critical. However, if applied in emergency response, 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 is becoming a crucial factor for successful prediction and managing the disaster. The next section concentrates on the use of geo-ICT in emergency response.

3. Geo-ICT opportunities for emergency response

Emergency response differs from the other phases in many aspects: time is critical, dynamics of events is higher than in normal circumstances, there is involvement of many people (who normally have different responsibilities), 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 been presented, which 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 large disasters (Kevany, 2005; Brecht, 2006) conclude on insufficient information about existing resources, types of data, availability and accessibility of data. Appropriate measures have to be taken prior to disaster to agree on access and availability of data. The lack of spatial data infrastructure has been reported as a major obstacle for quick data availability and transfer.

Related to this is the dynamic aspect of the information 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 this cloud develops 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 every moment, a continuous monitoring of the developments and a continuous distribution of monitored changes are necessary.

Collaboration and exchange of information. As emergency management is a multi-disciplinary 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 set up a temporal management centres in a fast manner. For example in the case of the Katrina disaster in the US, several ad-hoc centres have been created since existing structures for providing geo-information have been flooded. Another often 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 addition, experiences have shown that 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 is drawn on appropriate icons and symbols (Tatomir and Rothkrantz, 2005). The wishes for extended functionality or even artificial intelligence in support of decision-making are still minimal. 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. Interrelated to this is the desire to have a system that can be used in daily routine work that they are 'comfortable' with. The motivation behind this is directly related to the specifics of crisis response. Working with a non-familiar system will contribute to critical delays and operator stress which will inevitably lead to 'expensive' errors when mobilising emergency resources to life threatening situations.

3.2 Systems in use in emergency response

In the last several years many systems for emergency response have been developed for different types of disasters or for multi-disaster management, dedicated to a particular group of responders or multi-user. 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 integration of state-of-the-art technologies not only in GIS, but also in computer graphics, human-machine interfaces, communications, gaming, etc. Due to importance of location, most of the systems do use vector digital maps, raster maps, images (aerial, satellite, range, radar, etc.), three-dimensional 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.), others to a group of responders (e.g., fire brigade, ambulance, police, Red Cross), to a particular activity (e.g., early warning, evacuation, following patients to hospitals, etc.).

Generally, the systems can be subdivided into two large groups, i.e., 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 incorporated in the models can provide the best prediction and thus support the decision-making process. The second type is demand-based systems, which attempt to provide tools that can help in any kind of emergency. The concepts for these systems are relatively new, motivated by the fact that a disaster may change its nature and may require information (or models), which is not available for the programmed disaster type. Several examples are given below.

3.2.1 Scenario-based

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 enabling to forecast the results of the monitored process. This approach allows for an integrated data management (considering historical records), creation and integration of modelling and simulation methods, developing and adapting (calibration and validation) of scenarios with the support of advanced optimisation tools and thus allowing for forecast generation. The advantage of scenario-based approach is the possibility to concentrate and study particular phenomena in depth, involving needed specialists and carefully selecting tools and components. However, such systems have also 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 much vendor-oriented, making use of proprietary connectors and tools.

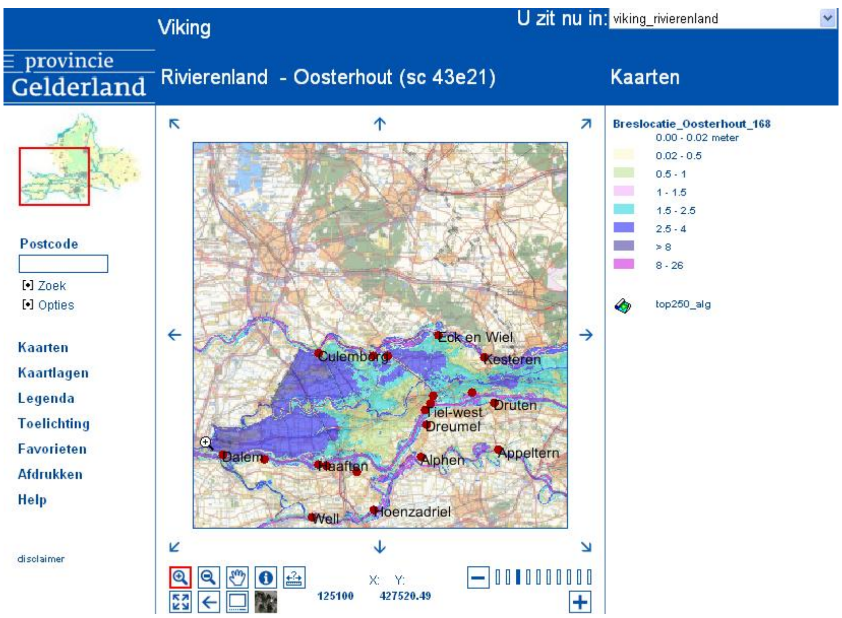

Figure 6: Viking flood warning module

VIKING: The project VIKING has started as a cross border cooperation between water management organisations and incident management organisation in the province of Gelderland, in the Netherlands and the province of Nordrhein-Westfalen, in Germany (http://www.programmaviking.nl/). The developed systems are a typical example of scenario-based (flood) disaster management system. The system has many of the functionalities of a traditional GIS. The graphic user interface is based on maps and aerial photographs, flooded areas are interactively shown on the screen with prediction animation. VIKING realizes communication between different systems (that provide needed information), interaction of separate procedures and cooperation between different organisations. One of the modules is the Flood information warning system (FLIWAS), which contains an evacuation model as described by van Zuilekom and Zuidgeest (2008). Additionally, Virtual Cockpit is available that allows training and simulations, as 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 highly-functional-real-time-simulation software. 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 are shown to allow natural integration of the system in the flood warning process, without the requirement of extensive migration to a specific modelling environment.

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

Indian Tsunami Early Warning System. The Indian Tsunami Warning Centre established at 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 one for protecting against tsunami. The centre reserves information from the national seismic network and other International seismic networks. The system running at the centre detects earthquake events of more than 6 Magnitude according to the Richter scale, which occur in the Indian Ocean in less than 20 minutes. Dedicated software is being used for automatic location of earthquakes that requires the use a large database of model scenarios for different earthquakes. On the basis of this information, the travel time and magnitude of tsunami is estimated. At the time of the earthquake occurrence, based on location and magnitude of the earthquake, an appropriate scenario is selected adjusting various predefined parameters. The scenario is needed for estimating travel time and magnitude at various locations. At the same time alert is sent to all the responsible organizations and people via e-mail, fax, sms, and telephone. The use of geo-information is quite advanced. Different visualization environments are used to display sensor information, to analyse measurements and plot results. Areas can be delineated in which the people can be warned for 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, such as ESRI (Amdahl, 2001), Bentley (www.Bentley.com), Integraph (www.intergraph.com), and others. Most of them, however, rely on prepared specific data sets and models.

3.2.2 Demand-based

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 cooperation, 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 case of emergency in the Netherlands. In both systems the different responding agencies (fire service, paramedics, police, municipalities, and other special units) can log-in in the system and exchange information about their location and the tasks that they are performing. They can exhibit the location of their mobile-units on a map (using special symbols) or mark important areas, e.g., those not accessible to the public. Each user of the system can select from a number of maps. Some maps are accessible form other institutions via 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 accessing distributed information (stored within the organizations responsible for their own service delivery). In both systems, however, the spatial functionality is limited, i.e., extended spatial analyses are not available yet. The only available operation is map overlay, which is further estimated by visual inspection. Simulations (as discussed in flood risk management) are not available. In addition, compatible communication systems are being developed to improve communication during imminent floods.

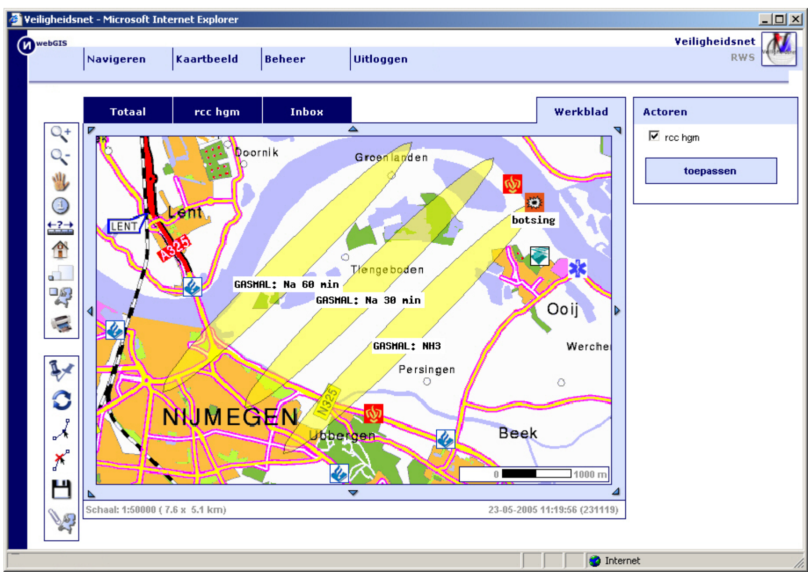

Figure 7: CCS showing prediction of a plume

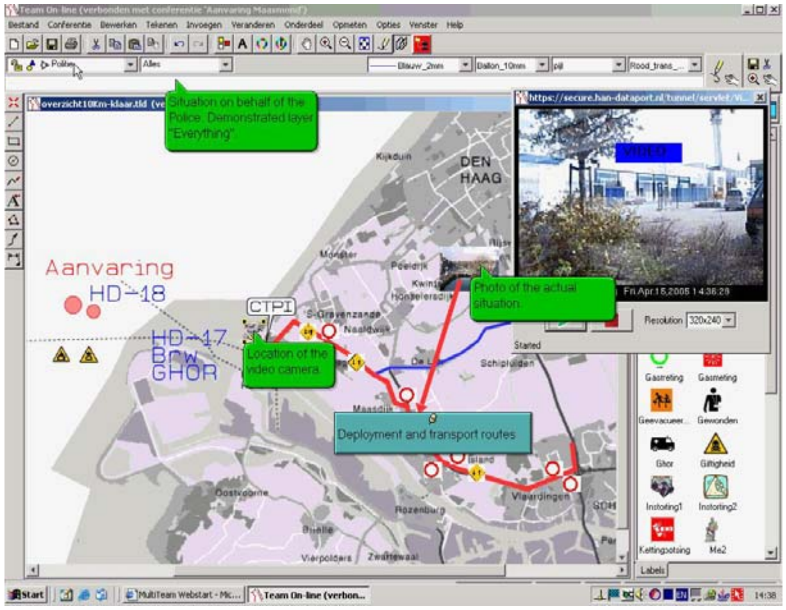

Figure 8: MultiTeam interface

A remarkable work has been completed within the OGC OWS Phase 4 test bed. Within this test bed, which has been used for two major demonstrations, 36 interoperability program reports have been written, and 59 components have been developed. One of the demonstrations is devoted to various aspect of emergency response: i.e., integrating data from GIS and CAD applications (in a 3D viewer), monitoring dangerous gas dispersion, integrating data from various sources and all was based on OGC web services such as WFS, WCS, SOS, etc. Noticeable, 72 organizations have responded to the call for participation (Döllner and Hagedorn, 2008; Lapierre and Cote, 2008).

3.3 The human perspective

Presently, geo-information is 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 those systems are still understandable only for the specialists. It should not be ignored that in risk and disaster management many professionals take part who are not familiar with GIS technology and have difficulties even in reading maps. Several publications (Kevany, 2005; Neuvel and Zlatanova, 2005; Brecht 2006) have discussed the various challenges in using GIS technology during disasters. Observations and test have revealed many interesting issues.

The range of end users is getting wider in the last several years. The actual use of geo-information, however, continues to be very limited, primarily to those operating with geo-ICT technology in their day-to-day operations. Reports from recent emergencies have been indicating geo-ICT use for a wide range of activities from those managing and combating the emergency, to search and rescue, to support operations in transportation, medical care, evacuation and shelter, security, and recovery.

Slowly, the technical skills of those involved in emergency management are improving, though the majority of persons still lack geo-ICT knowledge. Most operations with geo-information continue to be performed by geo-experts who generate products for emergency personnel. Very often hard copy maps continue to be the primary geo-products used in emergency response. The understanding of their effective use is still limited to general knowledge of maps with little special emergency training available (Kevany 2005).

Various organizations have recognized this problem and have formally or informally identified multiple persons to provide staffing for emergency response on an 'all-times' basis. For example 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 organizations. Presently (end of 2007), GISCorps has over 1,100 enlisted volunteers. They reside in 47 countries over five continents and are natives of 57 countries. The US volunteers come from all 50 states. GIScorps has implemented 20 missions around the world, and has contributed with over 5,100 volunteer working hours.

Geo-ICT experts remain only advisors and hardly become emergency managers and decision makers. In contracts to all other activities in emergency response, little has been done to develop emergency geo-information leadership through training programs 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 persons are generally at a disadvantageous position relatively to emergency managers and responders. Geo-ICT usage is not identified as a specific emergency response function in most emergency response units. The alternative, i.e., training managers to a level of becoming expects in understanding and operating with geo-information is also hardly applied

The emergency managers are trained to saving lives and protect infrastructures. The tools of the geospatial professionals are never first in anyone's mind when actually people are hit by disaster. People on the field react according to their experience, training, instincts. Humans in a crisis situation hardly take the risk of relying on technology if they are not familiar with it. Recent studies have shown that only after employing technology in daily work, the trust is increased to a level to be used in emergency situations.

Generally a tendency for increased interest in geo-ICT is observed. A large user investigation performed in early 2007 among fire fighters, police, ambulance and municipality in a province in the Netherlands (Snoeren, 2007) has clearly revealed a wish for better systems providing good overview on the combat with the disaster. Exhausted information (from a large numbers of updated maps to locations of responders and in-situ sensors data), better hardware (fast servers and communication channels) and improved graphic user interfaces are some of the mentioned issues.

4. What else can be done with Geo-ITC for DM?

Utilisation of geo-information in risk and disaster management is rapidly increasing, but a large number of geo-technology developments 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 of 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: INSPIRE and GMES, for harmonisation of geo-information and global monitoring for environmental management and security purposes, respectively. The European commission has funded numerous large projects, e.g., for defining services (ORCHESTRA), developing data models (WIN), monitoring and processing of sensor networks (OSIRIS) and co-operation between different systems (OASIS). Various similar initiatives are initiated at national level (e.g. in the Netherlands: www.gdi4dm.nl, http://www.geonovum.nl/ontwikkeling-imoov.html). In this respect, much attention is paid to all projects and initiatives on client-server architectures, which make a use of standardized services. There is growing understanding that the information needed for risk and disaster management should be available for access at the source (and thus ensuring updated ness and reliability) and should not be managed centrally with replicas from the original host.

To be able to successfully integrate various data, analyse them and provide appropriate information to the end users, not only standards but also a strong formalism is needed to deal with the most difficult problem, i.e., semantics (meaning) of data. The spatial data users in disaster management are usually fetched and managed within a specific domain (cadastre, topography, utilities, water, soil, etc.) using specific representations and notations. Those need to be understood by the users in the response sector, in risk management and in land-use planning. Moreover, these users have different expressions and use specific languages 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 their combinations) can be employed currently for data management of existing and operational (*in situ*) data. One of the most critical aspects of a system for emergency response is time. Fast and efficient storage of newly arriving 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 can be seen as sensor data delivered by stationary gouges for monitoring particular phenomena (river level, gas dispersion, volcano’s activities, etc.) or sensors (cameras, laser scanners, radars), mounded on mobile, aerial or satellite platforms, or information about moving objects (such as ambulance and police cars, fire brigade trucks, humans) (Zhang *et al* 2002).

The second problematic issue is the third dimension. 3D geospatial information has always been a challenge due to a variety of data models, resolutions and details, ways of representation (boundary representations, voxel, constructive solid geometry, CSG), etc. Since the so-called 9/11 disaster in the US, the interest in 3D models (buildings or undergrounds) for emergency responses has increased, but still no commercial system exists that can be used easily for management and analysis of 3D data. Obtaining 3D models of indoor environments is a challenging issue, especially when they have to be created in real-time. Indoors can be measured (using laser scanning or images) and reconstructed (by 3D modelling software) but usually this process 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 construction standard IFC (Industrial foundation classes) (Isikdag, 2006). This approach allows a high level of automation but the risk exists that the building has been modified during the construction. Besides indoor, 3D outdoor models of disaster areas might appear very appropriate for damage assessment and possibilities to make good estimations of needed efforts and time for recovery and reconstruction.

Spatial Analysis

Many tasks in disaster management are related or require effected area to be delineated (even with their spatial variation of impact). In GIS technology, this operation is known as the buffer operation. Suppose response units are looking for a water supply nearby a building in a fire. The first step for this operation can be to create a buffer object from a feature (such as a building in fire), and then water suppliers will be identified within the buffer object using an overlay operation. In 2D, the buffer object is a polygon, while the buffer object is a 3D solid object in 3D. The 3D searching operation should deal with complex geometric computational problems involved with defining topological relationships (inclusion relationships) between the 3D buffer object and well-formed 3D objects representing a micro-scale urban area (such as spatial units in a building) (Lee and Zlatanova 2008).

Another needed and challenging operation is a shortest path analysis in 3D space. Several evacuation algorithms are already reported in the literature (e.g., van Zuilekom and Zuidgeest, 2008). Most of the evacuation algorithms are predominantly 2D and mostly outdoor (considering the road networks). Scott (1994) implemented a shortest path algorithm for an un-indexed 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 three-dimensional shortest path algorithm moves through the 'cost volume' along the steepest cost slope from target to origin using a 3 by 3 by 3 search kernel (Raper, 2000). For B-rep approaches, 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, still a lot of research is required to address the diversity of problems in evacuation from large buildings.

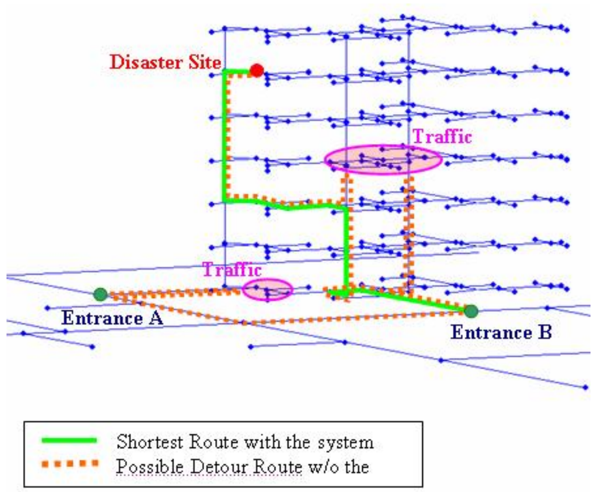

Figure 9: Navigation routes in a building (from Kwam and Lee, 2004)

Visualization 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 Live, or even more elaborated such as CAVE (Cave Automatic Virtual Environment) or Augmented Reality systems still have to be explored. In this respect, a very interesting tool is the so-called 'touch table', shown in Figure 10. Users around the table interact with the system directly with their hands avoiding input devices, such as a mouse or a keyboard. The information displayed on the table is tangible for the users, allowing them to retrieve information with a direct contact on the table (Scotta *et al.*, 2008). The system permits multiple users to work together and in parallel when gathered around the table. The 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 especially successful in command and control centers, where decision makers analyze incidents and discuss response actions.

Figure 10: Touch table within Geodan B.V, The Netherlands

5. Discussion

In this chapter we have discussed the importance of location and geo-ICT in Disaster Management. We have introduced the disaster cycle and its associated terminology. This was to justify how an increase in awareness has led to critical needs for Geo-ICT advances to overcome many of the present pitfalls in DM. Risk maps were discussed next, to cover both the natural and the technologic risks. Developments in emergency response followed that are hinged on time and timeliness to be effective. Present and future new developments were pointed out in the areas of SDI, dynamic data, spatial analysis and visualization environments in DM.

Clearly the Geo-ICT is largely used in risk and disaster management, but depending on the disaster management phase, the complexity of the models used varies. Maps are largely used as background information for location awareness and decision-making. But the provided functionality differs. While the risk prevention phase can benefit from elaborate modelling and simulation tools, the 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 or leaving decisions to be taken by "machines." A further increase of the trust and awareness in geo-ICT technology is definitely needed. This can be achieved by new training activity or initiatives, but also by developing systems and tools that can be used in daily routine work.

It is increasingly important to allow sharing and exchange of information within the entire disaster management cycle, from risk prevention and mitigations to response and recovery. As mentioned earlier, the results of risk management have been mostly used by land-use planners who, however, are more and more recognising the need to study disasters in order to be able to improve the quality of their planning decisions and especially to ensure preventative evacuation in threat of a disaster. Perhaps if municipal or provincial authorities knew that an area might be more vulnerable to a disaster than another, also because the escape routes are poor, they would not allow the same spatial developments for both areas. The emergency sector, is also seriously considering the implications of risk criteria and vulnerable objects used by the land use planners. The systems that are used in land use planning contain information on hazard 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 of an 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 newly developed systems rely on client-server architectures using web services.

Risk and disaster management can be seen as an emerging science in which spatial information takes a significant place. It should be again distinguished between risk management and disaster management. While risk management could be referred to as an *explicit spatial* discipline, disaster management is still more *implicitly spatially-oriented*. As mentioned previously in case of an emergency, use of spatial information (except location) is not the first priority. However as the technology develops and new tools allow for a better use of spatial information, the crisis management will evolve to a typical spatial discipline. Making available GIS analytical functions such as buffers, within-area, field-of-view, shortest distance, best distance (avoiding blockings and dangerous areas), as well as dynamically monitoring and forecasting hazards or trajectories of moving vehicles and people during crisis response, will contribute to DM converging into a fully spatially-oriented discipline. In addition, more advanced analytical tools should be developed to move from static to dynamic representations of spatial information. Target will have to be a spatial risk database in which risk zones can be identified, queried in different manners, and supported by reliability and certainty labels for task prioritization.

Clearly, in both risk management and disaster management is growing awareness of the importance of spatial information. Two general tendencies can be distinguished here. Firstly, increasing types of spatial data is used for performing tasks within risk and disaster management; secondly a general understanding is building up about sharing information between the two domains. This tendency is especially strong for spatial information. Historically, it is even difficult to estimate the first use of spatial information in risk or disaster management. As far as hazards go (natural and man-caused), they have been studied and modelled as real world phenomena. Modelling has always been based on some kind of spatial information. However, the last several years have revealed the need for an integration of multiple spatial data sets 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.

5. References

Ale, B.J.M, 2002, Risk assessment practices in the Netherlands, Saf. Sci. 40 (2002) 105–126.

Amdahl, G, 2001, Disaster response; GIS for public safety, ESRI press, ISBN 1-879102-88-9, 108 p.

Bonachea, J., 2006, Desarrollo, aplicacion y validacion de procedimientos y modelos para la evaluacion de amenazas, vulnerabilidad y riesgo debida a procesos geomorphologicos. Ph. D. Thesis, Universad de Cantabria, Spain, 358 p. (ISBN SA. 1046-2006 / 978-84-690-3575-7), http://www.tesisenred.net/TDR-1124106-134112/

Borkulo, E van, H.J. Scholten, S. Zlatanova and A van den Brink, 2005, Decision making in response and relief phases, in: Van Oosterom, Zlatanova & Fendel (eds.), Geo-information for disaster management - late papers, pp. 47-54.

Bottelberghs, P.H, 2000, Risk analysis and safety policy development in the Netherlands, J. Hazard. Mater. 71 (2000) 59–84.

Brecht, H, 2006, The Application of Geo-Technologies after Hurricane Katrina, Proceedings of The Second Symposium on Geo-information for Disaster Management, Goa, India, September, p. 21-23.

Chung C.F. and Fabbri A.G., 2001: Prediction models for landslide hazard using a fuzzy set approach. In, M. Marchetti and V. Rivas, eds., Geomorphology and Environmental impact Assessment, Balkema, Rotterdam, 31-47.

Chung C.F. and Fabbri A.G., 2004: Systematic procedures of landslide hazard mapping for risk assessment using spatial prediction models. In, Glade T., Anderson M.G., and Crozier M.J., eds., *Landslide Hazard and Risk*. New York, John Wiley & Sons, 139-174.

Chung, C.F., Fabbri, A. G., Jang, D. H., and Scholten, H. J., 2005: Risk assessment using spatial prediction model for natural disaster preparedness, in: Van Oosterom, Zlatanova& Fendel (eds.), Geo-informastion for Disaster Management. Berlin, Springer, 619-640. Procs. of Gi4DM, The First Symposium on Geo-information for Disaster Management, Delft, Netherlands, March 21-23, 2005.

Coe J.A., Michael J.A., Crovelli R.A., Savage W.Z., Laprade W.T. and Nashem W.D., 2004, Probabilistic assessment of precipitation-triggered landslides using historical records of landslide occurrence, Seattle, Washington. Environmental Engineering Geoscience, 10/2, 103-122.

Cutter, S.L., Richardson D. B. and Wilbanks T.J. (eds.) 2003, The Geographical Dimensions of terrorism, Taylor and Francis, New York, ISBN 0-415-94641-7

Diario Oficial de la UE., 1989. Resolución del Consejo, de 16 de octubre de 1989, relativa a las orientaciones en materia de prevención de riesgos técnicos y naturales Diario Oficial n° C 273 de 26/10/1989, P.0001-0002.

Diehl, S. and J. van der Heide, 2005, Geo Information Breaks through sector think, in: Van Oosterom, Zlatanova & Fendel (eds.), Geo-information for disaster management, Springer Verlag, Heidelberg, pp. 85-108

Döllner, J. and B. Hagedorn, 2008, Integrating GIS, CAD and BIM data by service-based virtual 3D city models, in Coors, Rumor, Fendel & Zlatanova (eds.): Urban and Regional Data Management; UDMS Annual 2007, Taylor and Francis, London, pp. 157-170

Erlich, M., 2006, OSIRIS - an example of citizen-oriented technology development in the area of dissemination of information on flood risk management, International Journal of Natural Hazards, special issue: ‘Flooding in Europe: Risks and Challenges’, Springer

Erlich, M and S. Zlatanova, 2008, ICT for Integrated Disaster Risk and Emergency Management: Scenario based and on-demand spatial DSS, in: Weets&Fabbri (eds.) Science for disaster reduction, Chapter 8, Springer-Verlag, 8 p.

Fabbri A.G., Chung C.F. and Jang D.H., 2004, A software approach to spatial predictions if natural hazards and consequent risks, in: Brebbia (ed.), *Risk Analysis IV*, Southampton, Boston, WIT Press, 289-305.

Green, R.W., 2002, Confronting Catastrophe, A GIS handbook, ESRI press, ISBN 1-58948-040—6, 140 p.

Isikdag, U., 2006, Toward the implementation of building information models in geospatial context, The Research Institute for Built and Human Environment, University of Salford, Salford, UK, PhD thesis, 468 p.

Kerle, N., S. Heuel and N. Pfeifer, 2008, Real-time data collection and information generation using airborne sensors, in: Zlatanova&Li (eds) Geospatial information technology for emergency response, ISPRS book, Taylor & Francis, pp. 43-75

Kevany, M. 2005, Geo-information for disaster management: lessons from 9/11, in: Van Oosterom, Zlatanova & Fendel (eds.), Geo-information for disaster management, Springer Verlag, Heidelberg, pp. 443-464

Kirkby, S., Pollitt, S. & Eklund, P. 1997. Implementing a Shortest Path Algorithm in a 3D GIS Environ-ment. In M.J. Kraak & M. Moleanaar (eds), Advances in GIS Research II ; Proc.

of the 7th International Symposium on Spatial Data Handling. London: Taylor & Francis Inc. 437-448.

Kwan, M-P. & Lee, J. 2005. Emergency response after 9/11: the potential of real-time 3D GIS for quick emergency response in micro-spatial environments. Computers, Environment and Urban Systems, 29: 93-113.

Lapierre, A. and P. Cote, 2008, Using Open Web Services for urban data management: a testbed resulting from an OGC initiative offering standard CAD/GIS/BIM services, in Coors, Rumor, Fendel & Zlatanova (eds.): Urban and Regional Data Management; UDMS Annual 2007, Taylor and Francis, London, pp. 381-393

Lee, J. and S. Zlatanova, 2008, A 3D data model and topological analyses for emergency response in urban areas, in: Zlatanova & Li (eds.), Geospatial information technology for emergency response, Taylor & Francis Group, London, UK, pp. 143-168

Li, J and M.A. Chapman, 2008, Terrestrial mobile mapping towards real-time geospatial data collection, in: Zlatanova&Li (eds) Geospatial information technology for emergency response, ISPRS book, Taylor & Francis, pp. 103-122

Monmonnier M. S., 1997: *Cartographies of Danger: Mapping Hazards in America*. Chicago, University of Chicago Press, 363 p.

Neuvel, J. and S. Zlatanova, 2006, The void between risk prevention and crisis response, in: Fendel&Rumor (eds); Proceedings of UDMS'06 Aalborg, Denmark May 15-17, 2006, TU Delft, 2006, pp. 6.1-6.14

OGC, 2007, OGC Web Services, Phase 4 (OWS-4) Interoperability Testbed, OGC Document 07-037r4, available at http://www.opengeospatial.org/projects/initiatives/ows-4

Plattner, T., 2004: An integrative model of natural hazard risk evaluation, in: Brebbia (ed.), *Risk Analysis IV*, Southampton, Boston, WIT Press, 649-658.

Raper, J. 2000. Multidimensional Geographic Information Science. New York: Taylor & Francis.

Schneiderbauer, S. 2007, Risk and Vulnerability to Natural Disasters – from Broad View to Focused Perspective, PhD thesis, University Berlin, 102 p.

Scott, M.S. 1994. The development of an optimal path algorithm in three dimensional raster space,' In Proc. of GIS/LIS '94: 687-696

Scotta, A., H. Scholten and H. Hofstra, 2008, Multi-user tangible interface for decision making in emergency responses, in: Coors, Rumor, Fendel & Zlatanova (eds.), Urban and Regional data Management, UDMS Annual 2007, Taylor and Francis, London, pp. 357-379

Schulz W.H., 2007, Landslide susceptibility revealed by LIDAR imagery and historical records, Seattle, Washington. Engineering Geology, v. 89, p. 67-87.

Snoeren, G. 2007, User requirements for a Spatial Data Infrastructure for Emergency Management, GIMA MSc Thesis, 94 p.

Tatomir, B, and L. Rothkranz, 2005, Crisis management using mobile ad-hoc wireless networks, in: Proceedings of the 2nd International ISCRAM Conference April 2005, Brussels, Belgium, pp. 147-149

UNISDR (United nation International Strategy for Disaster Reduction) 2007. Glossaries, Available at http://www.unisdr.org/eng/library/lib-glossaries.htm .

Van Loenen, B., 2006, Developing Geographic Information Infrastructures: the role of information policies. PhD Thesis Delft: Delft University Press.

van Zuilekom, K. and Zuidgeest, M.H.P. 2008 A decision support system for the preventive evacuation of people in a dike-ring area, in: Zlatanova & Li (eds). Geospatial Information technology for Emergency response. ISPRS book series, Taylor&Francis, pp. 329-351

Xu, W. and S. Zlatanova, 2007, Ontologies for Disaster Managmement, in: Li, Zlatanova&Fabbri (eds.) Geomatics Solutions for Disaster Management, Lecture Notes in Geoinformation and Cartography, Springer-Verlag Berlin, Heidelberg, pp. 185-200.

Zhang Y, and N. Kerle, 2008, Satellite remote sensing for near-real time data collection, in: Zlatanova&Li (eds) Geospatial information technology for emergency response, ISPRS book, Taylor & Francis, pp. 75-103

Zhang, F., Xu, B., and Zhou, M., 2002, Data Modelling of Moving Objects With GPS/GIS in Web Environment, In Communications, Circuit and Systems and West Sino Expositions, IEEE International Conference, Volume 2, Issues 9, pages 1581-1585, 2002

Zhu, Q., Y. Li and Y.K. Tor, 2008, Multidimensional and dynamic vehicle emergency routing algorithm based on 3D GIS, in: Zlatanova & Li (eds). Geospatial Information technology for Emergency response. ISPRS book series, Taylor&Francis, pp. 169-184

Zlatanova, S., 2005, Crisis designs, Geospatial Today, May-June 2005, Vol. 4, No. 1, pp. 30-36

Zlatanova, S., D. Holweg and M. Stratakis, 2007, Framework for multi-risk emergency response, in: Tao&Li (eds.) Advances in Mobile Mapping Technology, Taylor&Francis, London, ISPRS Book Series, pp. 159-171