제9차 GIS 국제세미나

The 9th International Seminar on GIS

Emergency and Disaster Response with GIS

GIS기반 방재국토 구현전략

• September 8~9, 2004

• Seoul Education & Culture Center, Seoul, Korea

• Organized by Korea Research Institute for Human Settlements

후원 : 건설교통부, 소방방재청, 디지털타임스
협찬 : 대한측량협회, 한국지리정보산업협동조합,
선도소프트, 삼성SDS, 쌍용정보통신

History of International Seminar on GIS

Year	Theme	Date	Place	Organizing Committee	
				Chair	Member
1st (1996)	Strategies for NGIS Development	4.18-19	Seoul Education & Culture Center, KRIHS	Young-Pyo Kim, Director, Geospatial Information Center	Woo-Seok Cho, Mi-Jeong Kim
2nd (1997)	GIS Applications in the Public Sector	10.16-17	Seoul Education & Culture Center	Young-Pyo Kim, Director, Geospatial Information Center	Yong-Bok Choi, Mi-Jeong Kim
3rd (1998)	GIS Development Strategies for the 21st Century	9.10-11	Renaissance Seoul Hotel	Young-Pyo Kim, Director, GIS Research Center	Mi-Jeong Kim, Sung-Mi Park
4th (1999)	GIS in Local Government	9.16-17	Renaissance Seoul Hotel	Young-Pyo Kim, Director, GIS Research Center	Mi-Jeong Kim, Sung-Mi Park, Hong-Jun Choi
5th (2000)	Toward a Knowledge-based Society: NGIS Policy and Technological Development	9.28-29	Ritz-Carlton Seoul Hotel	Young-Pyo Kim, Director, GIS Research Center	Sung-Mi Park, Hong-Jun Choi
6th (2001)	Present and Future of GIS Technologies	5.17-18	Seoul Education & Culture Center	Young-Pyo Kim, Director, GIS Research Center	Sung-Mi Park,
7th (2002)	GIS Workshop & Seminar	11.8	COEX Intercontinental Hotel	Hyung-Min Yeom, Director, GIS Research Center	Dong-Han Kim
8th (2003)	Envisioning Cyber-geospace and Spatially enabled E-government	11.20-21	COEX	Young-Pyo Kim, Director, GIS Research Center	Jung-Hun KIm, Dong-Han Kim, Seung-Mi Hwang, Ki-Hwan Seo
9th (2004)	Emergency and Disaster Response with GIS	9.8-9	Seoul Education & Culture Center	Young-Pyo Kim, Director, GIS Research Center	Jong-Taek Park, Dong-Han Kim, Ki-Hwan Seo

GIS국제세미나 개최실적

구분	회의주제	개최일	장소	행사준비	
				총괄책임	주관팀
1차 (1996년)	국가GIS 구축 및 활용을 위한 국제세미나	4.18-19	서울교육문화회관 국토개발연구원	김영표 국토정보센터장	조우석, 김미정
2차 (1997년)	공공부문 GIS활용에 관한 국제세미나	10.16-17	서울교육문화회관	김영표 국토정보센터장	최용복, 김미정
3차 (1998년)	21세기를 향한 GIS발전전략에 관한 국제세미나	9.10-11	르네상스서울호텔	김영표 GIS연구단장	김미정, 박성미
4차 (1999년)	지방자치단체의 GIS활용에 관한 국제세미나	9.16-17	르네상스서울호텔	김영표 GIS연구단장	김미정, 박성미, 최홍준
5차 (2000년)	지식기반사회를 대비한 국가GIS정책 및 기술개발방향	9.28-29	리츠칼튼호텔서울	김영표 GIS연구센터장	박성미, 최홍준
6차 (2001년)	GIS기술의 현재와 미래	5.17-18	서울교육문화회관	김영표 GIS연구센터장	박성미
7차 (2002년)	GIS국제세미나・워크샵	11.8	코엑스 인터컨티넨탈호텔	염형민 GIS연구센터장	김동한
8차 (2003년)	사이버국토 구축과 전자정부 발전방안	11.20-21	삼성동 코엑스	김영표 GIS연구센터장	김정훈, 김동한, 황승미, 서기환
9차 (2004년)	GIS기반 방재국토 구현전략	9.8-9	서울교육문화회관	김영표 GIS연구센터장	박종택, 김동한, 서기환

제9차 GIS 국제세미나

The 9th International Seminar on GIS

Emergency and Disaster Response with GIS

GIS기반 방재국토 구현전략

September 8~9, 2004

Seoul Education & Culture Center, Seoul, Korea

Organized by Korea Research Institute for Human Settlements

후원 : 건설교통부, 소방방재청, 디지털타임스
협찬 : 대한측량협회, 한국지리정보산업협동조합,
선도소프트, 삼성SDS, 쌍용정보통신

Opening Address

Honored professor Michael Batty from University College London; Chang-Soon Park, Vice Administrator of the National Emergency Management Agency; and distinguished participants and professionals,

On behalf of the Korea Research Institute for Human Settlements, I would like to welcome all of you to the 9th International Seminar on GIS.

Since 1996, the Korea Research Institute for Human Settlements has invited scholars and professionals from home and abroad and annually held this international seminar in order to search for development directions of GIS policy and technology.

The theme of the 9th International Seminar on GIS is "Emergency and Disaster Response Based on the GIS Application," which is one of main goals of the Comprehensive National Territorial Plan of Korea.

Recently we have suffered from great natural disasters such as flood, overflowing of the sea, landslide damage, and forest fire due to severe and unusual weather all over the world. And there are a lot of urban disasters such as gas explosion, collapse of building, and fire in urban areas.

We have to predict the occurrence or magnitude of disasters in order to take measures to minimize damage from disasters.
To predict, respond to, and cope with disasters, scientific prediction and various application of spatial information are essential.

Specially as the need of GIS application is growing in the field of emergency and disaster response, it is urgent to develop emergency and disaster response based on the GIS application in order to enhance policy efficiency in disaster response.

And in the NGIS policy, disaster response is one of the most key issues to upgrade GIS applications. In this sense I believe this international seminar on「Emergency and disaster response with GIS」will bring new opportunities for advancing national disaster management policy and NGIS policy.

I believe that it is possible to develop most appropriate strategies for emergency and disaster response if the cases and policies of advanced foreign countries are discussed during this international seminar and the National Geographic Information System of Korea is applied to the emergency and disaster response system.

In this regard, I expect that this seminar will be a turning point in advancing emergency and disaster response of Korea.

I cordially ask all of you to strongly support the renewed interest in the development of national emergency and disaster response of Korea through this seminar.

Finally, I would like to take this opportunity to extend my appreciation to all the related agencies including the Ministry of Construction and Transportation, National Emergency Management Agency, and Digital Times to their devoted efforts for this seminar.

And please allow me to extend once more my sincere gratitude and appreciation to presenters and panels and all the honored participants and professionals.

Thank you.

September 8, 2004

Kyu-Bang Lee, President
Korea Research Institute for Human Settlements

Seminar Program

< September 8, 2004 (Wednesday) >

09:30 - 10:30	Registration
10:30 - 10:50	Opening Address: Kyu-Bang Lee (President, KRHIS, Korea)
	Congratulatory Remarks: Chang-Soon Park (Vice Administrator, NEMA, Korea)
10:50 - 11:30	Keynote Speech I: Michael Batty (Director, CASA, UK)
11:30 - 12:00	Keynote Speech II: Jae-Joon Lee (Director, National Institute for Disaster Prevention)
12:00 - 14:00	Luncheon

Session 1 Concepts and Technologies of Disaster GIS

Moderator: Woo-Suk Cho(Inha University, Korea)

14:00 - 14:50	GIS for Disasters and Emergency Management (Paul Yoshitomi, ESRI, USA)
14:50 - 15:40	GIS and Weather Service: From the Viewpoint of Numerical Weather Prediction (Woo-Jin Lee, KMA, Korea)
15:40 - 16:10	Coffee Break
16:10 - 17:00	Interfacing GIS and Natural Hazard Risk Management: Issues and Approaches for Improved Decision-Making (Andre Zerger, CSIRO, Australia)
17:00 - 17:50	GIS-Based Flood Disaster Mitigation System (Keon-Yeon Han, Kyungpook University, Korea)

< September 9, 2004 (Thursday) >

Session 2 Disaster GIS in Practice

Moderator: Sang-Gi Hong (Anyang University, Korea)

09:00 - 09:40 GIS Application for the Mitigation of Flood Disaster (Duck-Ku Ko, KOWACO, Korea)

09:40 - 10:20 Geoinformation Science and Earth Observation for Municipal Risk Management (Cees Westen, ITC, Netherlands)

10:20 - 10:40 Coffee Break

10:40 - 11:20 Emergency Response after 9/11: The Potential of Real-time 3D GIS for Quick Emergency Response in Micro-spatial Environments (Mei-Po Kwan, Ohio State University, USA)

11:20 - 12:00 Fire Emergency Rescue Service Based on GIS (Jin-Taek Kim, City of Tae-gu, Korea)

12:00 - 13:30 Luncheon

Session 3 Strategies for Fostering GIS-based Disaster Management

Moderator : Jong-Yeol Lee (KRIHS, Korea)

13:30 - 14:10 Spatial Data Infrastructure for Disaster Management in the US (Alan Stevens, FGDC, USA)

14:10 - 14:50 Disaster GIS Program in Japan (Takara Kaoru, Kyoto University, Japan)

14:50 - 15:10 Coffee Break

15:10 - 15:50 Strategies for Realizing GIS-based Disaster-free Territory (Young-Pyo Kim, KRIHS, Korea)

Plenary Session GIS in Preventing and Confronting Disaster

Moderator: Michael Batty (CASA, UK)

16:00 - 17:00 Panel Discussion

Alan Stevens (FGDC, USA)
Cees Westen (ITC, Netherlands)
Paul Yoshitomi (ESRI, USA)
Takara Kaoru (Kyoto University, Japan)
Hae-Young Bae (Inha University, Korea)
Myung-Hee Cho (Kyungil University, Korea)
Keun-Young Kim (Kangnam University, Korea)
Dong-Seung Baek (Kyunggi-do, Korea)

Contents

Large Scale Disasters in Small Scale Spaces:
Simulating Crowd Movements, Congestion, and Panic 1

Disaster Management through GIS 27

GIS for Disaster and Emergency Management 35

GIS and Weather Service:
from the viewpoint of numerical weather prediction 41

Interfacing GIS and Natural Hazard Risk Management:
Issues and Approaches for Improved Decision-Making 51

GIS-based Flood Disaster Mitigation System 73

GIS Application for the Mitigation of Flood Disaster 81

Geoinformation Science and Earth Observation for Municipal Risk Management:
The SLARIM project 91

Emergency Response After 9/11:
The Potential of Real-Time 3D GIS for Quick Emergency Response
in Micro-Spatial Environments 121

Fire Emergency Rescue Service Based on GIS:
Daegu Metropolitan City FGIS 147

Spatial Data Infrastructure for Disaster Management in The US 161

Disaster GIS Program in Japan 175

Strategies for Realizing GIS-based Disaster-free Territory 187

Large Scale Disasters in Small Scale Spaces: Simulating Crowd Movements, Congestion, and Panic

Michael Batty

Centre for Advanced Spatial Analysis,
University College London,
1-19 Torrington Place,
London WC1E 6BT
http://www.casa.ucl.ac.uk/

Abstract

This paper reviews the development of new computer technologies for simulating disasters and emergencies which occur when small scale spatial events generate congestion and panic in large crowds. The events in question involve large concentrations of people in small spaces which are affected by one-off events such as those caused by accidents, terrorist attacks, or simply by the build up of congestion through the convergence of large numbers of people intospaces with too little capacity. We examine the history of events of this kind and then look at a recent event, the movement of very large numbers of people to Mecca to celebrate the Hajj, a holy event in the Muslim calendar. We then look at typical models being developed in this field and review their theory, showing how one of these can be used to model a large festival, the Notting Hill Carnival, which is held annually in West Central London. The agent models used in such applications represent new challengesfor GI science taking this science to a finer scale and involving models that incorporate temporal processes and their dynamics as well as spatial structure.

Acknowledgements

I wish to thank the various pedestrian modeling groups around the world for use of their web pages and simulations, in particular Keith Stills of Crowd Dynamics Ltd., the Fire Safety Engineering Group at the University of Greenwich, UK, and Dirk Helbing's Institute for Economics and Traffic Group at Dresden University of Technology. All

interpretations are solely those of the author.

1. Emergencies and Disasters in Small Spaces

We are only just beginning to get to grips with developing spatial analysis and GIS at the small scale. Most analysis to date has been at much larger scales, at the scales of cities and regions, in large scale environments, and often at the global or continental scale. At the very fine scale of complexes of buildings in cities, for example, this has been the domain of property analysis and urban design and only recently has good digital data become available for analysis at these scales. However it is not only the existence of data that is forcing us to look at these scales but the fact that important contemporary events occur at the small scale where crowds gather. It is in this domain that we are beginning to develop scientific analysis of related problems and developing structured methods of design and problem solving for ensuring that such events reach minimum standards of design and performance.

Increasingly we are concerned with the design of small spaces where people come together so that safety is ensured and the quality of interaction in such spaces is optimized. Moreover many problems of movement and migration involveaction and interactions in small spaces and the kind of crowding and congestion that can occur at these focal points makes such spaces and the people within them extremely vulnerable to natural and man-made disasters. The kinds of spaces that we are interested in are office complexes and shopping malls but also entertainment centers such as theatres, rock concert venues, and football stadiums which are places where standards need to be enforced for safety reasons. Places where crowds gather more spontaneously like street festivals and concerts-in-the-park are also subject to the same problems and it is in this context that large scale disasters can be generated from the vulnerable situations which are always associated with such gatherings.

In this paper, we will begin by noting the sorts of spaces in which such emergencies and disasters can occur and then discuss one of the most significant of such events of recent years the Hajj or Pilgrimage to Mecca which has been subject to some severe emergencies and deaths from fire and panic in the last decade. We will then stand back a littleand illustrate how we can begin to design models of movement which show us how such events function. We will take an agent-based view and show how geometry, randomness and behavior come together in simple models of random walks which present rather good bench-line models to simulate the movement in such spaces.

We thenadd intentions to this behavior and illustrate how these can be used to generate models of crowding. These can be used to show how panic and fear develop and how safety can be reinforced through various issues associated with evacuating and stabilizing the spaces that are involved. We then turn to our major example, The Notting

Hill Carnival which is a street festival held each year in west central London and which has all the problems of crowding and safety posed here. We will show how the models is built around swarms and then we illustrate how it can be used to illustrate the effects ofnew policies which change the physical structure of the environment in which these events take place. This shows us how we can begin to usesuch models in policy analysis and it illustrates the way spatial technologies are being stretched to deal with new problems.

2. Typical Examples of Large Scale Disasters in Small Spaces

The sorts of spaces which we are concerned with here tend to be smaller than the city block and often at the level of individual buildings and parts of buildings. Usually such spaces are complex in that they involve many corridors and links which relate to movement although the kinds of disasters and emergencies that can take place in such spaces are best visualized in terms of the simplest, often in terms of congestion and crowding which occurs when too many people in larger space compress themselves into a smaller space such as into an elevator or a corridor where the prime purpose of the movement is egress. These are the kinds of movement that one can see in complex structures such as high office blocks, rail stations and airports where there may be several levels and where the movement patterns tend to criss-cross one another due to the complexity of the layouts involved. The same may also occur in hospitals in accident and emergency rooms,and although one might consider stadiums and theaters associated with entertainment to be somewhat simpler in structure than malls or office centers, the key problems in such venues involve the fact that large numbers of people must locate together as closely as possible in order to partake of the entertainment. If the crowding gets too great and people pack into levels in which fear and panic are generated, then disasters can occur as barriers to constrain the crowds are broken and as the crowd seeks to stabilize itself in ways that lead to some being crushed and trampled.

In Figure 1, we show some typical examples of spaces where crowds gather the new Kyoto Station Complex (a), the Jamarat Bridge which is a key stage in the annual Pilgrimage or Hajj (b), a rock concert (c), and a football stadium (d).

Figure 1: Typical Small Spaces Containing Large Crowds
(a) Kyoto Station Complex (b) The Central Mosque Mecca
(c) Rock Concert in Berkeley, CA, and (d) Texas A&M Football Stadium

Helbing and his colleagues have listed a sample of key events over the last 100 years where major disasters have occurred in that crowds have become too great for the spaces available. These show how important it is to consider ways in which the individuals that form such crowds need to be understood in terms of the way they interact with each other and the geometry of the local situation (http://angel.elte.hu/~panic/). We show some of these in Figure 2. Such events are dramatic enough and need little comment: they come from many sources packing too many people into a space is the obvious problem and this relates to a breach of safety standards but natural disasters such as 'Acts of God', terrorist attacks such as 9/11, and human error in driving and navigation are all key issues. The important question is that whatever the cause, the consequences can be quite similar and these usually involve being unable to evacuate a large population fast enough with sufficient space to avoid the disaster. In this paper, our focus will be much more on disasters that occur through overcrowding rather than terrorist threats or natural disasters and to this end, we will very briefly outline one of the most routine but one of the most problematic of all large crowds the Pilgrimage to Mecca which over the last decade has experience significant and traumatic crowding disasters despite extremely detailed safety measures being put in place.

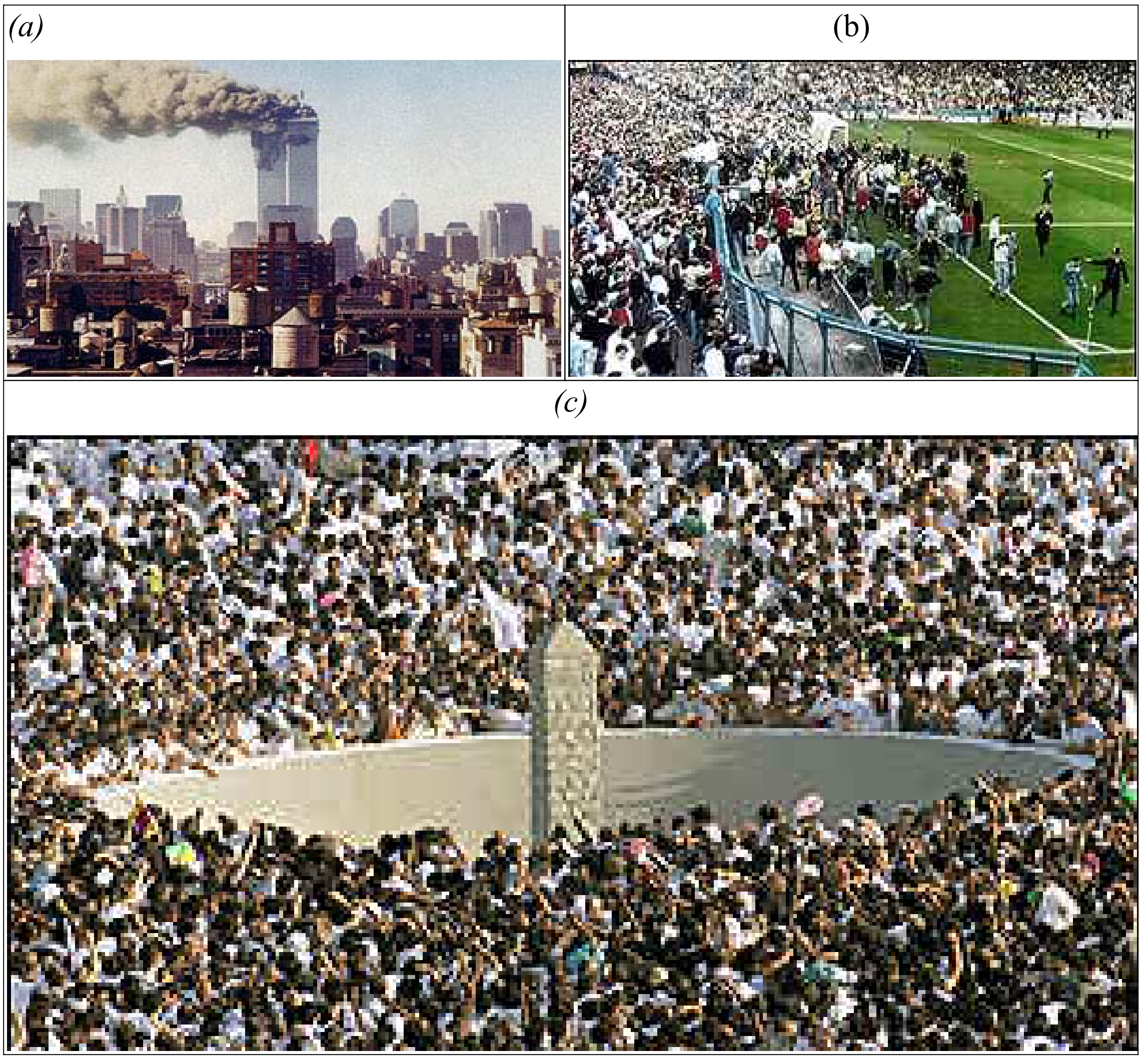


Figure 2: Disasters in Small Spaces
(a) 9/11 (b) Hillsboro'Sheffield 1988 (c) Jamarat Bridge

Let us now look in a bit more detail at the Hajj. This is a pilgrimage that involves upwards of some 2 million Muslims who make their way to Arabia from all over the world to celebrate their faith during a 5 dayperiod which culminates in the city of Mecca. This is an annual event which occurs during the last month of the Islamic year, called "Dhul-Hijjah". The pilgrimage begins at the holy shrines in Mecca itself, The pilgrims then journey some 5miles to Mina where they camp and then walk another 10 miles to Mount Arafat where they pray. They return to Mina and at the Jamarat Bridge, 'stone the pillar' with stones picked up at Arafat. This, in a way, is the focus of the entire event and it is also the most dangerous. The pilgrimage finishes at Mecca and sometimes pilgrims then visit the Holy Mosque in Medina. In the last 10 years, there have been a series of disasters which all involve crowding of people in small spaces combined with extreme hysteria involving the various events that comprise the rituals, especially the stoning ofthe pillar that is said to represent the devil at the Jamarat Bridge. This year 244 people where killed when for 30 minutes the crowd stampeded at the Jamarat Bridge. In fact in each previousyear, people are killed in the same locations, 50 in 2002, 35, in 2001, and 107 in 1998. In fact in 1990, 1425 were killed in the pedestrian tunnel in this location. This is all independent of the other disasters that plague the Hajj. In 1997, it was reported that 2000 died in fire that swept through the tent city in Mina. Clearly safety precautions are all important in such situations and it is to this end, that the models we will review in this paper are devised.

3. Walking and Crowding: Behavior, Randomness and Geometry

We will begin by looking at some simple models of how people move in crowds. These models are based on identifying each member of the crowd as an object an agent and simulating its motion with respect to all other agents and the environment in which it moves. There are two critical issues that need to be noted at the onset. This style of modelis called 'agent-based' in that it depends on simulating the behaviors of an object or agents individually from the bottom up. Second this style of modeling is based on averages. In short we model how a large number of agents respond although the particular behaviors of each agent is a combination of responses which are based on how average behavior or routine behavioris modified by the presence of other agents and by the particular environment in which the agent finds itself. It is this that generates particular situations which can generate quite diverse behaviors given that there are many possibilities of interaction when a large number of agents interact.

The concept of the agent is most useful when it is mobile, in terms of dynamics and processes. Behavior is not simply a product of intentions. It is as much a product of uncertainty, hence randomness and physical constraints, of geometry. The concept of an agent is also quite diverse in that there are atleast four types that can be identified in terms of simulation. There are objects or agents that exist in the virtual world software objects that move on networks which are referred to as bots. Objects in the physical world are things like particles and there is much agent-based modeling in this domain, some of which we will draw on for the physics of crowds. There are objects in the natural world which classically are plants and other animals which can be thought of as having behavior and motion while in our own world, objects are people, perhaps institutions and agencies and it is these that we will deal with here. Agents are thus mainly people, literally individuals, but sometimes other objects, such as physical features like streets and barriers and plots of land, can be treated as agents which is often a matter of convenience in terms of the software used. Finally agents as people can have different kinds of behavior from the routine to the strategic and it is our contention that agent-based models are much better at simulating the routine rather than the strategic.

Our first models of how people move in geometric spaces begin with randomness. This is at the basis of much movement in most physical systems, and by then adding geometry, we can produce models of walking which in some respects represent ourbaselines or null hypotheses. Our first model is a one-dimensional random walk which is simply a random deviation from a straight-line which represents the forward direction. This direction is the general intentionality of the walk which is positioned in one or two-dimensional space. If it were in time, then this would be a random series such as those which mirror economic price indices.We show this model in Figure 3 (a) but as such, this lacks any memory as the implication is that the agent returns to the straight line direction each time, with the next deviation being with respect to this baseline. If there is a one step memory with the deviation taken from the position just reached, then this gives a series which is much more like the kind of randomness that one sees in stock markets. This is shown in Figure 3(b). If we then put this into a two dimensional situation a plane, then we see that the walk with memory criss-crosses the space, In Figure 3(c), we have kept the walk within the two dimensional square but in the forward direction, and in Figure 3(d), aswe reduce the size of the step, this gives a much more realistic motion, akin if you like to an ant wandering randomly across a landscape.

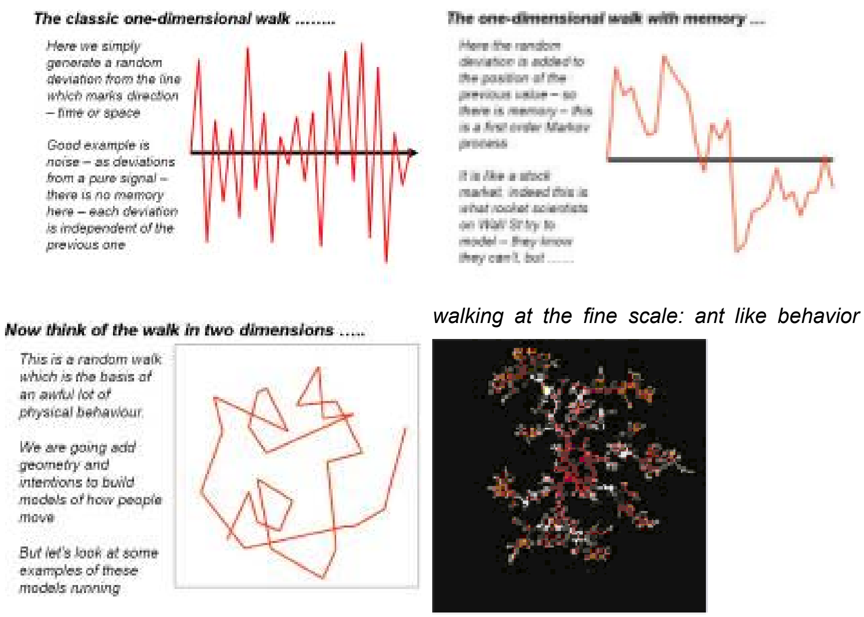


Figure 3: Random Walking

In Figure 3(d), it is easy to see how this two-dimensional random walk 'fill' space and can be regarded as afractal. In Figure 3(c), the one dimensional line also fills the space and this is a classic example of a shape with a fractal dimension of 1 and a Euclidean dimension of 1. As a digression, it is this kind of model that is at the basis of many physical processes which when constrained in terms of their geometry, and simple rules about connections and adjacency generate fractals of quite elaborate organization such the dendritic structures that one sees in cities as transport networks and patterns of urban density.

We must now make such walks more purposive by embedding some utility into their structure. Wewill assume that the walkers are moving to some specific destination and we will encode this into the spatial environment on which the walkers are moving. Let usintroduce a source of walkers and move then towards the destination with the walkers climbing a regular gradient surface to the destination. We will add various degrees of randomness to these walksand then constrain the geometry. What we will do is add a light source into a corridor and agents will sense this source using it like a directional beacon and heading towards it. In essence, this is the easiest way of adding intention and purpose to suchwalks in that we encode the purpose within the environment and let agents react to it. This light source might be like the Jamarat Bridge for example and we could produce a reasonablyeffective simulation of the structure of this movement to 'stone the pillar' by simply letting walkersmove randomly to this source. In fact we know that we need to add flocking and panic reactions to this movement but we will postpone this until our later discussion of the Notting Hill model. In Figure 4, we show how walkersare attracted to a light source moving randomly towards it. We then also introducevarious obstacles into the picture and show how walkers circumvent these obstacles, milling round the narrowing corridor until they find a way through.

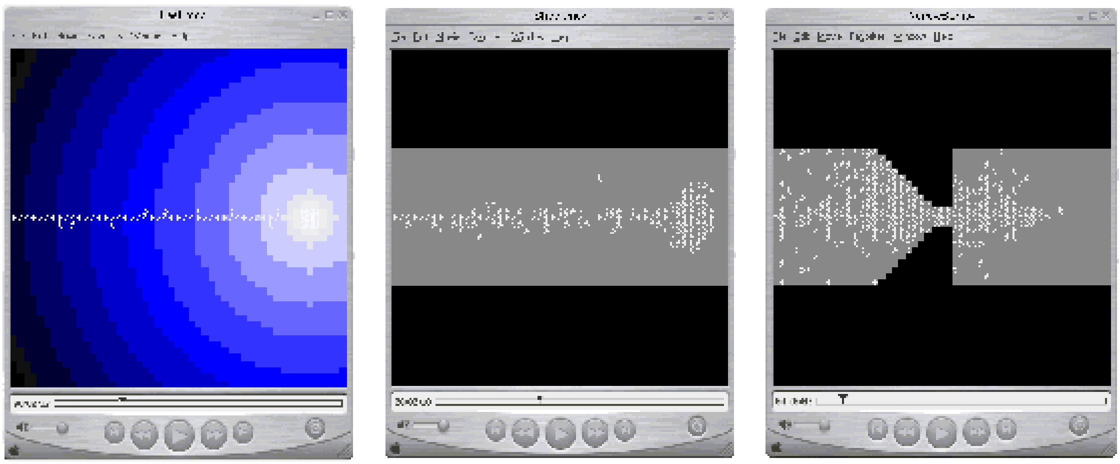


Figure 4: Encoding the Purpose into the Environment
A Light Source (a) Movement to the Light Source (b), Introducing Obstacles (c)

This kind of experiment is the essence of simulating the effects of geometry on crowds. It is the kind of work which Helbing and his colleagues have developed (http://www.helbing.com/) and which is at the basis of the dynamic models developed by Keith Stills (http://www.crowddynamics.com/). In Figure 5, we show the problem that occurs when two crowds come into contact. This is a picture of a simulation a parade which is moving around a street intersection – the central potion of the movement (walkers in white) is the parade and the walkers around this in grey/red are the watchers. This model can be used to simulate the build up of pressure through random motion which then generates a break-through of the watchers into the parade, an event that often leads to disasters of the kind experienced in festivals, rock concerts and football matches as well as ritual situations like the Hajj.

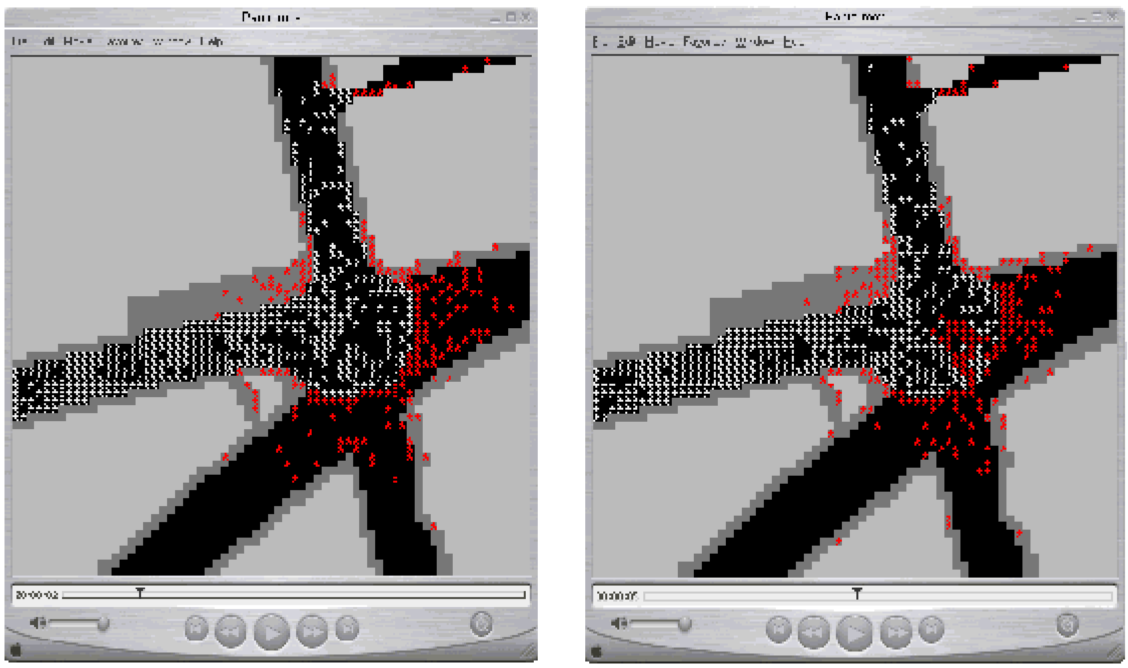


Figure 5: How the Watchers of the Parade (a)
Build Up Pressure and Break Through into the Parade (b)

4. Models of Crowding: Typical Examples

Before we launch into our own model of a street festival and carnival where public safety is a major problem, let us review very briefly a number of different examples. All these models are agent-based or particle-based in that individuals are simulated with respect to the way they move and interact with other individuals and their environment. In essence, these models have five key features, namely

- intention or purpose of walking, either encoded into the environment or encoded into a protocol or behavioral profile which the walkers attempts to implement. This is the difference between passive and reactive agents although the line between these extremes is blurred.

- geometry to which walkers react in term of obstacle avoidance: walkers avoid obstacles by seeing ahead and making changes in their direction or by literally bumping into an obstacle and taking counter measures to step around it.

- randomness which is a feature of any direction of walking based on the notion that walkers cannot actually walk in a straight line but also based on the idea that there are local features of interest in the environment which any walker reacts to and that this needs to be encoded randomly. Randomness also enables new directions to be explored and chosen.

- diffusion for dispersing congestion when crowds build up and people become uncomfortable

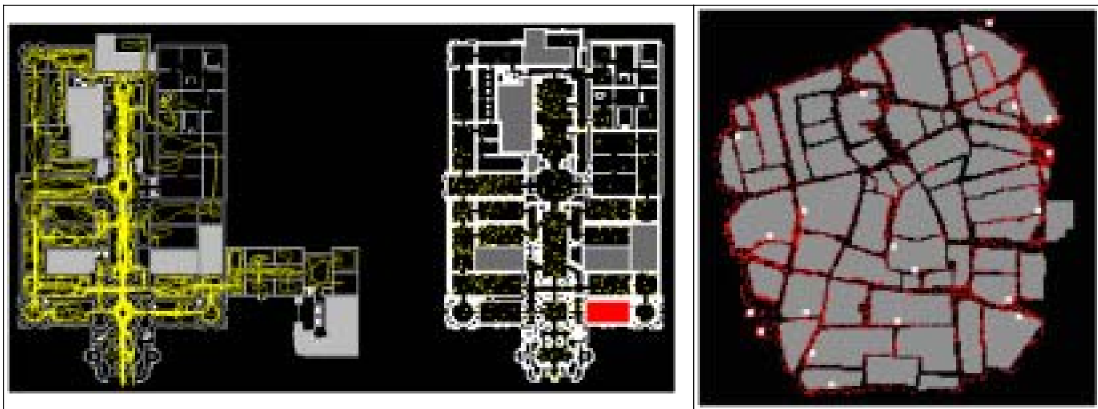
- flocking for copying what others do with respect to where the crowd is going. This is useful in situations where crowds have a single goal such as getting to a venue or in situations where most of the crowd does not know which way to go. Flocking does not necessarily lead to the right direction being chosen but it is an essential feature of crowd dynamics – the 'madness of crowds' as Newton once called it.

We will show four examples. The first is the simplest and involves simulating the movement in some 45 rooms in a well-known British art gallery – the original Tate – in which visitors enter at one point only and then spread out to look at paintings in the various rooms. The attraction of the rooms is coded into the pixels which represent the environment in which the walkers move and the object of the project was to assess the impact of how rooms might be closed or opened and how different types of exhibits could attract different volumes of visitors. In this model, the key issue that was explored was the notion that what we are interested is the steady state distribution of walkers which is the average number of visitors in each room over a long period of time. Each walker is in fact an independent agent by the time it begins to walk around the gallery because the accumulation of random decisions and the great variation in room geometries leads to 'unique' paths taken. Walkers do not follow the same paths but overall, the model is tuned so that the observed average behaviors in terms of visitation patterns are replicated. We show a typical simulation and paths in

Figures 6(a) and (b)

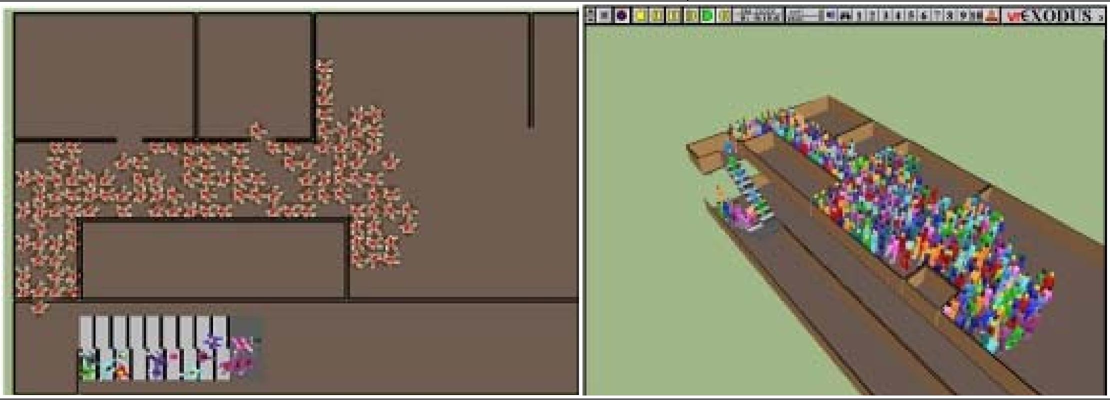
Our second example deals with shopping where we simulate movements from points of ingress – car parks, bus stations and on-street parking – in an English town centre (Wolverhampton ~ 250K population) which is largely a shopping and commercial centre about 1 square kilometer in area. The movement is purposive in that a retail surface is encoded into the environment and this directs walkers as though they are hill climbing to the points where the 'retail pitch' is greatest. In fact this is a particularly simple way of representing retail attraction and a more elaborate model of the same town centre has also been built using the Swarm programming language which enables us to encode retail attraction in a much more specific way in terms of what shops are offering and also lets us incorporate specific buying profiles into the behavior of the walkers/shoppers. In this way, we are able to simulate a matching between what shoppers want – their demand – and what is supplied. The model that we show in Figure 6(c) is simply a trace of movement from the pedestrian gateways – car parks and so on but this does give some sense that in this kind of model, the issue is to match spatial demand and suppliers in a dynamic environment which simulates how people explore a space and choose to satisfy their wants. The use of this kind of application is largely to assess how retailers can maximize profits and shoppers gain their wants in the most acceptable way (which may be may the lowest cost). It follows the tradition of retail modeling in spatial economics which began with Hotelling in 1929.

Our last two examples deal with more local problems. Disasters associated with crowds often come from 'Acts of God' as in the burning of the tent city in Mina in 1997 . The Fire Safety Group at the University of Greenwich (UK) has developed a variety of models which involve not only how fire burns through building and other kinds of restricted spaces such as ships and aircraft but also how pedestrians can be best evacuated from such situations (http://fseg.gre.ac.uk/). In these kinds of problem, the emphasis is on how the physical conditions posed by the building and the hazard interact with natural movement patterns inevitably leading to panic. In Figure 6(d), we show some of the examples of a simulation of fire that swept through a night club in Gothenburg, Sweden in 1998 which lead to 63 deaths.



(a) paths in the Tate Britain gallery(b) distribution of agents in the various rooms

(c) distribution of shoppers in Wolverhampton center



(d) evacuation of disco-dancers from the Gothenburg night club fire in 1998
from http://fseg.gre.ac.uk/fire/Gothenburg_fire_proj.html

Figure 6: Examples of Agent-based Models in Galleries and Shopping Centers

Our last example simply shows how crowds are formed through positive feedback. One of the main algorithms that we will use in the Notting Hill example we will detail below is one which begins with random walking but in an exploratory fashion with some goal in mind. Once that goalhas been reached, walkers who have not yet reached it see signs of how thegoal has been successfully reached and act accordingly. A particularly good example of this occurs when a person wishes to cross a field from one corner to the other, cannot see the goal but strikes out in the approximate direction. Those who come next will beat a similar path though the grass and when people are coming from many different directions they will tend to react positively to paths that have already been impressed. In this way, a kind of historical path dependence (forgive the pun) takes place as paths become impressed on the ground. In general,such models lead to good routes between which are efficient and parsimonious. These kinds of models have been developed by Helbing and his group and a good illustration of the reality that can be simulated is picturedin Figure 7 which shows how paths are established when people cross a grassy square.

Figure 7: How Positive Feedback Reinforces Pedestrian Tracking
From http://vwisb7.vkw.tu-dresden.de/TrafficForum/forumArticles/pedopus.pdf

These examples illustrate a cornucopia of possible examples which involvemodels of walking with similar structures but with applications to many different situations. In the sequel, we will illustrate one such model which was developed for problems of crowd safety in a context where there were many signals that the event in question was 'a disaster waiting to happen'.

5. The Structure of the Pedestrian Model

We are not able to undertake a review here of all the approaches but even within the agent-based domain, very different simulationspedestrian movement have been adopted at different geographical scales, and it is worth noting these. In confined spaces of no more than tens of square meters, models based on analogies with social force and fluid flow have been used (Still, 2001; Helbing, 1991; Henderson, 1971), mainly to predict panic situations in highly focused events such as football matches and rock concerts (Helbing et al., 2000). For events associated with long narrow spaces where the order of the flow is important, queuing theories have been adopted (Lovas, 1994). For buildings and urban spaces such as shopping malls, event simulation based on task scheduling, often usingcellular automata, has been applied (Baer, 1974; Dijkstra et al., 2002; Burstedde et al., 2001). For larger areas measured in square kilometers, accessibility models which simulate decisions between competing attractions have been developed (Borgers and Timmermans, 1986). Recently methods which embody properties of self-organization characterizing how crowds form and disperse have become significant (Vicsek et al., 1995; Helbing et al., 1997). In all these examples, there is an emphasis on the density of flows to measure crowding and vulnerability to accidents.

The model we propose for an event over a wide area of something like 3square kilometers is based on a mixture of these ideas. We first infer the relative accessibility of different attractions which make up the entire event and we then simulate how visitors walk to the event from locations at which they enter. In events such as these, we are never in a position to observe the flow of pedestrians in an unobstructed manner because the events are always highly controlled. Moreover although we have good data on densities, we rarely have data on the actual paths taken and it is unlikely that we will ever do so, despite advances in laser scanning and closed circuit TV. We have thus designed our model in three stages. First we build accessibility surfaces from information inferred about how walkers reach their entry points (origins) relative to their ultimate destinations at the event. Second, we use these surfaces to direct how walkers reach the event from their entry points and then assess the crowding that occurs. Finally we introduce controls to reduce crowding, changing the street geometry and volume of walkers entering the event, operating this process iteratively until an acceptable solution is reached. These three stages loosely correspond to exploration, simulation, and optimization.

We will present a very brief summary of the model at the level of interactions between agents in cells which represent the space on which the event takes place. This space is represented by square cells $i, j = 1, 2, ..., N$. Walkers $k = 1, 2, ..., K$ are defined by the binary variable w_{it}^k at a time $t = 1, 2, ..., T$. In the exploratory stage, we begin with walkers located at their destinations w_{D1}^k where $w_{D1} = \sum_k w_{D1}^k$. Walkers move from i to j in each time period $[t \rightarrow t+1]$ where $j \in \Omega_i$ and Ω_i is the eight cell neighborhood around i. In general, some of these cells will not be accessible because of obstacles such as buildings and barriers; we thus define a block mask as

$b_j = 1$ if cell j is accessible and $b_j = 0$ otherwise. Movement from i to j in search of an origin O is then determined by the probability

$$p_{ijt+1} = \frac{\tau_{jt}\ b_j}{\sum_{j\in\Omega_i} \tau_{jt}\ b_j}, \tag{1}$$

where τ_{jt} is theroute accessibility to origins. A move from i to j is determined randomly according to the schedule of probabilities in (1). If $w_{it}^k = 1$ and $w_{jt+1}^k = 1$, the accessibility surface to destinations is updated as

$$\eta_{jt+1} = \eta_{jt} + \sum_k \left(d_{Djt+1}^k\right)^{-\beta}. \tag{2}$$

β is a tunable parameter. The density of walkers at j is then computed as .
$w_{jt+1} = \sum_k w_{jt+1}^k$

The process implied by (1) and (2) continues until a walker discovers an origin O. For w_{jt+1}^k, if $j \in \Omega_O$, the walker switches from exploratory to discovery mode $\overline{w}_{jt+1}^k$ and returns to the destination D with knowledge of the discovery. The probability of returning is

$$q_{ijt+1}^k = \frac{\pi_{jt}^k\ b_j}{\sum_{j\in\Omega_i} \pi_{jt}^k\ b_j}, \tag{3}$$

where π_{jt}^k is the difference between headings in the direction from i to j and from i to the position defined by w_{D1}^k. This move is also chosen randomly and when $\overline{w}_{it}^k$ moves to $\overline{w}_{jt+1}^k$, the walker marks the move by updating τ_{jt} as

$$\tau_{jt+1} = \tau_{jt} + \sum_k \overline{w}_{jt+1}^k. \tag{4}$$

This process is akin to the walker laying a pheromone trail when a discovery has been made. When the walker comes within the neighborhood of the destination $j \in \Omega_D$, the walker switches back to exploration mode and the search begins over again.

It takes some time before agents discover an origin. Before this, the search is a random walk with the route accessibility surface set as a uniform distribution. If a walker crosses the edge of the event space, it is absorbed, regenerates at its destination, and begins its search again. In its early stages, this is a random walk with absorbing barriers with the variance of its lengths proportional to $t^{0.4}$. As the process continues, more and more origins are discovered while during exploration, walkers 'learn'to direct their search at routes to origins already discovered. Those origins closest to destinations are discovered first and a hierarchy of 'shortest routes' is built up, continually reinforcedby this positive feedback. This is a variant of a generic algorithm predicting trail formation and collective foraging behavior amongst animal populations such as ants (Helbing et al., 1997; Camazine et al., 2001). The swarms created are extremely efficient in predicting shortest routes in geometrically constrained systems (Bonabeau et al., 1999). Here we do not let the pheromone trail τ_{jt} decay, while the accessibility surface η_{jt} gives the relative attraction of destinations to different street locations. Figure 8illustrates this for the accessibility to various destinations and shortest routes to the tube (subway) stations in Notting Hill. To impress its efficiency, we first show the simulation without obstacles to movement $b_j = 1, \forall_j$ (Figs 8c & 8d), and then with the real street pattern imposed (Figs 8e & 8f).

The exploratory stage finishes when the difference in path densities $\sum_j |\tau_{jt+1} - \tau_{jt}|$ falls below a predetermined threshold. In the second stage, we launch walkers from their entry points, and these walkers move towards the event using the surfaces τ_{jT} and η_{jT} as indicators of accessibility. We normalize these as τ_j and η_j and combine them as $\tau_j^{\alpha} \eta_j^{1-\alpha}$. The basic probability of movement is

$$q_{ij} = \frac{\tau_j^{\alpha} \eta_j^{1-\alpha} b_j}{\sum_{j \in \Omega_i} \tau_j^{\alpha} \eta_j^{1-\alpha} b_j} \quad , \tag{5}$$

where α is a tunable parameter. Using (5) for selecting directions of movement, new headings are computed as $\overline{\theta}_{it+1}^{k}$ and then used to update the existing heading from $\hat{\theta}_{it+1}^{k} = \lambda \overline{\theta}_{it+1}^{k} + (1-\lambda)\theta_{it}^{k}$ where λ reflects a lag in response.

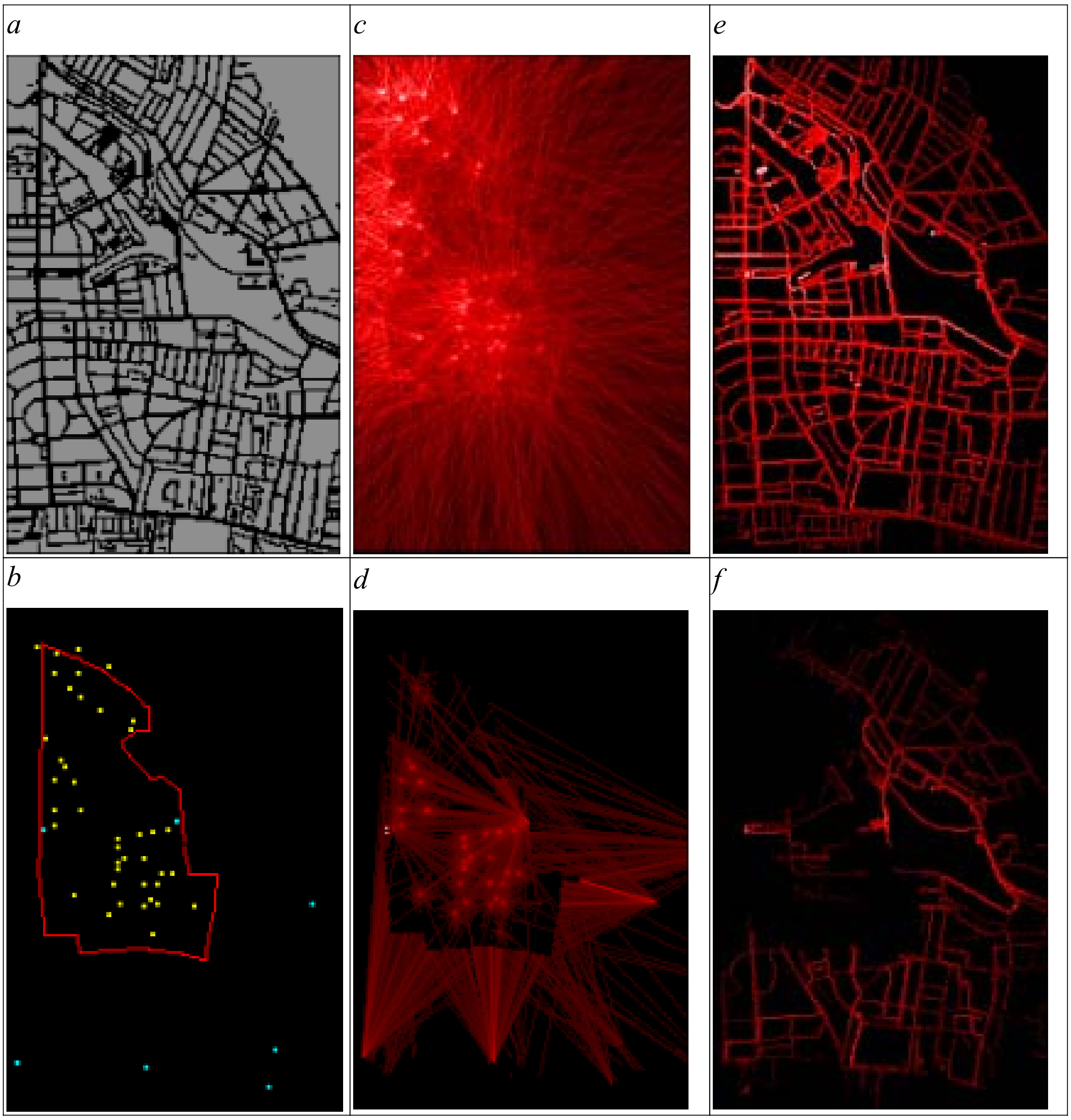


Figure 8 Exploration of Street System and Discovery of Entry Points (Tube Stations)

The street geometry in *a*, the parade route (red), sound systems (yellow) and tube stations (blue) in *b*, accessibility $\{\eta_{jt}\}$from the parade and sound systems without streets in *c*, shortest routes $\{\tau_{jt}\}$ to tubes without streets in *d*, accessibility $\{\eta_{jt}\}$ with streets in e, and shortest routes $\{\tau_{jt}\}$ with streets in *f*. Relative intensities (of accessibility in *c*-*f*) are shown on a red scale (light=high; dark=low) with $\beta = 0.65$ and $\gamma = 0.01$. Horizontal width of each map is 1.7 kms.

There are two effects that complicate this movement. The first is herding or flocking

(Vicsek et al., 1995; Reynolds, 1987). This directs movement as an average of all movement where $\theta_{it+1}^{k} = \sum_{k\in j}\sum_{j\in\Omega_i}\hat{\theta}_{jt+1}^{k}\, w_{jt}^{k} \Big/ \sum_{k\in j}\sum_{j\in\Omega_i} w_{jt}^{k}$, in the immediate neighborhood. However a move by walker w_{it}^{k} to w_{jt+1}^{k} only takes place if the density of walkers in cell j is less than some threshold Ψ based on the accepted standard of 2 persons/m^2 (Still, 2001; Fruin, 1971). If this is exceeded, the walker evaluates the next best direction and if no movement is possible, remains stationary until the algorithm frees up space on subsequent iterations. These rules are ordered to ensure reasonable walking behavior. This second stage is terminated when the change in the density of walkers in each cell $\sum_k \left|w_{it+1}^{k} - w_{it}^{k}\right| \Big/ \sum_k w_{it}^{k}$ converges to within some threshold where it is assumed a steady state has emerged. We can now assess how good the model is at predicting the observed distribution of crowds. We compare the predicted density w_{it} and average neighborhood density $\tilde{w}_{it} = \sum_{k\in j}\sum_{j\in\Omega_i} w_{jt}^{k} \Big/ \sum_{j\in\Omega_i} b_j$ in cells where observed densities are available. We then relate these to the number of occupied cells $\sum_i n_i$ (where $n_i = 1$ if $w_{it}^{k} > 0$, otherwise $n_i = 0$) and the number of available cells $\sum_i b_i = N$ defining system averages as $\rho(t) = \sum_i w_{it} \Big/ \sum_i n_i$, $\sigma(t) = \sum_i \tilde{w}_{it} \Big/ \sum_i n_i$ and $\vartheta(t) = \sum_i n_i \Big/ \sum_i b_i$. For different threshold values Ψ, if $w_{it} > \Psi$, then $c_{it}(\Psi) = w_{it}$ otherwise $c_{it}(\Psi) = 0$, and the proportion of the population at risk is thus $Z_t(\Psi) = \sum_i c_{it}(\Psi) \big/ M$. Average distance traveled in each time period $[t \rightarrow t+1]$ is $U_{t+1} = \sum_{ijk} d_{ijt+1}^{k} \big/ M$ with the percent actually moving $V_{t+1} = \sum_{ijk} w_{it}^{k} w_{jt+1}^{k} \big/ M$.

The third stage of the model is more informal. It consists of examining statistics from the second stage, and gradually making changes to reduce the population at risk by introducing barriers, capacitating entry points, and closing streets. This is achieved by changing the mask b_j to b_j'. As the repercussions of this are not immediately obvious, we make these changes one by one forming $b_j', b_j'', b_j''', \cdots$, and re-running the model until an acceptable solution emerges. In estimation, this stage can be also used to assess the efficacy of existing controls. It is not possible to develop a formal optimization procedure as so many additional factors such as resources for policing etc. cannot be embodied in the model. Nevertheless we consider this interactive method of introducing control the best approach so far for assessing alternative routes.

6. The Notting Hill Carnival: The Problem of Public Safety

The Notting Hill Carnival has grown from a small West Indian street celebration first heldin 1964 to a two-day international event attracting 710,000 visitors in 2001. It consists of a continuous parade along a circular route of nearly 5 kms in which 90 floats and 60 support vehicles move from noon until dusk each day. Within the 3 km^2 parade area, there are 40 static sound systems, and 250 street stalls selling food. The peak crowds occur on the second day between 4 and 5 pm when last year there were some 260,000 visitors in the area. There were 500 accidents, 100 requiring hospital treatment with 30 percent related to wounding, and 430 crimes committed over the two days with 130 arrests. Some 3500 police and stewards were required each day to manage the event. The safety problems posed by the event are considerable (Carnival Review Group, 2001). There are many routing conflicts due to crossing movements between the parade and sound systems while access to the carnival area from public transport is uneven with four roads into the area taking over 50% of the traffic. A vehicle exclusion zone rings the area, and thus all visitors walk to the carnival. Crowd densities are high at about 0.25 persons per m^2 of which 0.47 ppm^2 line the carnival route and 0.83 ppm^2 lie inside. We have good data for crowd densities from our own cordon survey, surveys by London Underground of entry/exit volumes at subway stations, and 1022 images of the parade taken by police helicopters in the early afternoon of the second day (Intelligent Space Partnership, 2002).

In building the model, we start by finding the shortest routes from the parade and static sound systems to the 38 entry points located on the edge of the traffic exclusion zone (Figures 9a and 9b). The swarm algorithm predicts the numbers of walkers who 'find'each entry point and we compare this uncontrolled prediction to the cordon survey, thus explaining 64% of the variance. We then use the observed volumes of visitors at entry points to launch these as agents who climb the accessibility surface indicated by equation (5). We show the crowd density distribution in its steady state in Figure 9c, and this identifies significant points of crowding. We predict 72% of the variance of observed density for 120 locations where good observed data is available. At the third stage, we rerun the model with the official street closures and barriers imposed (Figure 10a). This stage increases the variance explained to 78%, but not all the points of extreme crowding have been removed. This suggests that even in estimating the model, it can be used in a diagnostic manner to identify vulnerable locations (Figures 10b and 10c).

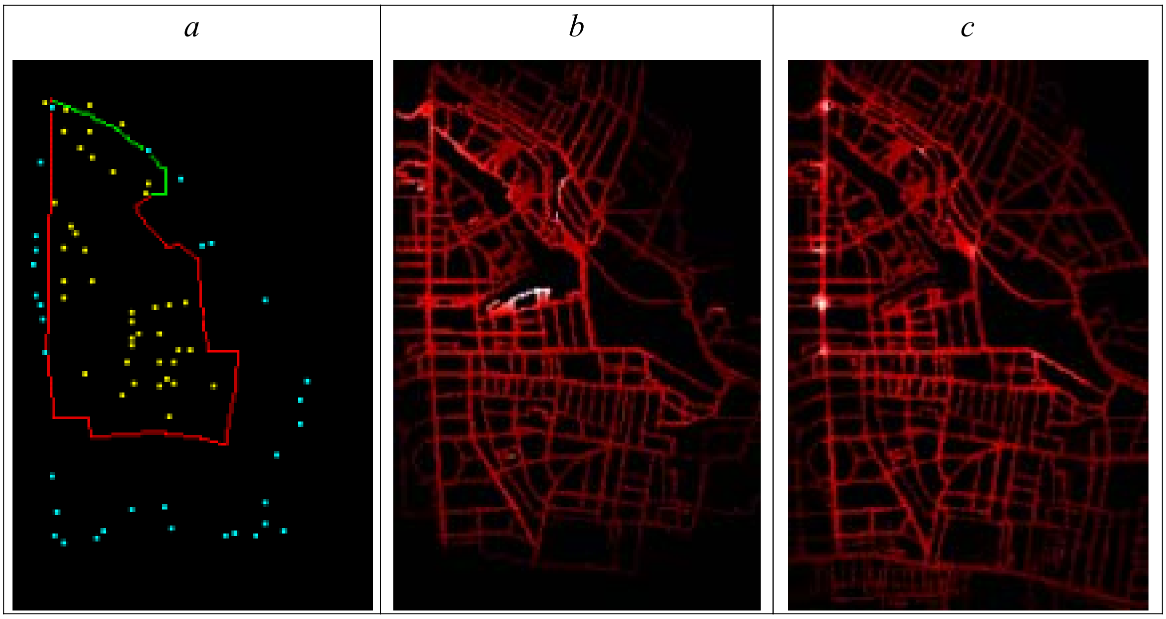


Figure 9: Swarm and Crowd Densities in Stages 1 and 2.

The 2001 parade route (red and green) with proposed 2002 route in red, sound systems (yellow), and entry points (blue) are shown in a. The composite accessibility surface $\{\tau_j^{\beta}\eta_j^{1-\alpha}\}$ from swarms in stage 1 in b and traffic density from stage 2 in c.

More focused analysis requires an examination of average density values for cells and neighborhoods, pedestrian space occupied, and average distance traveled which we graph in Figure 11, where we also show vulnerability to overcrowding $Z(\Psi)$ at two threshold values. These graphs reveal that at each stage, walkers who begin at dense locations, spread out with congestion decreasing rapidly. This then begins to increase, and in the second and third stages, reaches a threshold and settles down. The statistics show considerable temporal volatility around stable trends which illustrate how congestion is continually dispersed. The population at risk stabilizes but most important is the effect of street closures introduced in the third stage (Figure 10a)

which reduce congestion considerably. The model reveals some potential for more effective management of the existing carnival.

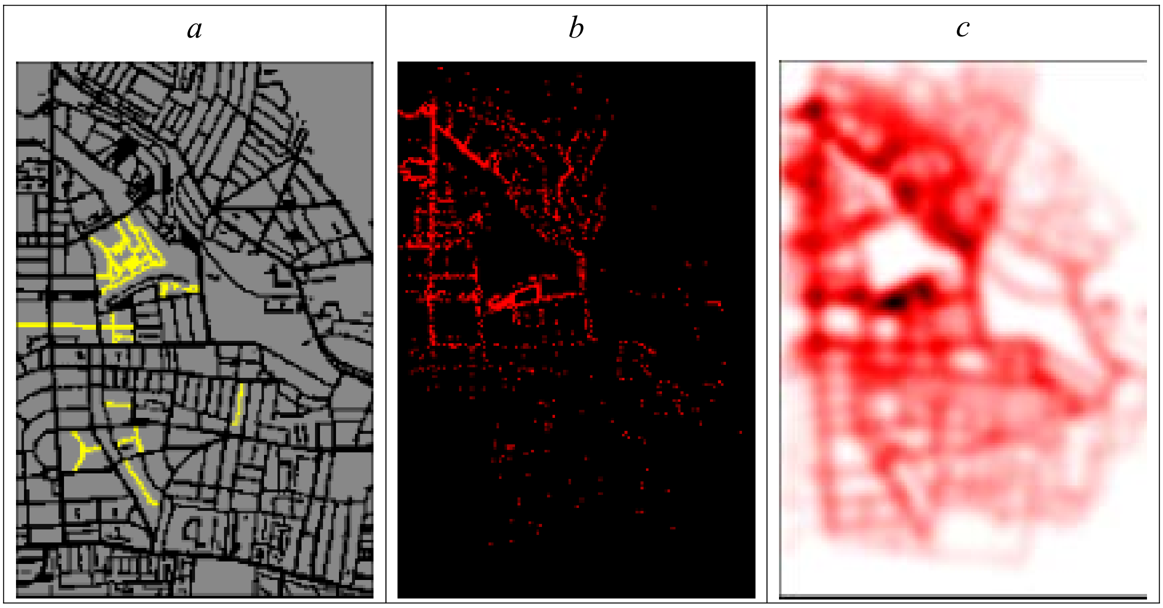


Figure 10 Control of Crowds and Identification of Vulnerable Locations.

Areas closed by the police used in stage 3 are shown in yellow in a. The location of walkers in the stage 3 is shown in their steady state in b. The vulnerability of locations predicted from stage 3 in c isshown on a red scale with the darkest $\Psi \geq 1$ ppm2 the most vulnerable points. Best parameter values are set at $\beta = 0.65$, $\alpha = 0.5$, and $\lambda = 0.4$.

We can now test alternative routes. At the time of writing, after considerable political debate, an interim change in route has been decided for Carnival 2002 where the northern most section of the parade (shown in Figure 9a in green) is to be removed. Running the model leads to slightly reduced average crowding but other problems associated with starting and finishing the parade not included in this model, emerge. The process of changing the carnival route is still under review with better data to be collected at this year's event. Many of the problems of using this model interactively with those who manage the event are being improved as we gain more experience of this approach. The model is general enough to be applicable to crowd situations of a less volatile nature where convoluted geometries and competing attractions are important as in malls, supermarkets, or airports. It may also have relevance to other human or animal circulation systems where swarm intelligence provides a useful way of exploration and control.

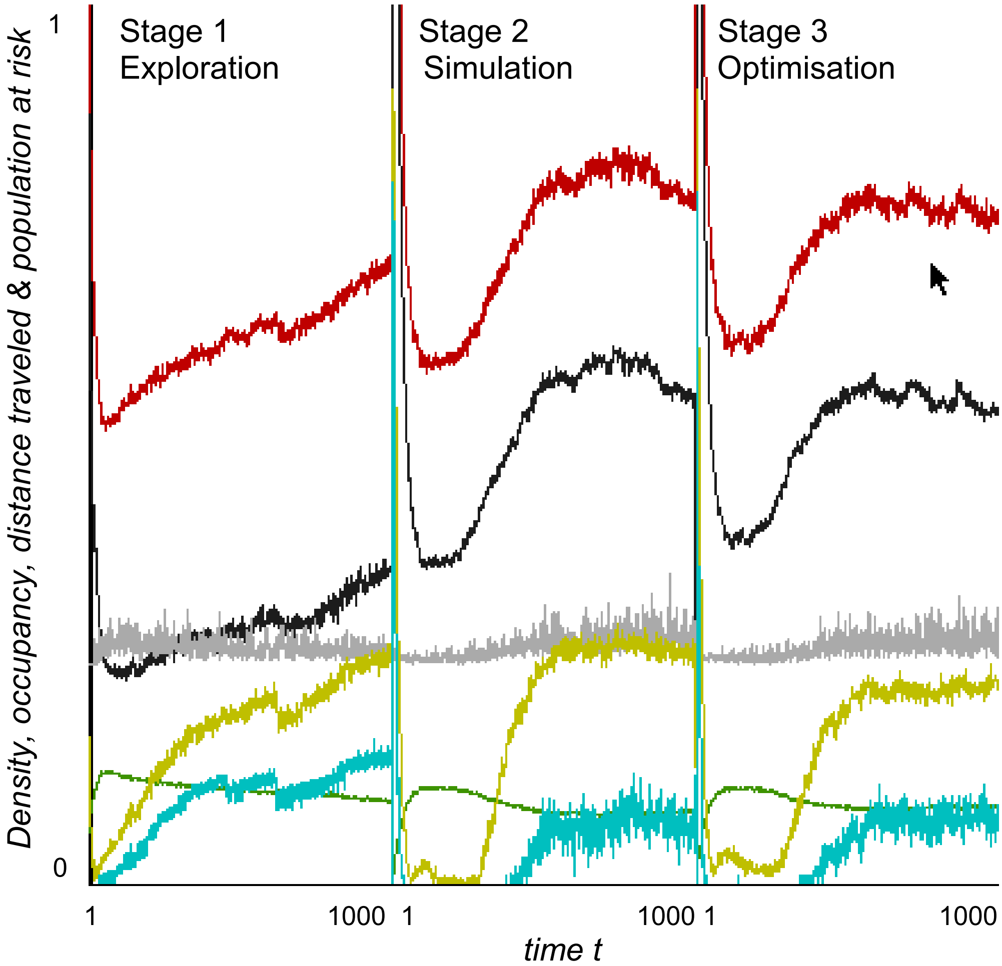


Figure 11 Variations in Average Density, Occupancy, Distance Traveled, and Population at Risk at Each Stage of the Modeling Process.

Average cell density $\rho(t)/3$ in red, neighborhood density $\sigma(t)/3$ in black, distance traveled $U_t/4$ in gray, percent population at risk with $Z_t(\Psi \geq 0.5\text{ppm}^2)$ in yellow, and $Z_t(\Psi \geq 1\text{ppm}^2)$ in blue, and percent occupancy $\vartheta(t)$ in green.

7. Conclusion

The models presented in this paper are but a beginning in attempting to simulate crowding at the finest spatial scale. Agent-based approaches are essential at this level because the intricaciesof geometry combined with randomness and variations in preferences are such that aggregate models remove too much detail and are not up the task of producing good simulations. In terms of designing to alleviate disasters, there has been much less progress although Helbing's group is working on these problems (Helbing, Busna, and Werner, 2004). Much remains to be done. These kinds of models need to be linked to geodemographics, to the behavior of various actors and agents in a much more reactive way than is currently embodied in these models. Most of the model strategies are rather physicalist in structure with geometry dominating and the notion of behavior constituted as social forces. It might be possible to embed much more economic theory and choice theory into such structures but what is clear already is that models of this kind of complexity require extensive visualization if they are to communicated and used effectively to solve and anticipate problems which require direct and effective disaster management.

REFERENCES

Baer, A. E. (1974) A Simulation Model of Multidirectional Pedestrian Movement Within Physically Bounded Environments. Institute of Physical Planning, Report 47, Carnegie-Mellon University, Pittsburgh, PA.

Bonabeau, E., Dorigo, M., and Theraulaz, G. (1999) Swarm Intelligence: From Natural to Artificial Systems. Oxford University Press, New York.

Borgers, A. and Timmermans, H. (1986)A model of pedestrian route choice and demand for retail facilities within inner-city shopping areas. Geographical Analysis 18, 115-128.

Burstedde, C., Klauck, K., Schadschneider, A., and Zittarz, J. (2001) Simulation of pedestrian dynamics using a two-dimensional cellular automaton. Physica A 295, 507-525

Camazine, S., Deneubourg, J-L., Franks, N. R., Sneyd, J., Theraulaz, G., and Bonabeau, E. (2001) Self-Organization in Biological Systems. Princeton University Press, Princeton, NJ.

Carnival Review Group (2001) Interim Report and Public Safety Profile Recommendations GLA, London; http://www.london.gov. uk/mayor/carnival/interim_report/interim_ review_report.pdf

Dijkstra, J., Jessurun, J., and Timmermans, H. J. P.(2002) A multi-agent cellular automata model of pedestrian movement, in M. Schreckenberg and S. D. Sharma (Eds.) Pedestrian and Evacuation Dynamics. Springer-Verlag, Berlin, 173-180.

Fruin, J. J. (1971) Pedestrian Planning and Design. Metropolitan Association of Urban Designers and Environmental Planners, Inc., New York.

Helbing, D. B. (1991) A mathematical model for the behavior of pedestrians. Behavioral Science 36, 298-310.

Helbing, D., Farkas, I., and Vicsek, T. (2000) Simulating dynamical features of escape panic. Nature 407, 487-490.

Helbing, D., Schweitzer, F., Keltsch, J., and Molnar, P. (1997) Active walkermodel for the formation of animal and trail systems. Physical Review E 56, 2527-2539.

Helbing, D., Busna, L., and Werner, T. (2004) Self-organized pedestrain dynamics and design solutions, at http://vwisb7.vkw.tu-dresden.de/TrafficForum/forumArticles/pedopus.pdf

Henderson, L. F. (1971) The statistics of crowd fluids. Nature 229, 381-383.

Intelligent Space Partnership (2002) Carnival Public Safety Project Assessment of Route Design for the Notting Hill Carnival. Greater London Authority, London.

Lovas, G. G. (1994) Modeling and simulation of pedestrian flow traffic, Transportation Research B 28B, 429-443.

Reynolds, C. W. (1987) Flocks, Herds, and Schools: A distributed behavioral model. Computer Graphics 21, 25-34.

Still, G. K. (2001) Crowd Dynamics. PhD Thesis, University of Warwick, Warwick, UK; http://www.crowddynamics.com/

Vicsek, T., Czirok, A. Ben-Jacob, E.,Cohen, I., & Shochet, O. Novel type of phase transition in a systems of self-driven particle. Physical Review Letters 75, 1226-1229 (1995).

Disaster Management through GIS

Jae-Joon Lee, Director

National Institute for Disaster Prevention
National Emergency Management Agency

1. Prologue

As our industry structure grows more complicated and diverse, the importance of disaster management is spreading, requiring the establishment of a composite all-inclusive disaster management countermeasure.

When examining our past cases in dealing with disaster, our lack of understanding of safety and disaster management technology has led us to focus on handling the situation on site.

However, recently we have suffered large and small natural disasters and man-made disasters and the issue of disaster management has come into the limelight. In order to protect the people and their properties, there is now heightened expectations on the construction of a system that can effectively manage disaster from prevention through the swift acquisition of disaster information to actually dealing with the situation

Against this backgrounds, the feasibility of the utilization of the Geographic Information System (GIS) in various social areas such as land management, environment management, business and the people's daily lives is being discussed. It is also called the infrastructure of the knowledge-information civilized society and even in the disaster prevention fields, talks on enhancing the nation's capacity in preventing disasters through effective use of GIS are actively taking place.

The 21st Century we are living in today is an information society where information and knowledge is the basis of wealth to nations, and in such a society, the acquisition of a nation's capacity in the prevention against disaster through nation-wide information based system, such as an appropriate utilization of GIS in the prevention, response and restoration of disasters to minimize the damages caused by disaster and protect the lives of our people, is becoming one of the top agendas.

2. Korea's Disaster Occurrence Trend

Korea has a unique topographical characteristic in that over 70 percent of the total land is composed of mountainous regions and in case of a rainfall, the outflow of sediments rapidly flows downstream so that in a short period of time, the amount of flooding increases and lead to damaging results.

The geological features of the mountains and forests are mostly composed of granite and gneiss of which the outer layer of soil is thin and the capacity to contain moisture small that it is unsuitable for the growth of trees. Mountain slides caused by the weather or erosion and increased river outflow cause the downstream waters to rise, bringing on a sudden outflow of sediments and lowering the river's capacity of water control, increasing flood damages.

The annual average rainfall for Korea is about 1,315mm but two thirds of the rainfall distribution range is concentrated between June and September and at this time, the danger of flooding is huge, letting disasters repeat themselves.

Through the 1995 typhoon "Janis", the localized torrential heavy rainfall in 1996 and 1998 hurricane "Yanni", we came to realize the mighty power of the damages caused by floods and in the 1999 localized torrential heavy rainfall in the northern part of Kyounggi, we suffered property damages that amounted up to 1.2trillion KRW.

One of the main characteristics of year 2002 was the long-term downpour that lasted for more than 10 days nationwide. In particular, while the entire country was suffering from the long-term downpour, the hurricane "Rusa" claimed 246 lives in 16 cities and caused a 5 trillion 147.9billion KRW worth of damages in property. In 2003, "Hurricane Maemi"caused 132 deaths and a property damage of 4.7trillion KRW.

In addition, in relation to man-made disasters, the industrialization and urbanization of our society is rapidly progressing, leading to a variety of facility usage methods such as larger sizes, underground and high-rise. The emergence of various potential dangers have brought about painful accidents such as the collapse of the Seongsu Bridge in 1994, the collapse of the Sampoong Department Store in 1995 and the fire breakout at the Incheon Pub in 1999, and the Daegu subway fire tragedy in 2003 re-uncovered the problems in disaster accidents that have grown large regarding public facilities and multiple use facilities.

3. Considerations in GIS-Disaster Management

The most ideal condition for a disaster management office is to provide no services. In particular, the less actions taken by this office in response to a disaster, the more successful the office is. However, because modern society always retains the possibility of disaster and the principle of economy dominates over disaster management systems, sufficient measures are discussed.

Furthermore, it is difficult to discover where, when and what kind of disaster may occur. Therefore, during peaceful times, the prediction and preparation of various types of disasters must be made to respond to the uncertainty of the future.

The disaster management organization should always endeavor to provide the necessary equipments and tools need to respond to the unpredictable future crises and enhance its technology. In such expecting situations, assumptions made must range from extremely minute situations to radical disasters, and also take into consideration the participation of an organization unit in the provinces to the entire nation.

In addition, not only are there many offices that have to respond to each different disaster, but the costs that go into responding and restoration are extremely high and most of the time, the procedures are very complicated. Also, once the temporary administrative system for disaster management remains for a long time, there will be difficulty in the operation of appointed workers and resource management, the establishment of an administrative service for the victims of disaster, information-sharing between corresponding administrative offices and devising solutions to resolve adverse effects. Against this backgrounds, the GIS is expected to play a central role in disaster management.

4. Functions of GIS Disaster Management

As the first phase in the measure to minimize the damages caused by disasters, it is important first of all, to find out the extent of the damage. This is because by effective notification, the follow-up expansion estimation and delivery of damage information will be possible.

In order to provide a means to guide residents to take shelter and respond to such situations, it is necessary to be able to know when, where and what the damages are and predict the possibility of future expansion of the disaster. Prime examples are the expansion estimation of flood damage or the expansion estimation of simultaneously occurring fire emergencies.

Based on the facts of the situation collected from disaster management system, it is important to accurately predict the possibility of expansion of damages in connection weather conditions. For the expansion estimation of disaster, it is necessary to build a database of the building structures in the towns, information such as the building coverage, regional boundary lines, rivers and railroad information. Furthermore, data such as weather information changes from one minute to the next, therefore it is necessary to go online and use the most up-to-date information and directly apply to the situation.

The results predicted through real-time measurements help determine whether to urge residents at an area where damage is expected to find other shelters, if so, it provides essential information to the disaster management personnel in charge in inducing the residents to shelters by the selection of a shelter, the route to the shelter, the time they should move to the shelter and so on. This helps make responses more effective and smooth, and to this end, the construction of a GIS information database is.

5. GIS in Disaster Hazard Area Management

In order to protect lives, prevent damages to property from disaster and minimize the damages caused by disasters, Korea currently manages designated areas and zones in preliminary prevention measures, which have a possibility of disaster occurrence. This is determined according to various laws such as the Disaster and Safety Management Baisc Law, the Urban Planning Law and the Construction Law.

However, the designation and management system of such policies are separately decided by the related offices according to related laws, but because similar areas and zones exist, there is a chance of duplication in the designation and management of an area/zone. Disaster-possible areas such as disaster danger zones, disaster hazard area and flood hazard area and disaster prevention zone possess common characteristics.

In addition, designation of a disaster danger zone is usually determined later on after the zone is rated according to the frequency of disasters. Also, an objective criterion may be lacking such as unsatisfactory pre-investigation for disaster prevention and evaluation of damages, and after the designation of area or zone, management neglect may lead to repetitive accidents.

In such circumstances, the use of GIS in disaster information management is essential for it enhances disaster response, improves effectiveness in disaster prevention by shortening the time needed for data collection and handling, and in case of a disaster, it helps to swiftly understand a situation and devise countermeasures in preventing the expansion of damages by connecting different information of all facilities to the database.

In order to utilize GIS disaster information, it needs disaster prevention plans and information on the characteristics of the relative area, the program needs to be adjusted according to the purpose and in order to provide a guideline for land usage for disaster prevention, it is necessary to record the total danger rate of past information.

6. Utilization of GIS in National Disaster Management

6.1 GIS and the Central Government's Disaster Management System

The national disaster management system operated by the central government requires information to be simultaneous so that all operations related to disaster measures can flow smoothly and information to be intellectual so that cooperation with all disaster related offices and groups, sharing of information for effective communication on the site, collection of accurate disaster information, accurate decision-making and set up of plan through a process that understands the situation and a relative work process manual may be possible.

By building a ubiquitous environment where the different phases of disaster management; prevention, response and restoration, can be conducted anytime anywhere. Collection of information and conduct can be simultaneous, information collection and conduct on a chronological understanding of the circumstances on site is required and if related offices, the people and media cooperate, a more efficient and systematic disaster management will be achieved.

We need to connect the currently divided National Security Management Information System and Emergency Rescue System into one collective system and for a more efficient disaster management plan, set up a comprehensive plan based on swift and accurate sharing of disaster information and strengthen prevention activities.

The current direction of the central government is to make a database on information of past disaster cases thereby build the basic data on disaster prevention. Then by using the monitoring and mobile technology of the video information system, deliver real-time on-site information to the central and local disaster response office. The central and local Emergency Control Office will then make an accurate judgment by using GIS and GPS, and a system that will deliver accurate and appropriate orders to the disaster site

6.2 GIS and the Local Government's Disaster Management System

The local government's disaster management system uses GIS in a system that supports preliminary response and situation management beginning with the report registration when a disaster occurs, on-site response and preliminary restoration. This needs to be improved by supporting preventive and permanent restoration, building a disaster support information system and wireless order communication system in connection with the central government so that appropriate orders can be delivered directly from the control offices in the cities and provinces to the site. Also, a stronger cooperative system with other related offices through an information system connection is necessary.

The local authorities should enhance the function of the emergency control office, which is an integrated control management organization, and integrate all kinds of control offices and focus their operation on the disaster response organization. In the case where a disaster out-break is suspected, a system is necessary, which can minimize the damages by collecting disaster information through GIS, estimate the total damage size through a damage estimation simulation and thereby determine whether to usher the residents into a shelter or not.

The emergency control office conducts preliminary response and management starting from registering the report upon the disaster outbreak to response, produces statistics on daily disaster situations and gathers information from prevention work and restoration situation management through wireless networks to understand the situation and reports the circumstances.

In addition, the local authorities must actively utilize the existing high-speed telecommunications networks and wireless communications that connect the central and local authorities to the site of disaster, and methods such as utilizing state-of-the-art mobile and satellite communication technology for text messaging and large capacity video data must also be studied.

7. Conclusion

Effective disaster management can only be achieved when the functions and roles of the central government, local autonomies and disaster sites form a cooperative relationship.

For effective disaster management, the central government must support the local autonomies with a flexible cooperative system and the local autonomies must manage the areas where disasters are likely to occur or facilities as a preventive measure, and for areas where disaster has already occurred, they must be able to respond to it systematically and possess the function to minimize the spread of damages.

On the disaster site, the activities of rescuers must be performed smoothly and acquire information on the disaster site swiftly and accurately.

The GIS is an important tool in the effective operation of such disaster management systems and decision-making. I hope there will be lively discussions on the development and utilization of the various technologies of GIS in this seminar.

Thank you.

GIS for Disaster and Emergency Management

Paul Yoshitomi

Research Center for Disaster Reduction Systems
DPRI, Kyoto University, Gokashou, Uji, Kyoto, 611-0011 Japan
paul@drs.dpri.kyoto-u.ac.jp

1. Introduction

In emergency situations, numerous issues and problems must be processed, analyzed, and understood simultaneously. In some cases, one must also face the harsh reality that he or she may not be able to save all lives. In a situation where every second counts in saving a life, it is vitally important to have the means to gather and analyze information as promptly as possible in order to protect lives and property. Whether responding to a natural hazard or human induced hazard, it is critical for emergency management personnel to have the right information at the right time to respond effectively. A GIS provides a framework in which appropriate data can be gathered, organized, accessed, analyzed, and displayed logically so decision makers can respond and take appropriate action based on accurate information. Additionally, a GIS-based framework makes data maintained by various agencies readily accessible so relevant organizations can obtain timely information immediately as the situation evolves over time. A GIS also allows public safety personnel to effectively plan for emergency response prior to an event, determine mitigation priorities, analyze historical events, and predict future events.

2. GIS The Foundation for Emergency Management

The effectiveness of implementing a GIS as the foundation of emergency management can be summarized as follows.

1. The success of an emergency management depends on data and a GIS can present the appropriate data (layers) gathered from a variety of sources logicallywhenever required. The appropriate data can be gathered, organized, analyzed, and displayed

logically to determine the size and scope of emergency management programs. During an actual emergency it is critical to have the right data, at the right time, displayed logically, to respond and take appropriate action, and a GIS provides a mechanism to centralize and visually display critical information.

2. GIS allows emergency management needs to be identified prior to an incident. As with any hazard, in order to reduce the loss of life and damage to property, public safety officials, policy decision makers, and the general public must be aware of potentially hazardous conditions well in advance. Disaster events, such as wildfires, tsunami, floods, earthquakes, hurricanes, epidemics, chemical cloud dispersion, and oil spills, can be modeled and displayed in a GIS. Emergency management personnel can use modeling for training, for actual tactical deployment during a disaster, or to analyze the consequences of a possible disaster.

3. Majority of information is spatial and can be mapped, and emergency management programs can be developed and implemented through the spatial analysis of information.

4. Various organizations can share the same information utilizing a GIS. Emergencies can impact all or a number of government departments, and emergency personnel often require access to a varietyof scale and detailed information. By making use of a GIS, all departments can share the same information through databases on computer-generated maps, and can view various datasets within a single environment.

5. Various methodologies of spatial analyses utilized and developed by different organizations can be shared. Even though the processes that generate the disaster might be fundamentally different, techniques to assess risk, evaluate preparedness, and assist response have much in common and can be shared and be widely distributed.

3. GIS in All Phases of Emergency Management

Emergency management activities can be grouped into five phases that are related by time and function to all types of emergencies and disasters, and GIS can be utilized in all of the phases.

1. PlanningActivities necessary to analyze and document the possibility of an emergency or disaster and the potential consequences or impacts on life, property, and the environment. This includes assessing the hazards, risks, mitigation, preparedness, response, and recovery needs. Emergency management programs begin with locating and identifying potential emergency problems. Using a GIS, officials can pinpoint hazards and begin to evaluate the consequences of potential emergencies or disasters. When hazards (earthquake faults, fire hazard areas, flood zones, shoreline exposure, etc.) are viewed with other map data (streets, pipelines, buildings, residential areas, powerlines, storage facilities, etc.), emergency management officials can begin to formulate mitigation, preparedness, response, and possible recovery needs. Lives, property, and environmental values at high risk from potential emergency or disaster become apparent. Public safety personnel can focus on where mitigation efforts will be necessary, where preparedness efforts must be focused, where response efforts must be strengthened, and the type of recovery efforts that may be necessary. Additionally, GIS can facilitate the development of an effective emergency management program by allowing planners to view the appropriate combinations of spatial data through computer-generated maps for thorough analysis.

2. Mitigation Activities that actually eliminate or reduce the probability of a disaster (for example, arms buildup to deter enemy attack, or legislation that requires stringent building codes in earthquake prone areas). Human life and other values (property, habitat, wildlife, etc.) at risk fromemergencies can be quickly identified and targeted for protective actionutilizing a GIS. A GIS can also be used to help develop long-term activities designed to reduce the effects of unavoidable disaster (for example, land use management, establishing comprehensive emergency management programs such as vegetation clearance in high fire danger areas, or building restrictions in potential flood zones).

3. PreparednessActivities necessary to prepare for actual emergencies. In the preparedness phase, governments, organizations, and individuals develop plans to save lives and minimize disaster damage (for example, compiling state resource inventories, mounting training exercises, installing early warning systems, and preparing predetermined emergency response forces). Preparedness measures also seek to enhance disaster response operations (for example, by stockpiling vital food and medical supplies, through training exercises, and by mobilizing emergency response personnel on standby).A GIS can provide answers to questions such as Where should fire stations be located if a five-minute response time is expected? How many paramedic units are required and where should they be located? What evacuation routes should be selected if a toxic cloud or plume is accidentally released from a

plant or storage facility based on different wind patterns? How will people be notified? Will the road networks handle the traffic? What facilities will provide evacuation shelters? What quantity of supplies, bed space, and so forth, will be required at each shelter based on the number of expected evacuees? GIS can also display real-time monitoring for emergency early warning. Remote weather stations can provide current weather indexes based on location and surrounding areas. Wind direction, temperature, and relative humidity can be displayed by the reporting weather station. Wind information is vital in predicting the movement of a chemical cloud release or anticipating the direction of wildfire spread upon early report. Earth movements (earthquake), reservoir level at dam sights, radiation monitors, and so forth, can all be monitored and displayed by location in a GIS.

4. ResponseActivities following an emergency or disaster. These activities are designed to provide emergency assistance for victims (for example, search and rescue, emergency shelter, medical care, and mass feeding). They also seek to stabilize the situation and reduce the probability of secondary damage (for example, shutting off contaminated water supply sources, and securing and patrolling areas prone to looting) and to speed recovery operations (for example, damage assessment).One of the most difficult jobs in a disaster is damage assessment. A GIS can work in concert with GPS to locate each damaged facility, identify the type and amount of damage, and begin to establish priorities for action (triage). Laptop computers can update the primary database from remote locations through a variety of methods. A GIS can also provide one of the primary components for computer-aided dispatch (CAD) systems. Emergency response units based at fixed locations can be selected and routed for emergency response. The closest (quickest) response units can be selected, routed, and dispatched to an emergency. Depending on the emergency, a GIS can provide detailed information before the first units arrive. For example, during a commercial building fire, it is possible to identify the closest hydrants, electrical panels, hazardous materials, and floor plan of the building while en route to the emergency. For hazardous spills or chemical cloud release, the direction and speed of movement can be modeled to determine evacuation zones and containment needs.

5. RecoveryActivities necessary to return all systems to normal or better. They include two sets of activities: (1) short-term recovery activities return vital life support systems to minimum operating standards (for example, cleanup, temporary housing, and access to food and water), and (2) long-term recovery activities may continue for a number of years after a disaster. Their purpose is to return life to normal or improved levels (for example, redevelopment loans, legal assistance, and community

planning).The immediate recovery efforts can be visually displayed in a GIS and quickly updated until short term recovery is complete. This visual status map can be accessed and viewed from remote locations. A GIS can also display the number of shelters needed and where they should be located for reasonable access. A GIS can also display areas where services have been restored in order to quickly reallocate recovery work to priority tasks as well. Additionally, long-term plans and progress can be displayed and tracked utilizing a GIS. Prioritization for major restoration investments can be made with the assistance of a GIS. As funds are allocated for repairs, accounting information can be recorded and linked to each location as well.

GIS and Weather Service: from the viewpoint of numerical weather prediction

Woo-Jin Lee

Korea Meteorological Administration
wjlee@kma.go.kr

1. GEOGRAPHICAL CHARACTERISTIC OF WEATHER IN KOREA

The weather over Korean Peninsula is highly variable in space and time, and often accompanied with heavy rain or snow, lightening strikes, storm force wind, cold surge, and transboundary transport of dusts from the Asian continent. Mountains which cover more than 80% of land areas and rugged coast lines add complexity in weather and climate of Korea. Heavy rain frequently occurs in the southern and northeastern mountain areas when prevailing wind from the sea slide up the hills (Fig. 1). The western and northeastern coasts faced with warm ocean are preferred areas for the heavy snowfall in winter.

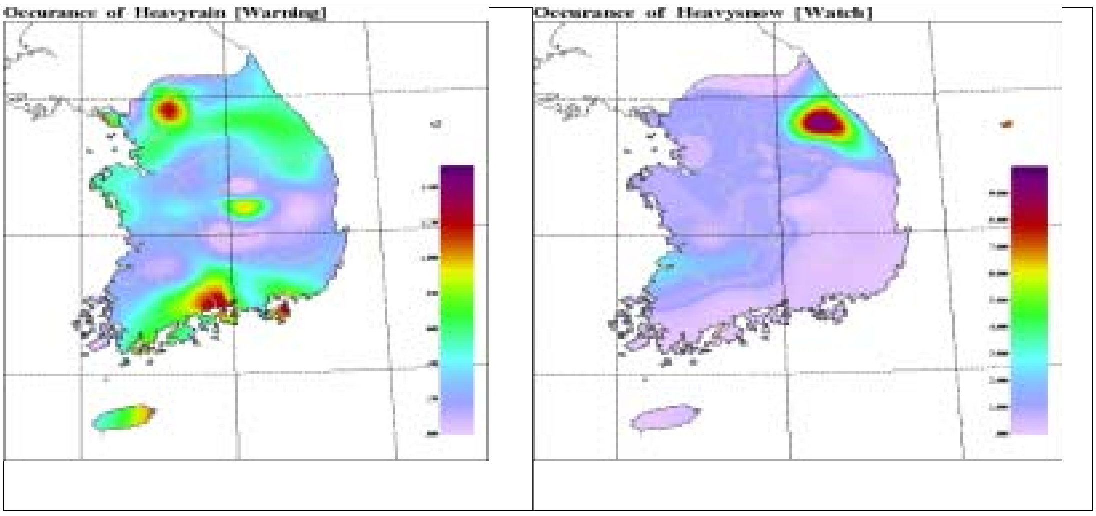


Fig. 1. 30 year (1973-2002) mean frequency of extreme weather in units of days for 24 hour rainfall exceeding 150 mm (left panel), and for 24 hour snowfall exceeding 10 cm except for 5 cm in large cities, and 20 cm in Ulreung-Island (right panel). Data source: KMA (2004)

Every year about 200 human lives were lost, and 1 M US dollars equivalent economic loss are caused by severe weather including typhoons and storms. The scale and intensity of meteorological loss is on increasing trend in recent years. The damage by recent typhoons RUSA (2002) and MAEMI (2003) is beyond the ten times of annual average in 90ties. The society become more vulnerable to severe weather as more construction and industrialization are built on the low lying areas and coastal areas.

The geographical information is indispensible component for the production and visualization of weather forecasts and warnings to accomodate with the public understanding and interest. The windward side of the high mountain range are preferred locations for excessive rainfall. The catchment areas in the river upstream are major concerns for the flood forecasting. The heavy snowfalls often accumulated in depth during night or early morning to cause heavy traffic jams and power shut downs particularly in metropolitan cities. Thousands of cars were caught on the highway for a couple of days without help due to unexpected heavy snowfall in Spring. Few tens of cars were collide each other near the bridge due to early morning fog. Lightening and hail are major concerns for the airliners to avoid on the route. The weather forecasts and warnings gain meaning to society only when combined with the geographic information system (GIS) in an appropriate manner.

2. LOCATION SPECIFIC FORECASTING AND WARNING

2.1 Nowcasting Severe Weather

Mesoscale or stormscale convective systems develops within half an hour, and maintain its strength for an hour or two. They often have highly localized structures, such as line band or ameba cell. The heavy rain or snow, and strong gust imbedded within them are major concerns of forecasters in duty. The chaotic character of the systems limit the predictability, and monitoring of the system with reference to GIS only make the very short term forecasts in terms of movement and strength. The satellite imagery, radar reflectivity and Doppler winds, lightening signals, ground automatic weather station data are indispensible information for the nowcasting of severe thunderstorms. These data can be queried interactively on the Intranet and displayed on graphs, vector plots (for wind), color-filled contour maps and tables (Fig. 2). The warnings on heavy rain and/ or snow, strong wind are issued to a unit area as small as a county having few tens of km square. The geographical information is critical to fin point the target area for warning.

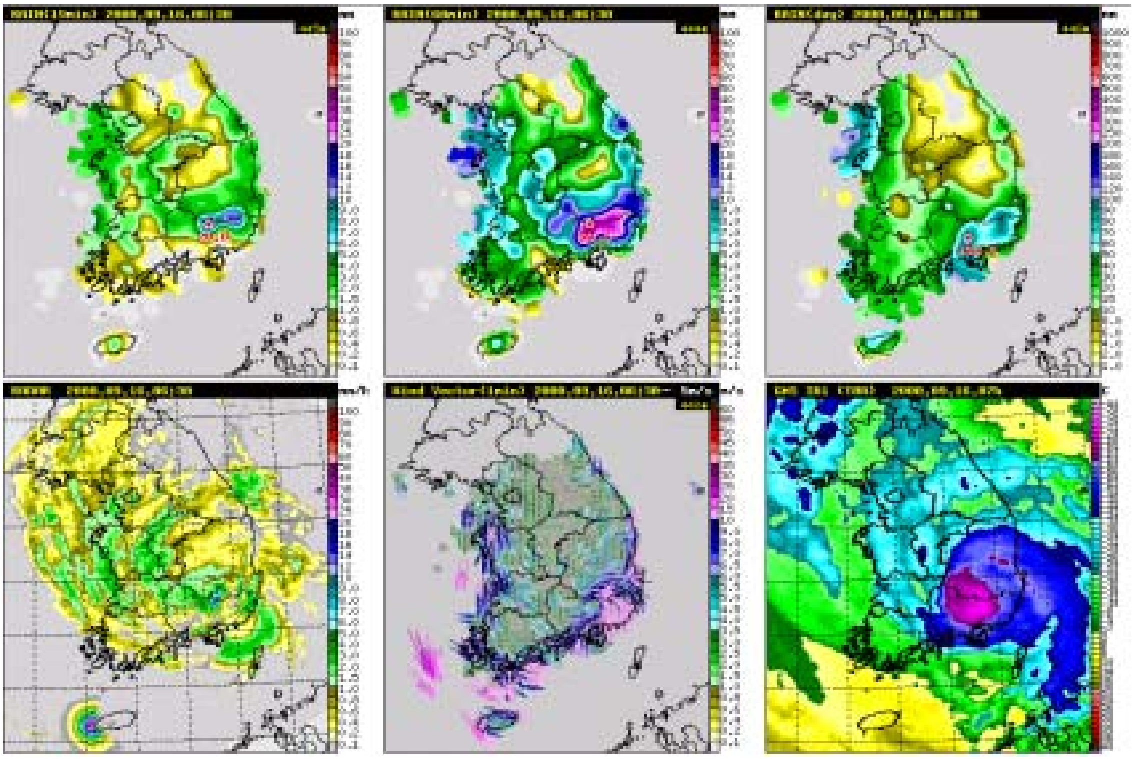


Figure 2. An example of meteorological data display. Six monitoring windows mode for 15 minutes, 60 minutes, and daily accumulated precipitation, radar image, wind vector, and satellite images

2.2 Landfalling Tropical Cyclone

Two or three typhoons (tropical cyclone developed in Northwest Pacific) make landfall over Korean Peninsula in a year. The typhoons normally make landfall near southern coast which has very complex coastal geography including bottom bathymetry under sea. The storm surges, induced by landfalling typhoon, critically depend on the direction of typhoon in reference to the coastal geometry. The surge near Masan was amplified much further due to jar like harbor when typhoon MAEMI approached from the South in 2003. The waves at sea depend on the wind, ocean current, and geography of coastal regions. The very high resolution wave model with 1km mesh is under test at Korea Meteorological Administration (KMA) incorporating bottom topography.

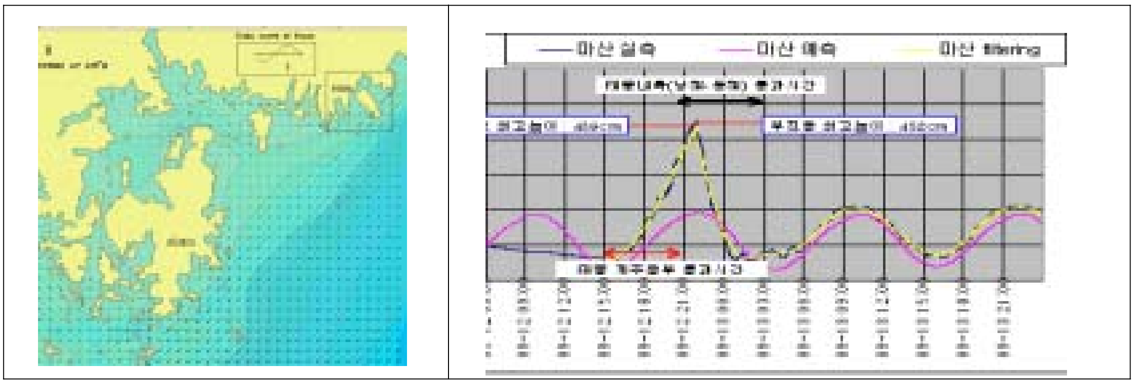


Fig. 3. (a) Geography near southern city Masan, and (b) the wave height recorded near Masan when typhoon MAEMI hit Korean peninsula from south in 12 September 2003.

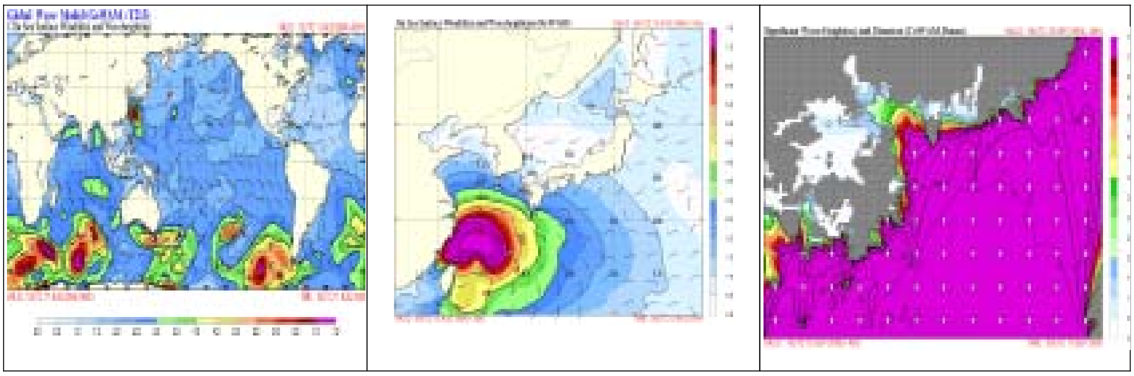


Fig. 4 Example plots for the wave heights from wave models with resolutions of 55 km (left), 30 km (middle), and 1 km (right)

2.3 Weekly Severe Weather Outlook

Various two-dimensional weather charts are available at KMA homepage (http://www.kma.go.kr) for experts who are familiar with weather symbols and synoptic legends. The weather code for sky condition convey the first expression for the local weather under progress. The various line-contours represents the geographical distribution of temperature, humidity, wind and sophisticated diagnostic variables such as potential vorticity, vertical velocity, cloud waters, moisture flux convergence and vertical instability indices. The animation of multiple 2d plots provide further insight on the evolution of weather systems with respect to ground position. The computer aided prediction, so called numerical weather prediction (NWP), are widely adopted at KMA to make weekly forecast and long term outlook.

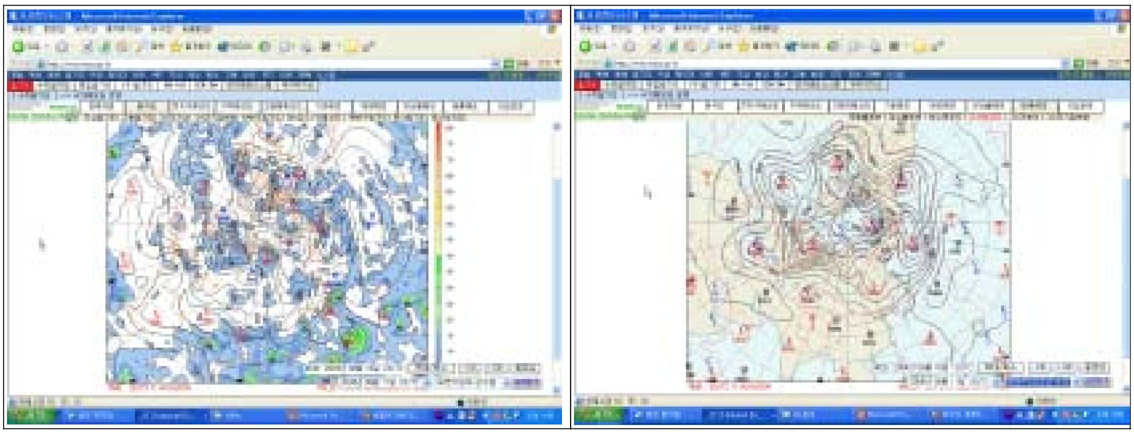


Fig. 5. Example of forecast fields at +5 days in advance from the global spectral model (http://www.kma.go.kr). (a) mean sea level pressure, and (b) geopotential height at 500 hPa

2.4 Asian Dust (Yellow Sand)

The Asian dust or Hwangsa is a phenomena or process of dry or wet deposition of floating dust on the ground which are often carried by upper level wind from source region in Asian continent such as Gobi desert. KMA issues advisory and warning when the density of yellow sand particle exceed 500 ㎍/m^3 and 1000 ㎍/m^3 respectively. KMA provide the track forecasts of yellow sand with reference to the soil and atmospheric condition at the source region.

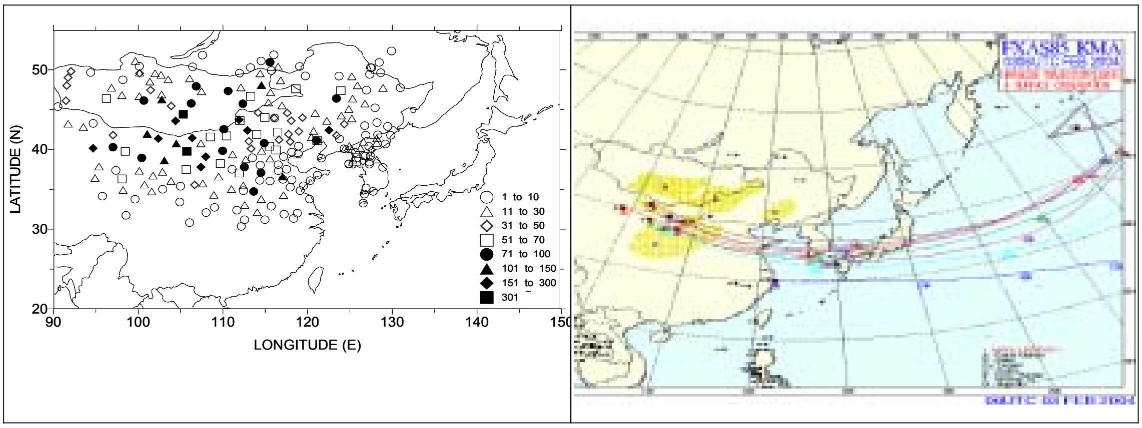


Fig. 6. (a) Occurrence frequency of dust reports for spring of 1996 – 2002 (left; In and Park, 2002), and (b) example track forecasts of yellow sand from the target source region in China (right).

3. GIS and Numerical Weather Prediction

3.1 Surface Boundary Condition

The NWP models simulate atmospheric process in cyber space, where the incoming solar energy at the surface is redistributed back to the atmosphere through multi-scale turbulence including convection. The strength of upward sensible and latent heat flux depend on the terrain, type of surface and land sea mask, roughness factor, and other salient features of GIS.

3.2 Interpretation of Model Output

The prediction of weather elements such as rain, snow, cold spell in the NWP models by and large affected by the surface boundary condition used in the model. It is critical to consider the model's geographic information to understand the characteristic of model output. The orographic rainfall is the best example to demonstrate the difference between the model topography and actual topography (Fig. 7).

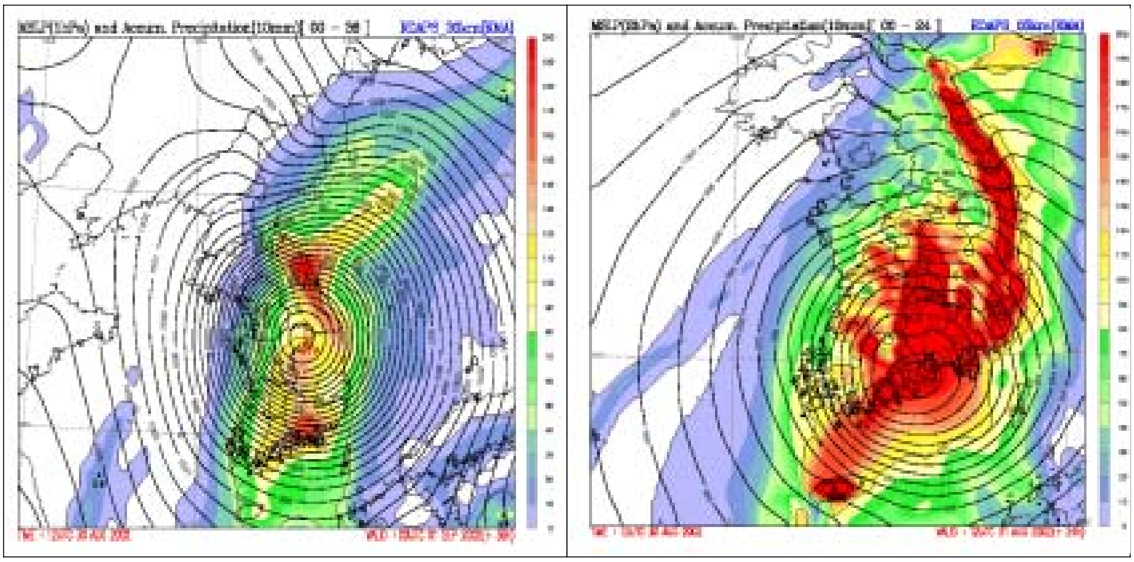


Fig. 7. Twenty-four hour accumulated rainfall amount predicted by the regional model with mesh size of 30km (left), and 5km (right) for typhoon RUSA in 2002. The max. rate are 199mm and 452 mm respectively.

The land sea contrast, the distribution of vegetation, roughness of terrain, the water content in the ground are few of the GIS elements used in a NWP model that are poorly represented with the lack of information or limitation of resolution.

3.3 Post-Processing of Model Output

The model fields such as temperature, wind and moisture are stored in 4-dimensional data volume in global or regional coverage. Normally the fields are displayed in 2-dimensional surface, depending on the height or pressure coordinate system in vertical direction, with specific map projection on earth to identify the weather system relative to the interesting place. The movie of 3-dimensional fields such as clouds and wind are effective to understand the physical process of weather in virtual reality (Fig. 8).

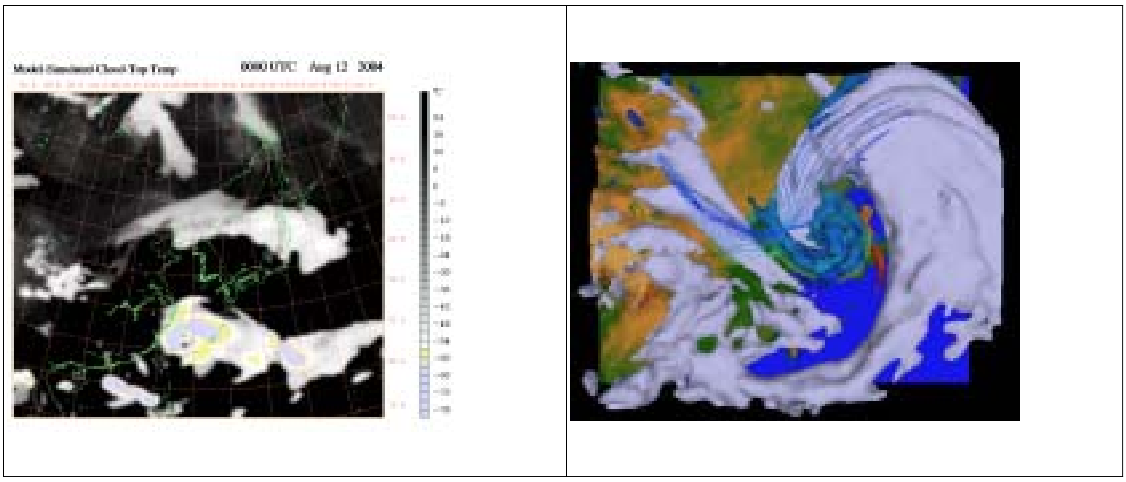


Fig. 8. Example for visualization of clouds from the numerical simulation with the regional NWP model in the view of two dimension (left), and 3 dimension (right).

KMA jointly developed with FSL/NWS an integrated visualization tools on workstation called FAS (Forecast Analysis System). It is a two-dimensional forecaster workstation based on the WFO-Advanced system developed to serve the National Weather Service (NWS) at USA. This system is designed to query all kinds of weather information interactively on a single display, and to overlay, combine, and animate different types of data and analyses (Fig. 9a). TAPS (Typhoon Analysis & Prediction System) is a similar tool designed for the tropical cyclone track and intensity forecasting aid. The position center and uncertain in radius are determined based on the various model outputs and latest observations. TAPS has been developed to provide comprehensive typhoon information at a window PC, and to provide an working environment that can be used to automatically produce typhoon information. The fundamental frame of TAPS consists of analysis mode, DB mode, and prediction mode (Fig. 9b).

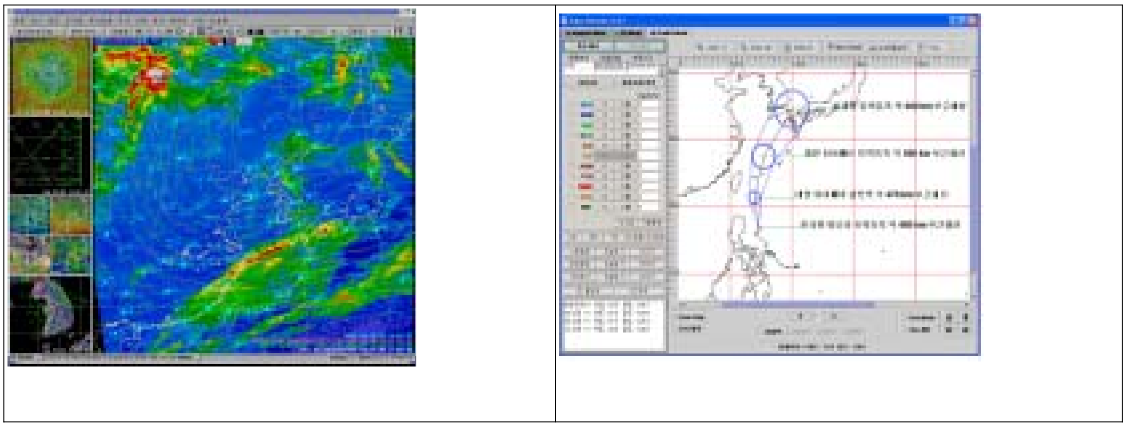


Fig. 9. The main frame of FAS with various meteorological data (left), and an example window in TAPS for the predicted typhoon track generated in the Prediction Mode (right).

3.4 Digital Forecast Service: Plan for the Future

KMA plans to provide digitized forecasts on a 5km mesh over Korean Peninsula with three hourly interval for various weather elements such as temperature, cloud coverage, rain or snow, wind, relative humidity, so on. The model outputs on 3-dimension grid points are edited interactively by manual key-in or automatic filtering tools, and displayed in various graphic mode on demand through Internet (Fig. 10).

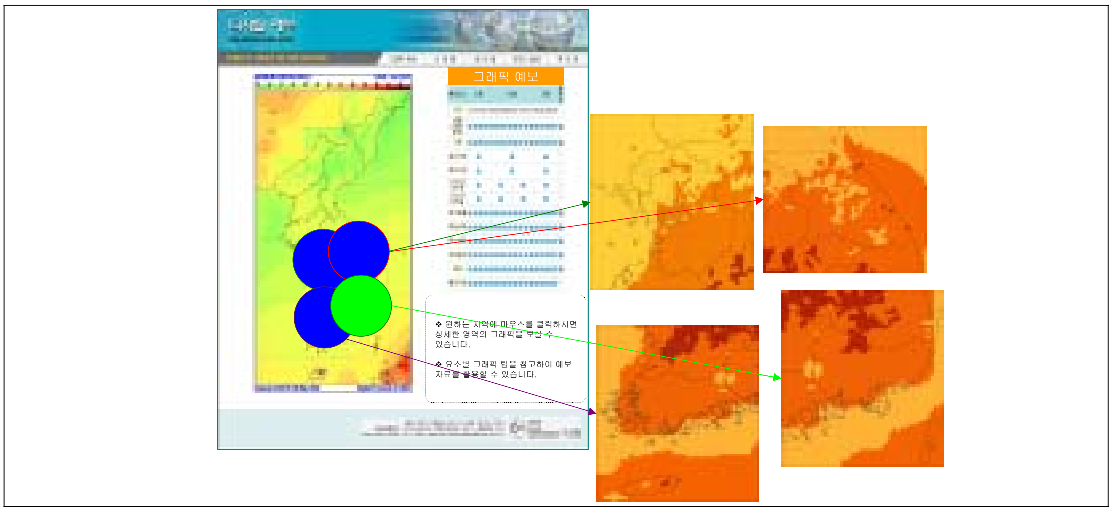


Fig. 10. An example window for the digital forecast service in the future.

4. Summary

The geographic information is an indispensible component in severe weather forecasting and warning service. Heavy rain or snow, and strong wind are highly influenced by the surface boundary condition, and the accuracy of numerical models in part depend on the use of appropriate GIS elements. Korea Meteorological Administration provide various warning and forecasting service on severe weather over Korean Peninsula and surrounding sea for the disaster prevention and preparedness. The geographical distribution of various weather elements can be accessible at the KMA homepage which demonstrate the usefulness of GIS on weather service.

Table 1. The specification of NWP models on operation at KMA

Model	Analysis	Resolution (Layers)	Lead time (Days)	Remark
Global Spectral Model (GDAPS)	3dVar	T213 (55km, 30 levels)	10	
	3dVar	T106 (110km, 30 levels)	8	17 Ensemble
	3dOI	T106 (110km, 21 levels)	90	Ensemble
Regional Model (RDAPS)	3dOI/ 3dVar	30/ 10/ 5km(33)	2	Triple Mesh
Typhoon Model (DBAR)	Bogus	30km (barotropic)	3	Typhoon Track
Wave Model		0.25°	2	Asian
		1°× 1°	10	Global
Statistical Model		-	2	Temp, PoP

REFERENCES

In, H.-J., A.-U. Park, 2002: A simulation of long-range transport of Yellow Sand observed in April 1998 in Korea. Atmospheric Environment, 36, 4173-4178.

KMA, 2004: Plan for improvement of warning service, Task force for the improvement of weather service, Korea Meteorological Administration.

Interfacing GIS and Natural Hazard Risk Management: Issues and Approaches for Improved Decision-Making

Dr. Andre Zerger

CSIRO Sustainable Ecosystems, Canberra, AustraliaGPO Box 284, Canberra, ACT 2601
Andre.Zerger@csiro.au

Abstract

GIS practitioners faced with the task of developing GIS for natural hazard risk management face a number of challenges. Natural hazards, unlike may other phenomenon are unpredictable spatially, temporally and in their magnitude. Similarly, natural hazard risk management has a number of components, each with varying decision-making requirements. For example, the commonly use prevention, preparedness, response and recovery typology highlights the differences in decision-making needs. This paper examines the varied decision-making requirements of hazard risk managers and links these needs to the challenge of GIS development. A key issue emerging from the research is the need to conduct iterative user-needs assessments do ensure technical developments compliment decision making requirements. One example of a novel application of GIS to flood risk management is then presented for a coastal community in tropical Australia. The 'Floodbank' system is a database driven approach for integrating flood model results with GIS for decision-support. The approach stresses the importance of developing effective interoperable 'back-end' data management systems for natural hazard risk management as this allows for flexibility when developing the 'front-end' components. The intent of developing Floodbank is to provide risk managers with rapid access to flood modelling results in a flexible and intuitive framework.

Keywords: GIS, Flood modeling, Internet, RDBMS, risk management

1. INTRODUCTION

Although GIS is already used routinely to support natural hazard decision-making, one could argue that its role has not extended far beyond providing cartographic support.For GIS to evolve to where it provides spatial decision support system (SDSS) capabilities, some important integration and implementation issues need to be overcome. This paper firstly examines the issues confronting GIS practitioners who attempt to develop a GIS for natural hazard decision support. It highlights key limitations based on outcomes of earlier research in Australia for flood risk modelling, and discusses why the requirements of hazard management are so challenging. In the second component of this paper, we present one approach for interfacing GIS with hazard models to provide decision-support capabilities to natural hazard and disaster managers. The example focuses on flood risk and pays particular attention to addressing the temporal component of the hazard using both Internet-based systems and a stand-alone custom built GIS. The approach is known as 'Floodbank'and it serves to highlight the importance of interoperable database management systems for natural hazard risk management. The conclusion of the paper introduces the results from a user evaluation conducted after the development of Floodbank. Results highlight the importance of evolving user-needs evaluations before and after system development. We argue that this is a critical, yet commonly neglected, phase of GIS development for natural hazard risk management decision making.

2. NATURAL HAZARD RISK MANAGEMENT DECISION MAKING

Our earlier work in coastal Queensland (Zergerand Smith, 2003) noted that GIS is fundamentally a technical tool for disaster reduction. GIS literature commonly suggests that the fundamental challenges for integration are software, hardware, data capture and integrating physical hazard models in a spatial framework. This technical focus on GIS is not unlike the historical view in disaster studies where the physical hazard event is seen as the primary driver of disaster. This dominant view focuses on technological solutions for disaster management including engineering solutions, hazard modelling and even the application of GIS. It has been observed that by focusing on technical solutions we may limit the number of intervention options available to us, or more importantly for this research, our solution may not address decision making requirements. As such, the use or uptake of GIS technology can be reduced. This is an important issue confronting GIS practitioners and points to a need for a greater understanding of hazard management decision making requirements before we embark on technical GIS solutions.

Our research in coastal Queensland has examined the practical decision making requirements of risk managers. Some of our findings included the need to better couple the scales of decision making with the scales of GIS data analysis and modelling. GIS practitioners will commonly focus on readily available databases, rather than contextualising the data needs in terms of decision making requirements. This issue has been recently addressed by Lilburne et al. (2004) in the broader context of GIS decision support. Of particular relevance to this paper is the recognition that GIS is well designed to deal with spatial information, but less apt at dealing with temporal data. We have attempted to overcome this criticism and propose a new approach for dealing with geo-temporal hazard information which is described below.

The integration of GIS for natural hazard risk management poses some important challenges for GIS practitioners. Of primary interest is developing GIS solutions which address the varied risk management decision making requirements of hazard managers. Unlike other spatially-enabled disciplines such as ecologicalmanagement, transportation logistics, hydrological analysis and forestry to name only a few, hazard risk management requirements will commonly vary as a function of the frequency, magnitude and location of the physical event. As such the partitioning of hazard management into the commonly adopted prevention, preparedness, response and recovery (PPRR) model is an extremely useful construct for GIS practitioners developing solutions for hazard managers. The PPRR model is by no means binding, and other typologies may provide a more useful construct. However, the PPRR model does recognise the varied decision-making requirements associated with hazard management and disaster. As GIS practitioners we must also recognise the temporal variability in natural hazard decision-making. Each hazard event can be fundamentally different and uptake of GIS technologies can be a function of this difference, rather than a function of perceived user-needs and expectations. This is an important observation when working in the realm of hazard research. Earlier research (Zerger and Smith 2003) identified the various components of natural hazard disaster management from a GIS perspective. Readers are urged to consult this paper for a more extensive treatment of this issue. The lessons learnedin these case studies are valuable for any GIS practitioner developing technical solutions for hazard risk management.

The research presented in the following sections attempts to overcome some of the earlier observed limitations. For instance, the temporal component of natural hazard modelling has been poorly handled using GIS. This has been highlighted viadetailed user-needs evaluations in Mackay and Cairns. Semi-structured interviews showed that risk managers would readily sacrifice the spatial resolution inherent in the GIS database for more detailed time series information for evacuation planning. Secondly, the response phase of cyclone inundation decision-making requires instantaneous risk assessments and hence hydrodynamic hazard models cannot be run in real time. The FloodBank approach provides a mechanism for storing, managing and analysing the output from hydrodynamic models in an interoperable frameworkand allows for instantaneous analysis of risk result. The final discussion examines the importance of post-system evaluation as this can highlight some important issues in systems design.

3. INTERFACING GIS AND FLOOD HAZARD MODELS

In this paper we focus specifically on flood risk. However, the issues confronting integration and decision support are nevertheless similar as for other hazards that have a temporal and spatial component. The link between GIS and flood hazard modelling has traditionally adopted a number of integration paradigms. These range from very tight integration (or coupling) where all modelling occurs within the GIS, to less integrated approaches where GIS is used for data pre-processing, model parameterisation and post event display and analysis via the use of common data interchange formats. Goodchild (1993 in Clark 1998 p.825) summarises the three broad approaches for integrating GIS and hydrology as:

- Pre-processing data into a format suitable for analysis (scale, coordinate system, data structure, data model etc).
- Direct support for modelling so that the GIS carry out tasks such as analysis, calibration and prediction itself.
- Post processing data through reformatting, tabulation, mapping and report generation.

The first approach is relatively ubiquitous in flood hazard modelling and can include the development of terrain/bathymetric models, integration of landuse and building databases to represent surface roughness, parameterisation of flood models, automated watershed and stream network delineation or for the preparation of spatial databases in a format suitable for modelling (Bates and Roo 2000, Pickup and Marks 2001). The second approach is relatively rare and most examples are restricted to 1D flow calculations (Jain et al 2000). Correia et al (1999) attributes this to the fact that for it to be successful, the GIS architecture must be sufficiently open. As most GISs are commercial products utilising proprietary data formats and algorithms, this is rarely possible. However, the advent of open GIS architectures provides significant opportunities (OGC 2002).

And finally, the use of GIS is common during the post-modelling phase for the presentation of maps that delineate flood zones, as a framework to integrate other contextual spatial data such as satellite imagery of hazard events, as a spatial decision support system (SDSS) for flood risk management and for impact assessment or cost-benefit analyses (Biza et al 2001). In the case of 2D hydrodynamic modelling, this third approach to integration is most common owing to the complexity of modelling spatially dynamic phenomenon such as flood events within a GIS (Dutta et al. 2000). The focus of this paper is this later model of integration, with the addition of an Internet capability.

Given that the role of GIS for flood modelling commonly focuses on post-modelling requirements, limitations exist in how model results are currently integrated with GIS. At the most common level of integration, linking means the simple conversion of a raster flood surface into a format suitable for GIS display and comparison with other databases (i.e. buildings, road networks, utilities). The raster flood surface will typically represent the peak flow, or a recurrence interval that has some risk management significance such as the 1 in 100 year event. A limitation of these approaches is that times-series data so critical to modelling an event is either not used, or proves so cumbersome to manage computationally, that it cannot effectively support decision making in a spatial environment.

In this research we introduce a database driven approach for hazard model integration called 'FloodBank'. Floodbank demonstrates how an affordable Internet mapping system can be developed to couple flood model outputs with GIS to provide a decision-support capability. A key feature of this approach is the ability to handle time-series information so central during the onset phases of a hazard event. We contend that database driven architectures for spatial data analysis represent the future of both data management, integration and analysis. In the long-term, database-driven architectures for spatial data analysis are flexible enough to also support innovative approaches to environmental decision support including data warehousing (Di Mauro et al. 2002), knowledge-based databases and decision support (Seder et al. 2000) or intelligent data analysis systems (Sanchez-Marre et al 2002). In addition, the Internet can provide the link between these new technologies. Cameron et al. (2002) describe the benefits of using the Internet as middleware for the development of decision support systems for natural resource management.

3.1. CASE STUDY - STUDY SITE AND THE FLOOD HAZARD

This paper describes a database-driven approach for integrating natural hazard risk data and GIS using the case study of flood (in this case, cyclone-induced storm surge) risk modelling and decision support. The focus of the following discussion is the development of an SDSS which can handle the large volumes of risk information generated by a hydrodynamic flood model run for multiple days and multiple flood scenarios. A storm surge (commonly called 'storm tide' when combined with tidal influences) is the term used to describe an anomalous elevation of water typically some 50 kilometres across generated by the action of a cyclone and the coastal bathymetry.

Cairns, (Figure 1) situated in Far North Queensland with a population of approximately 100,000, is one of Australia's most storm surge-prone regional centres. The linear nature of the coastal range in Cairns, combined with the desire for beach frontages, restricts urbanisation to a north-south corridor that leads to a greater risk. Although the incidence of major cyclone disaster in Australia is uncommon, events such as Cyclones Tracy (1974), Justin (1997) and Steve (2000) remind residents and policy makers that a substantial risk exists.

Figure 1. Cairns, Far North Queensland. Looking eastward from the coastal range over the central business district

3.2. HAZARD RISK MANAGEMENT DECISION MAKING REQUIREMENTS

Earlier research work in coastal Queensland examined the decision making requirements of risk managers (Zerger 2002). Some of these limitations included the need for overland inundation models to improve the reality of risk assessments as current approaches had not captured the dynamic behaviour of flood over land. Second, detailed user needs assessments with emergency managers in Mackay and Cairns have shown that they require additional temporal resolution rather than improved spatial resolution. Semi-structured interviews showed that risk managers would sacrifice the spatial resolution inherent in the GIS building database for more detailed time series information for evacuation planning. And finally, the response phase of cyclone inundation decision-making requires instantaneous risk assessments and hence hydrodynamic models cannot be run in real time. The paper by Zerger (2002) examines risk management decision making requirements in detail. These limitations have been overcome in this research; however some interesting new insights have emerged when a final user evaluation is conducted in Cairns (discussed below).

3.3. HAZARD MODELLING THE CHALLENGE OF TIME

To model the risk of flood from cyclone induced flooding in Cairns, the Mike21 system was used. Mike21 is a modelling system for 2-dimensional free-surfaceflows [DHI, 2000]. It has recently been accepted by the US Federal Emergency Management Agency (FEMA) as an approved coastal storm surge model for its National Flood Insurance Program. Water levels and fluxes are resolved in Mike21 for a rectangular grid representing the area of interest (Figure 2) using inputs including bathymetry, boundary conditions, bed resistance and wind fields (among other parameters). Over-land inundation modelling of storm surge, including the flooding and drying component of inundation, is critical for this research hence the importance of Mike21.

Water level datum information was provided by Queensland Transport (Maritime Division) and was used to adjust the bathymetry surface to the Australian Height Datum (AHD). The inclusion of flooding and drying in the model requires detailed topographic information for the urban area of Cairns. Anexisting 20 metre DEM was merged with the bathymetry to create the complete model domain shown at a combined grid resolution of 100 metres. In comparison to other attempts to model storm surge in Australia, this is a relatively detailed hydrodynamic model. Such detailed modelling was critical for Cairns, as similarly detailed spatial vulnerability databases were available and risk management needs demanded individual building risk estimates. Therefore, using this approach it is possible to assess the effect of landuse changeson flood risk including such changes as land clearing, urbanisation and road creation. Mike21 model runs were conducted for avariety of cyclone approach angles, central pressures, radius of maximum winds and crossing points to simulate likely scenarios.

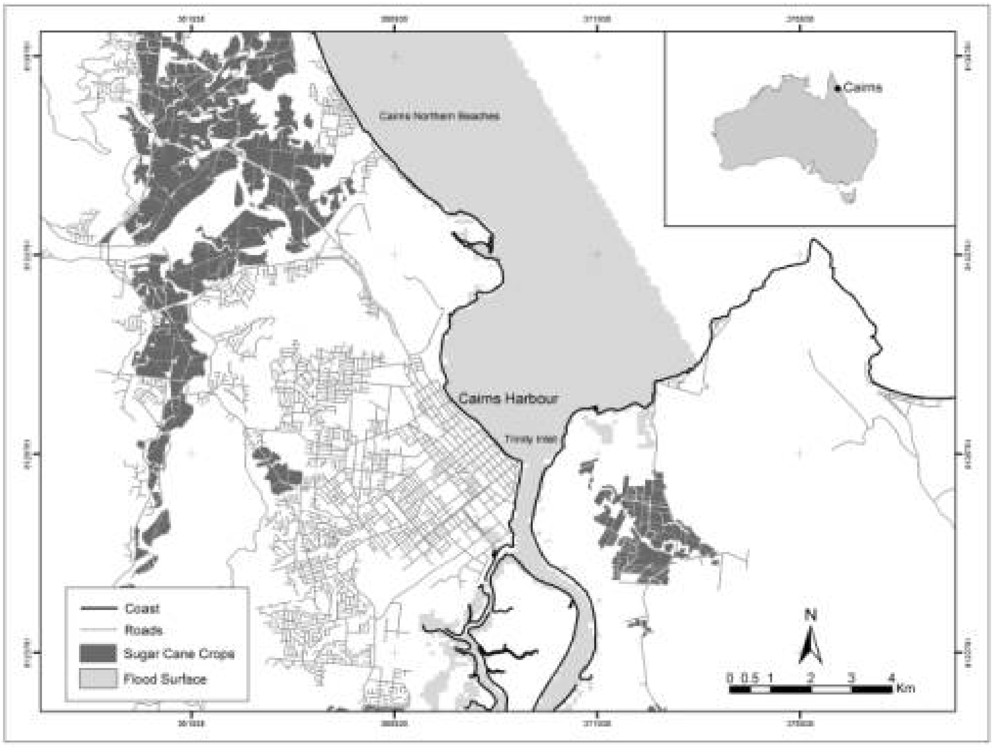


Figure 2. One Mike21 flood model time step for the Cairns study

Numeric modelling of storm surge inundations for multiple scenarios results in the generation of large inundation databases. In this project, a simple model run over 72 hours and analysedat 10 minute intervals leads to 432 raster inundation surfaces. As each surface is approximately 700 Kilobytes in size, this equates to some 30 Megabytes of data for only one model run. To perform a building risk analysis it is necessary to evaluate the inundation for every building in Cairns (approximately 27,000 buildings), for each time step in the scenario, and for multiple scenarios. This quickly generates millions of database records. As real-time risk modelling over such temporal domains is not feasible, the research pre-modelled realistic cyclone scenarios for Cairns. The objective is to develop and test the concept of electronic 'time-series look-up-maps'for future risk assessments. This dual requirement to manage vast databases, and to provide ongoing access to model results, drove the need for efficient and robust database management and consequently our shift towards adatabase-driven approach to data management and analysis.

3.4. SPATIAL DECISION SUPPORT SYSTEM ARCHITECTURE

The three critical components of our system are the Mike21 inundation model, the RDBMS and the GIS-based urban risk databases (buildings and roads).

Thehydrodynamic model permits the simulation of storm surge inundations for various time steps and cyclone parameters. The GIS provides an environment for data integration, analysis and visualisation, while the RDBMS facilitates temporal database management. In their own right these components are critical to perform a risk assessment. However, without integration their full potential to supportdecision making in Cairns cannot be realised. Through the integration of these components and a customised GIS interface, a spatial decision support system (SDSS) has been developed that allows risk managers to perform detailed temporal risk assessments (Figure 3). Decision-maker interaction is via a standalone software application called iFlood or an Internet application known as Floodbank. The following sections examine both these components.

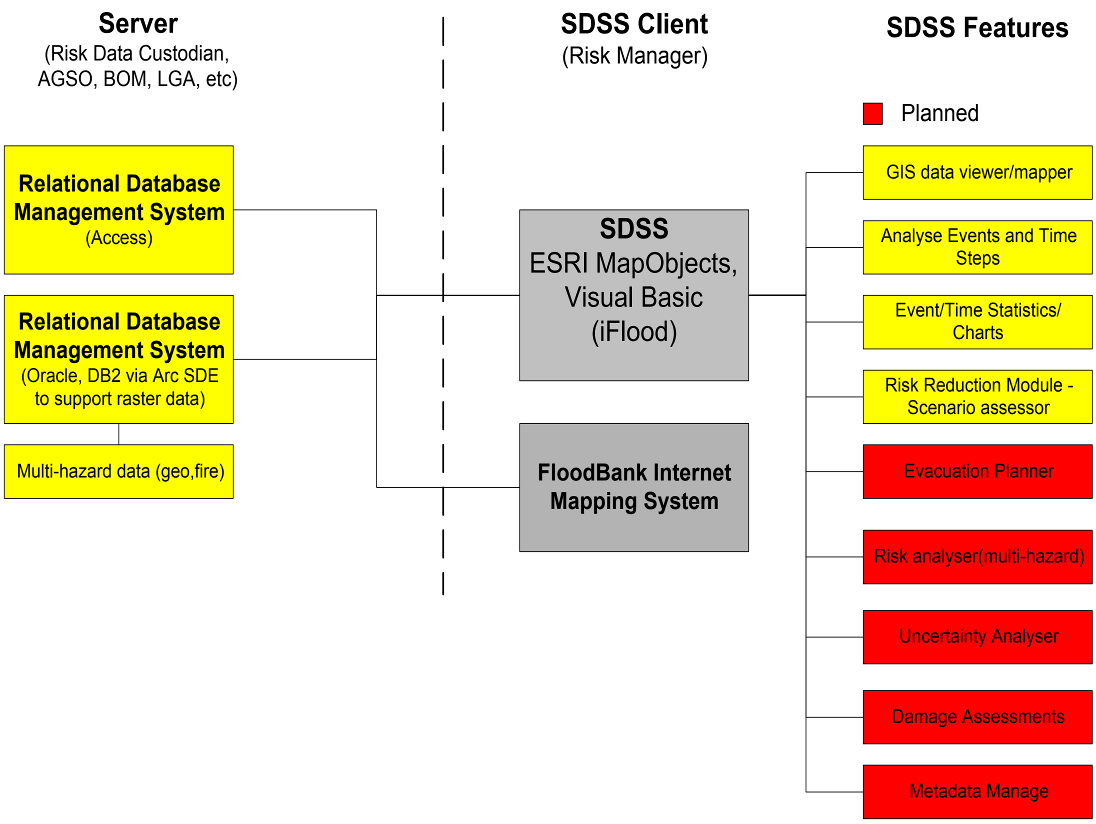


Figure 3. SDSS architecture and functionality

3.5. INTERNET MAPPING ARCHITECTURES

Map-based Internet applications have recently become available as decision support tools for organisations managing large amounts of spatial data. Data custodians often adopt proprietary software solutions such as MapInfo's MapExtreme, ESRI's ArcIMS or Autodesk's Mapguide. Each has very different capabilities, provide varying level of support for raster data, and most significantly, they adopt very different data distribution architectures. Primarily we see a difference between so-called 'thin-clients' such as ArcIMS, and 'thick-client' models such as MapGuide. The fundamental difference is that thick clients perform much of the processing at the client-end, while thin-clients rely on server-side processing. Each offers advantages, and the approach used will depend on the complexity of the spatial processing required, the anticipated number of users, data volumes commonly transferred, and the level of custodian control over analysis that is required. This paper describes the development and system components of an affordable Internet-based system for distributing flood hazard information to decision makers via the Internet called FloodBank. FloodBank is designed to allow multiple emergency management agencies to rapidly, and affordably, deploy new FloodBank nodes.

The most important benefit of Internet mapping systems is the ability to provide GIS functionality to multiple desktops, without the need for specialised GIS software. However, saying that, the development of an Internet mapping system utilising proprietary software can still be prohibitively expensive for smaller agencies, such as those involved in natural hazard risk management. For example, Internet mapping systems from companies such as ESRI and MapInfo can cost in excess of $20,000 to deploy. Such a system may only support less than 50 concurrent users, and costs increase when the user-base expands. This makes scalability and widespread deployment very expensive.

Foremost in the recent adoption of proprietary Internet mapping systems are utility companies and local governments, who have developed on-line asset and facilities management systems for spatial features such as pipelines, roads and telecommunication infrastructure. The rapid adoption by these industries is due to three factors. Developing an Internet mapping capability is very expensive; most proprietary systems to date have only supported vector data models, which are prevalent in the asset management industry; and these early-adopters traditionally service a relatively large user-base, with limited need for advanced spatial analysis capabilities. The natural resource and land management communities have seen a less rapid adoption, however it must be remembered that the technology is still in its infancy. For example, withinthe hazard community, CSIRO's Sentinel (http://www.sentinel.csiro.au/last accessed 10/8/2004) project has shown the benefits of Internet mapping to support real-time hazard risk management, in this case for bushfire mapping. The FloodBank system described in this paper, albeit simpler in GIS functionality than proprietary systems, shows how an affordable mapping solution can be deployed by hazard risk management agencies. Such anapproach may be an excellent first step, before a more ambitious internet mapping initiative is undertaken, or in other cases it may indeed provide the level of GIS functionality that is required for most lay users.

3.6. THE FLOODBAND DESIGN

FloodBank is an Internet mapping system used to catalogue study areas and associated flood event databases generated from flood models. The technology enables users to visually interrogate the catalogue of study areas and associated simulations of flood events, to spatially visualise flood risk, and for distributing flood event data to users requiring more sophisticated analysis. There are three major components to the FloodBank system including the FloodBank Internet system, the Pre-processor utility for migrating raw flood data to FloodBank, and the iFlood decision support system for performing more detailed risk assessments.

The data management framework is based on the assumption that risk models are pre-run and results are stored in a relational database management system (RDBMS). In this case study of FloodBank, a hydrodynamic flood modelling system called Mike21 has been used to create multiple flood events for Cairns, Queensland. This approach is designed to allow risk managers rapid access to model results (via SQL requests), and provides a generic data management framework that allows for rapid data analysis (creation of reports, summary statistics and graphs). In addition to providing an efficient data management framework, the RDBMS allows for rapid database queries that can include geo-temporal questions such as:

- How many buildings and roads are inundated at each time step for each scenario?
- Show all the buildings that are inundated for more than 1.5 hours, above floor height;
- For the building at 20 McLeod St., show the time-series inundation for a Cat 3 cyclone approaching from the northeast?
- How long does the building at 12 High Street stay inundated after the cyclone has passed?
- Show the maximum inundation for each building for all building events and all times steps; and
- Show all the buildings that were flooded greater than 0.5 metres above floor level for more than two hours for a Category 4 cyclone.

FloodBank is an Internet application comprising a user interface and a data querying and reporting toolbox, a data management catalogue (i.e. metadata database) and a data warehouse. The application has been developed using a range of technologies that includes Microsoft Active Server Pages (ASP) for the construction of the user interface and database querying engine, Microsoft Access databases for the data management catalogue and for the storage of flood event summary statistics and ASPMap, a third party component used for online map rendering of GIS data. The application is divided into two major modules including the Study Manager and User Manager, described below.

3.7 STUDEY MANAGER

The 'Study Manager' contains basic information about different study areas recorded in the system (Figure 4). Study areas can be added, edited and removed. Recorded attributes for each study area include the name of the study area, the software used to generate the flood model data, the agency responsible for the flood model and the location of the study area. Each study area can have any number of associated flood modeling events. For each flood modeling event a standard set of information is recorded. Event attributes include the description of the flood event, the number of surfaces generated in the modeling process, the model parameters used, the model start time and the time increment. Each event has a corresponding database derived from the preprocessing software, containing summaries of the modeling analysis. Databases must be uploaded when new events are recorded in the system.

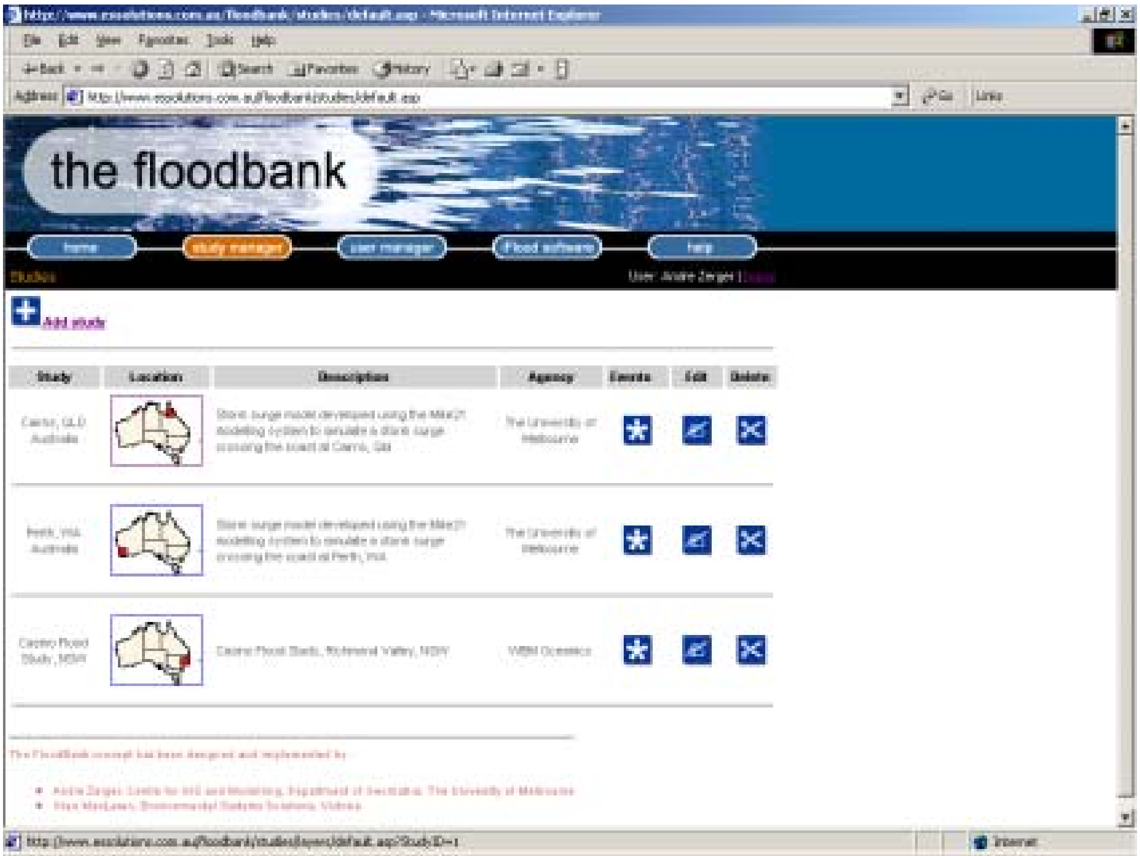


Figure 4. FloodBank Study Manager

Events and event databases can be interrogated with the aid of an Internet mapping utility (Figure 5), which allows users to execute basic queries on the database then visualize the results spatially.Point locations can be queried using a nominated threshold water height and a specified time. Point locations meeting the search criteria are displayed in a map with a series of GIS layers. The GIS layers used in the construction of the map can be formats supported by ASPMap and include ArcView Shapefies, MapInfo Tab files and GeoTiff images. The mapping utility provides users with a means to visualise and interrogate database content withoutthe need to download database files locally. This is important, as data custodians can periodically update flood models, hence controlling the information available to decision makers. If required, event databases in Microsoft Access database format can be downloaded for more detailed analysis using iFlood, or any other user customised software.

3.8 USER MANAGER

The user manager is used to delete, edit, and register users. The module is also used to modify and set user authentication and permissions. Permissions are set for each study area to ensure that any sensitive data can be hidden from unauthorized users. Each user has a username and password that must be used to access any part of the system. Users can be granted system 'Administrator' rights by existing system administrators.Microsoft Active Server Pages

- User Manager
- Model Metadata Manager
- Study Site Manager

PreProcessor The case study currently available to authenticated FloodBank users shows a Landsat TM satellite image for Cairns provided as a backdrop to road networks stored in the Shapefile format. Figure 4 shows the Study Manager used to manage the flood data multiple study sites, and Figure 5 shows the mapping tool used to analyse the risk for one event

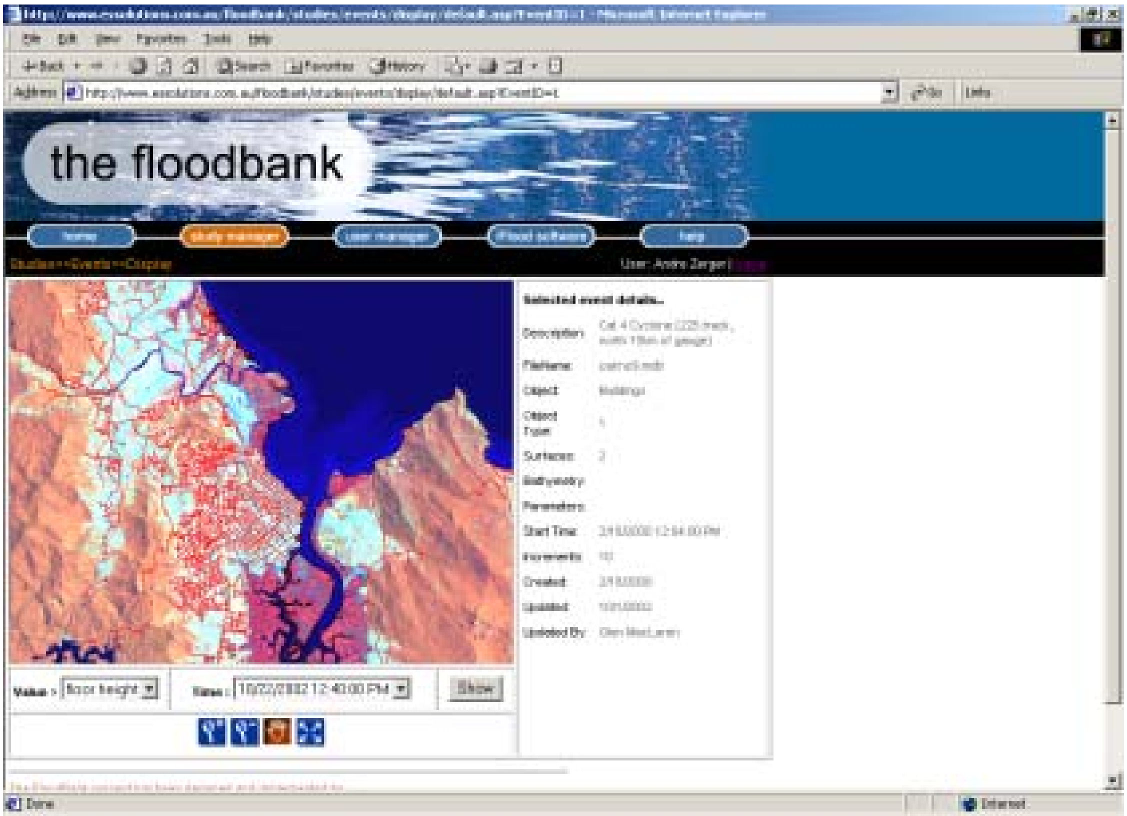


Figure 5. FloodBank Event Viewer

4. iFLOOD SPATIAL DECISION SUPPORT SYSTEM(SDSS)

Our earlier research attempted to interface flood model results with the proprietary GIS ArcView (Wealands et al. 2001). Developing SDSS software entirely within a proprietary GIS has a number of limitations including the high cost of ArcView, the size of the software installation and limited flexibility to customise its functionality. In addition, the ArcView approach was relatively slow in querying data and its database connectivity capabilities were limited. To overcome these limitations, development of the SDSS has been completed using ESRI's MapObjects 2.1 mapping components and Microsoft Visual Basic 6.0. The software application, iFlood, has been developed with viewing, analysis and hazard event management capabilities (Figure 6 and 7). Advantages of the iFlood approach include:

- Custom GIS functionality that removes the complexity of commercial GISs for risk managers
- A very small software footprint making for easy distribution;
- Efficient data management capabilitiesincluding fast SQL execution to external Relational Database Management Systems (RDBMS);

- An inexpensive software platform (approximately $300 per installation); and
- Ability to develop custom analysis algorithms using compiled code rather than interpreted macro languages such as Avenue.

iFlood is coupled with FloodBank as it adopts the same hazard event relational database design. In other words, a user with sufficient permissions, can download an event database to their local computer, and perform a more detailed iFlood analysis. Alternatively, iFlood users can connect to the FloodBank depository to perform an analysis using FTP protocols. However, owing to the size of event databases (i.e. 33mb for one event of 24,000 buildings, and 273 flood surfaces), local analysis is more efficient.

The shift towards database driven spatial data management provides opportunities not available in standard GIS data models (i.e. Shapefile and Coverage). This trend has been evidenced by the recent availability of spatial data modelling capabilities in RDBMSs, including such products as Oracle Spatial and IBMs DB2 Spatial Extender. Similarly, GIS vendors are moving towards RDBMSs as a way to manage spatial data models. For example, ESRIs Geodatabase format, is based on a Microsoft Access relational database model. Both industries are seeing a convergence in how spatial data aremanaged, with an overall shift towards SQL compliant, relational database models. Advantages of such approaches include:

- Query and data analysis capabilities not available in most GISs;
- Generic query languages such as SQL means data custodians can use other RDBMSs;
- The efficient management of time-series risk information such as flood data;
- Decision makers can develop their own DSS software using SQL protocols, and access existing FloodBank databases; and
- The ability to integrate hazard data with other corporate RDBMs.

A Cairns flood modelling exercise results in the output of raster or grid surfaces containing predicted water heights for each simulation time step. The FloodBank 'Preprocessor' is a desktop application developed in Visual Basic that interrogates these flood model surfaces using point location data. These data can represent any geographic feature of interest (e.g. Buildings, Bridges, Cultural Sites). Water height data are extracted for each point location for each time step. The summarised data are then organized and migrated into a new relational database, designed specifically to store this information.

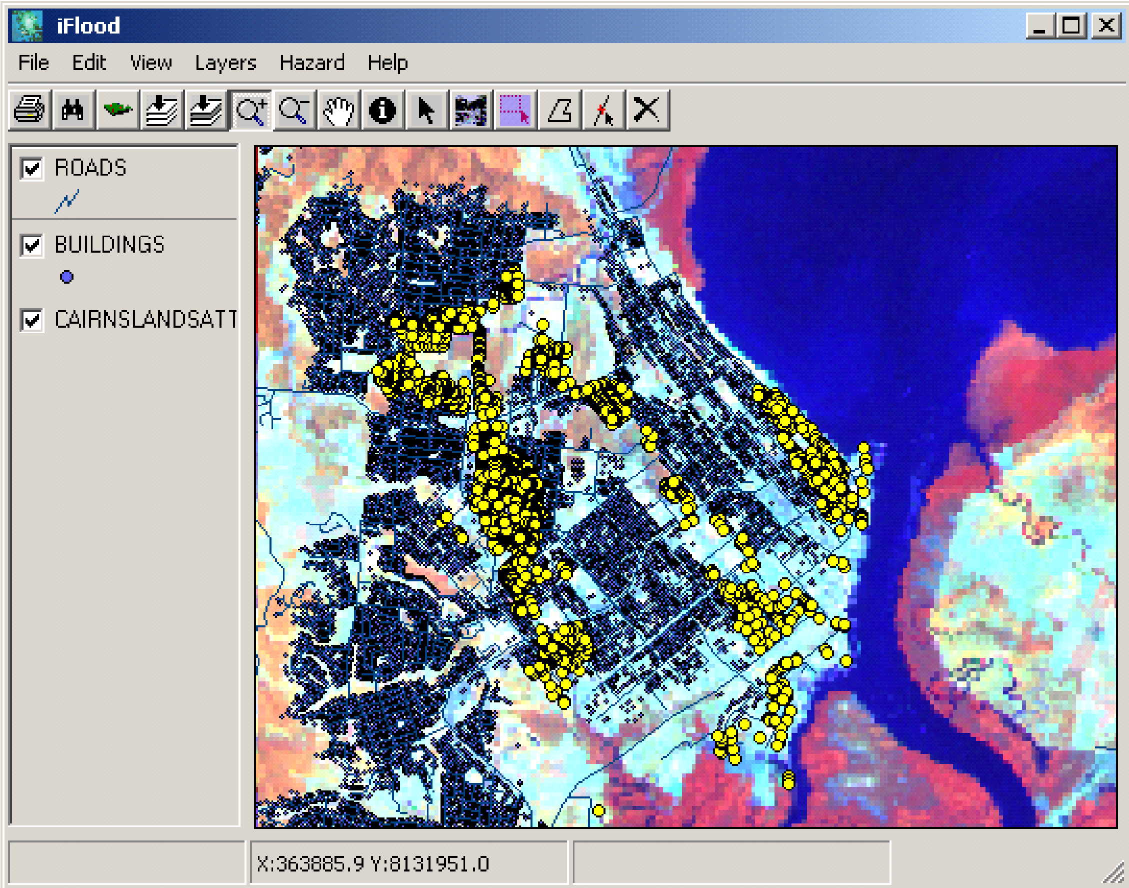


Figure 6. iFlood interface showing inundation for Cairns

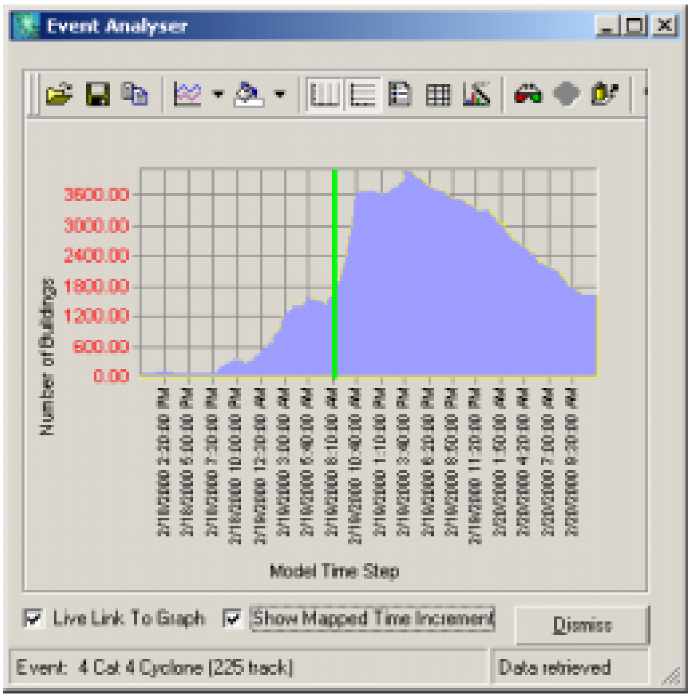


Figure 7. Event time series graphing and data analysis tool

4.1. FLLLDBAND AND iFLOOD - ASSESSING USER PERCEPTIONS

We have argued earlier in this paper that conducting a user perception evaluation is critical for any research whichattempts to develop decision support tools for complex decision-making tasks. Natural hazard risk management decision-making certainly falls into this category and owing to the temporal variability of decision needs, this becomes increasingly important. In addition, we stress the importance of identifying individual decision making requirements, rather than treating decision needs for hazard management as one entity. For instance the well documented prevention, preparedness, response and recovery model of disaster management is a very convenient construct for SDSS development and evaluation although other constructs do exist.

On May 20 & 21, 2003 a post-software development user evaluation was conducted with the cooperation of the Queensland Department of Emergency Services and the Cairns City Council. Following an initial information session a demonstration of both systems (iFlood and FloodBank) was provided to nine hazard risk managers. The iFlood demonstration introduced the users to the interface and tools available in iFlood and included a practical demonstration for a number of hazard scenarios. Users were encouraged to askquestions and to propose desired spatial decision support capabilities, in addition to those already present in iFlood. After completing the iFlood demonstration, an online demonstration of FloodBank was provided. Weacknowledges that the number of users evaluated represents only a small sample of a potentially larger audience, however, we believe that this cohort provides more information-rich responses owing to their interest in the study area adopted in this research. Responses garnered from participants were promising and highlighted the value of both software approaches.

However, it is clear that both technologies will benefit different users. Namely, FloodBank is of greater utility to data custodians and risk management agencies, while iFlood was more warmly received by emergency managers. Emergency managers recognised the importance of time series information for evacuation planning and acknowledged that iFlood was very intuitive to use for a non-expert. Respondents acknowledged that the greatest benefit from the technologies would be during the disaster planning stage rather than as a response tool, however it was recognised that it could also play a role in the training and education of emergency managers. This provides many unexplored opportunities for software development and adoption. Similarly, for the system to be more effective, a greater number of hazard events would need to be modelled and included in an event database. At present Floodbank has archived 16 flood model runs for Cairns.

During this evaluation, users were presented with only nine cyclone scenarios of varying approach angles, crossing points and intensities. There was agreement that a tighter integration with real-time meteorological data would be valuable although this poses some major technical challenges. The FloodBank approach was recognised as being a useful approach for sharing model results and hence for encouraging dialogue. Similarly, the use of a simple and efficient data sharing model was encouraged by those users with data management responsibilities. Both groups of decision makers believed FloodBank would be suitable for keeping abreast of modelling developments for their management domains.

4.2. CONCLUSION

The aim of developing FloodBank is to improve access to flood model results to multiple stakeholders, and to provide a structured framework to ensure the long-term utility of flood model outputs. There is little doubt that to date accessing flood model results from numerical models to support decision making is fraught with technical challenges. Similarly, we argue that a fundamental barrier to more informed natural hazard decision making is access to hazard model results in a structured and well contextualised manner. Floodbank moves some way towards achieving this. In addition to its on-line mapping capability, FloodBank also ensures that model results are stored systematically, with detailed metadata, and in a standard that facilities future software interoperability (SQL compliant RDBMS). The interoperability issue is receiving increasing attention in the geospatial industry as data custodians attempt to interface spatial data holdings with other corporate databases. There are examples in the hazard and risk management communities where such linkages could lead to improved decision support. For instance, establishing integration between multiple hazard risks (fire, flood and landslide) to buildings with corporate databases containing owner contact information may assist with evacuation planning. The development of Internet architectures such as FloodBank, in combination with iFlood, moves some way in this direction.

Practitioners attempting to develop GIS for natural hazard risk management are commonlyfaced with decisions regarding the choice of appropriate GIS software, programming languages, interface designs and spatial data models. These technical decisions are in addition to the user needs concerns described earlier. Based on our research findings, we would argue that more thought and attention needs to be devoted to data management and integration, or the 'back-end' component of hazard data management. If we take the example of using a RDBMS for managing geo-temporal hazard data, GIS practitioners have the capability to develop customised front-end SDSSs which utilise a common back-end. By using interoperable data exchange protocols such as SQL, we then have the flexibility to customise the 'front-end' to address the varying decision making needs of hazard risk managers, irrespective of the choice of their GIS. For instance, in our research both an Internet-based front-end and a standalone customised GIS can access the same data model. Further, the benefits of well-designed back-end database management systems can extend beyond the integration of hazard and vulnerability information. For example, the use of interoperable data management protocols allow for the integration with other corporate databases such as rates, land tenure and demography to name only a few examples.

Have we succeededin addressing decision-making requirements with the Floodbank and iFlood approaches? Anecdotally there is evidence from the user evaluation that the tools we have developed are an important step towards improved integration. However in terms of uptake, we would argue that our approach is yet to be fully proven, and as is the nature of natural hazard risk management, it will not be fully tested until a major event in Cairns occurs. However, this argument assumes that the major role of GIS for natural hazard risk management is during the response and recovery stages.As was noted in earlier sections of this paper, the prevention and preparedness stages have very different decision-making requirements and from this perspective some major gains have been achieved. Our paper has placed an emphasis on the need for GIS practitioners to adequately asses user-needs prior to system development. Some would argue in favour of developing prototypes to stimulate and elicit user feedback from natural hazard risk managers. However, GIS practitioners are also faced with a decision between building a fully featured GIS prototype to elicit user feedback that can be readily modified, versus developing too much inadequately considered functionality which does not address decision-making needs. As such, perhaps the most appropriate solution is one of iterative user-needs evaluation through all phases of system development. In other words, collaborative system development between GIS practitioners and natural hazard risk managers is essential for successful SDSS development.

4.3 ACKNOWLEDGMENTS

The FloodBank system has been developed with the assistance of a grant from Emergency Management Australia Projects Program for 2002-2003. Thanks are extended to DHI Water and Environment Australia for their support of this research, and for the ongoing contribution provided by Geoscience Australia. Elements of this paper have formed the basis of a paper submitted for publication in the journal Natural Hazard and the section introducing the Floodbank approach has been previously presented at the recent MODSIM03 conference. The presentation of this paper has been made possible through the support of the Korea Institute for Human Settlements. Sincere thanks are extended to Kyu-Bang Lee and Dong-Han Kim.

REFERENCES

Bates, P.D. and De Roo A.P.J. (2000) A simple raster-based model for flood inundation simulation, Journal of Hydrology, 236(2000) 54-57.

Biza, P.,V. Gimun, R. Knap, H. C. Ammentorp, T. Ihly and G. Smith (2001). The Use of a GIS-Based Software Tool for Benefit-Cost Analysis of Flood Mitigation Measures in the Czech Republic. DHI Software Conference, June 2001

Clark, M. (1998). Putting water in its place: a perspective on GIS in hydrology and water management. Hydrological Processes 12: 823 - 834.

Cameron, M. A., B. Croke, K. L. Taylor, G. Walker and B. Watson (2002). Regional Integrated Management Information System. iEMMSs, Lugano, Switzerland.

Correia, F.N., Saraiva, M.D. Da Silva, F.N. and Ramos, I. (1999). Floodplain Management in Urban Developing Areas. Part II. GIS-Based Flood Analysis and Urban Growth Modelling. Water Resources Management 13: 23 - 37.

Di Mauro, C., J. P. Nordvik and A. C. Lucia (2002). Multi-criteria decision support system and Data warehouse for designing and monitoring sustainable industrial strategies an Italian case study. iEMMSs, Lugano, Switzerland.

Dutta, D., Herath, S., and Musiake, K. (2000), Flood inundation simulation in a river basin using a physically based distributed hydrologic model, Hydrological Processes 14, 497519.

Fedra, K (1993), Models, GIS and expert systems: integrated water resources models. HydroGIS'93: Application of Geographic Information System in Hydrology and Water Resources, Proceedings, IAHS Publ. No. 211, Vienna, Austria.

Jain, S.K., Singh, R.D. and Seth, S.M (2000) Design flood estimation using GIS supported GIUH approach, Water Resources Management 14, pp.369-376.

Lilburne, L. R., T. H. Webb, Benwell, G.L. (2004) The Scale Matcher: a procedure for assessing scale compatibility of spatial data and models, International Journal of

Geographical Information Science 18(3): 257-279.

OGC (2002) Open GIS Consortium, http://www.opengis.org/ Last Accessed August 2, 2004.

Pickup, G. and Marks, A. (2001) Identification of floodplains and estimation of floodplain flow velocities for sediment transport modelling CSIRO Land & Water, Technical Report 10/01, July 2001, pp. 26.

Sanchez-Marre, M., K. Gibert, et al. (2002). Development of an intelligent data analysis system for knowledge management in environmental databases. iEMMSs, Lugano Switzerland, 421-425.

Seder, I., R. Weinkauf and I. Seder (2000). Knowledge-based databases and intelligent decision support for environmental management in urban systems. Computers, Environment and Urban Systems 24: 233 - 350.

Todini, E. (1999) An operational decision support system for flood risk mapping, forecasting and management. Urban Water 1: 131 - 143.

Wealands, S., Zerger, A. Szykalski, S., Carr, R. (2001) Integrating spatial information systems and hydrodynamic modelling for cyclone risk management, International Congress on Modelling and Simulation, The Australian National University, Canberra, December 2001.

Zerger, A. (2002) Examining GIS decision utility for natural hazard risk modelling, Environmental Modelling and Software, 17:287-294.

Zerger, A. and Smith, D.I. (2003) Impediments to using GIS for real-time disaster decision support, Computers, Environment and Urban Systems 27:123-141.

GIS-based Flood Disaster Mitigation System

Kun-Yeun Han

Professor, Kyungpook National University
kshanj@knu.ac.kr

1. INTRODUCTION

Due to the global warming, recent abnormal weather system results in concentrated local rainfall and alters runoff patterns to yield flood damages such as casualties and property losses. Since the flood damage is dramatically increased due to the rapid urbanization and industrialization, GIS-based flood disaster mitigation analysis is desirable not only for flood hazard mapping but also for Emergency Action Plan against dam-break or levee-break.

Recent flood disasters in Korea include Typhoon Rusa on August 31, 2002 and Typhoon Maemi on September 12-13, 2003. These flood poured record-breaking rainfall of 870mm in Kangnung area only for one day. Total property damages were estimated to be approximately 4.1 billion dollars and 3.4 billion dollars, and the number of loss of life were about 246 and 131 respectively. Thus, for disaster prevention it is important to identify flood area accurately and generate useful digitized maps for those regions. This paper focuses on GIS-based flood disaster mitigation plan in Korea by inundation analysis, flood hazard map and emergency action plan.

2. FLOOD INUNDATION ANALYSIS

The basic expression of flood inundation analysis in river basin is described by the one-dimensional Saint-Venant equations, in which the flow rate through a broken-levee, and the momentum effect of lateral outflow through the broken levee.

Floodwave in an inundated area can be simulated by two-dimensional shallow water equations, which consist of continuity and momentum equations. For the derivation of the levee breach hydrograph, which represents flow rate into the floodplain, the interface model was developed using the levee breach model and considering submergence effects.

The effective parameters for the derivation of breach hydrograph are water levels in the channel and floodplain, breach width, failure duration time, and final breached levee height.

3. RISK ANALYSIS

Accurate flood inundation modeling is essential for a clearer understanding of their prediction, risk zone mapping, evacuation planning, and insurance program. Despite the improvements in the numerical models that have evolved over the last decade, flood inundation modeling is still subject to great uncertainty. Several sources of error limit the accuracy of prediction of the time and magnitude of flooding occurrence at any specified location. One source of errors results from the uncertainty of river-floodplain hydraulic parameters. These include errors due to cross sectional geometry, and errors in estimation of Manning's roughness coefficient.

Determination of cross sectional geometry of a river is usually obtained from topographical maps. Errors are always present in the description of the cross sectional properties of a river. The main sources of errors regarding cross section uncertainty are field measurement error, errors inherent in the assumed linear change between contour intervals on topographical maps, and manual errors introduced when distances between contour intervals are measured.

Manning equation is usually used for the open channel flow to calculate frictional head losses. Manning's roughness coefficient is a comprehensive representation of channel resistance to flow in a river. For normal flood conditions, Manning's values are usually estimated by field observations, and calibrated using observed high water marks from historical flood records. However, for a levee-break flood, its larger magnitude makes it difficult to fully calibrate Manning's coefficient based on any previous flood information. Monte Carlo simulation technique is employed to examine the effect of uncertainty due to cross sectional geometry and hydraulic roughness on flood inundation modeling. Errors in the river geometry or the roughness are considered spatially uncorrelated and randomly distributed. For simplicity, uniform probability distribution is used for all error estimations in this study.

The dynamic wave model is studied to analyze the risk of levee breach, to compute the flow rate resulting from breached levee, and to estimate the inundated depth and extents. Fig. 1 shows the organization of GIS-based flood disaster mitigation system in this study.

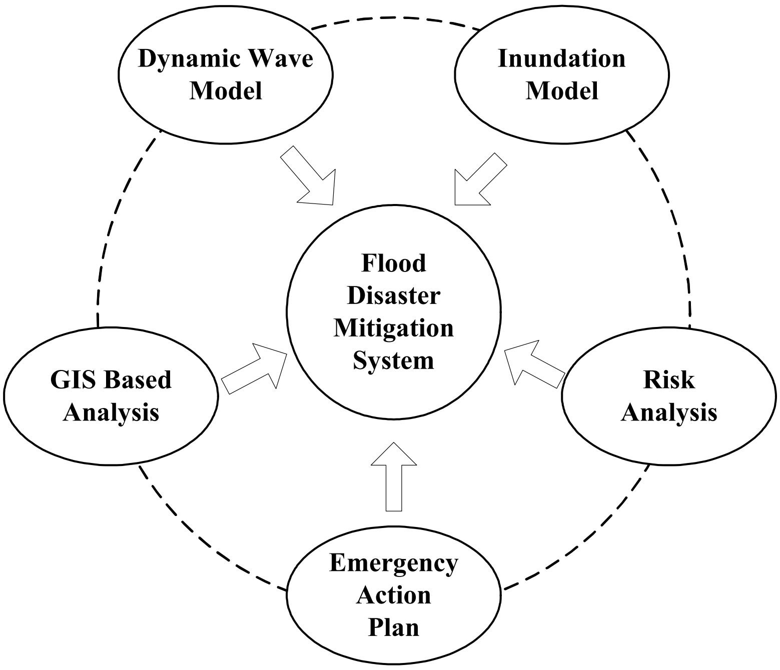


Fig. 1. Organization of FDMS

To simulate flood inundation, the dynamic wave model is developed as follows.

- The dynamic wave model is developed to simulate simultaneous multiple overtopping and/or the breaking of the levee. A interface program is constructed to inflow the inundated discharges from overbank spilling to the inundated area.
- The Monte Carlo simulation technique is employed to examine the effect of uncertainty due to cross sectional geometry and hydraulic roughness on the flood inundation analysis.
- The overtopping probability of the levee can be estimated for each iterative simulation. The maximum and minimum overflow discharge from overtopping and/or the breaking of levee, the inundated depth, and its extents can be obtained.

4. GIS APPLICATION

According to rules of digital maps, the transformation of the vectors of the base map was enforced, and three-dimensional topographic data of the protected lowland was developed. The three-dimensional topographic form was built for user convenience and includes the facility for accurate simulation. The basic data used to create the geometrical form of the protected lowland consisted of detailed field survey maps, a pre-existing 1/5,000 topographic map, and a longitudinal and horizontal map of the basic river plan.

Fig. 2 shows a flow chart outlining the geometrical form of the flooded area.

A digital base map is considered as the base map and organized TIN data for the necessary section and x, y coordinates are converted for each node of the organized geometric net to the text file, thereby building the applicable form for this study model. The digital model input data that contain the x, y coordinate for each spot and the applicable elevation data are both used in the topographic map auto-self-getting process for the terrain of the river, thereafter the grid and node of a particular section are selected. The geographical data related to the region of interest and the digital map of the channel are then combined.

When considering the flood overflow from a river, the flood overflow diagram needs to be created based on an analysis of the flood wave propagation characteristics, the range and level of inundation, and a numerical analysis model that can predict the scale of damage. The numerical analysis model used to create the flood overflow diagram should be designed to become the basic data for a prediction diagram of the flood overflow zone in the surrounding protected lowland, flood-insurance, and flood forecasting/warning using a temporal calculation of the flood wave propagation characteristics and flood water level.

More scientific flood management can be produced by relating the results of a flood inundation analysis to GIS.

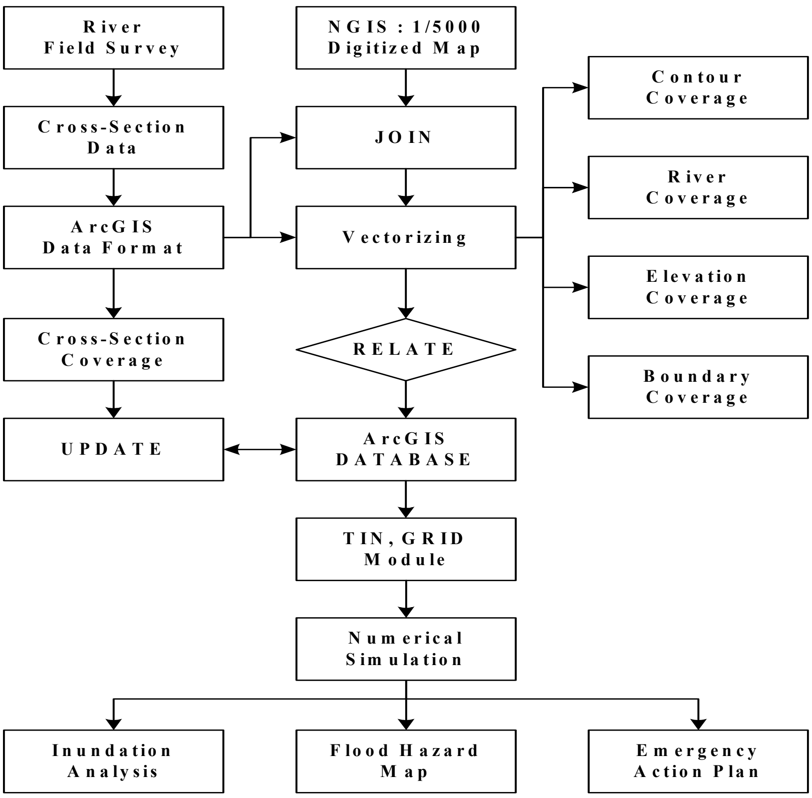


Fig. 2. GIS Analysis for Flood Hazard Mapping

5. DEVELOPMENT OF FDMS(FLOOD DISASTER MITIGATION SYSTEM)

For the flood disaster mitigation analysis, FDMS is developed using ArcGIS and applied to the some river basins in Korea. Fig. 3 shows the establishment process of FDMS, which combined the flood inundation model with the ArcGIS. As shown in Fig. 3, step one includes the establishment of the digital terrain model of the region using the ArcGIS, and the flood inundation is simulated in step 2. Steps 3 and 4 involve the risk analysis and establishing Emergency Action Plan on the ArcGIS, respectively. Finally, a maintenance process for the flood inundation analysis system is included in step 5.

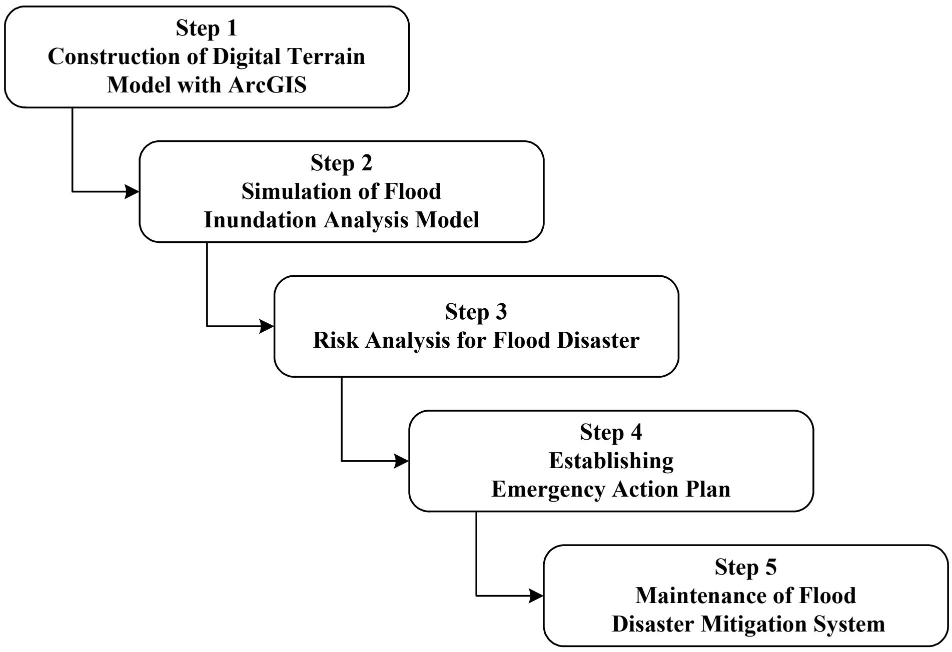


Fig 3. Establishment Process of FDMS

The required information to derive the hydrograph when the flood inundation occurs is: the flood depth of the channel, shape of the bank failure, and inundation depth of the bank protected region. For the case of the bank failure due to the channel overflow, the formula of broad crest weir is applicable, and for the inundation due to the piping, the orifice formula is valid.

After the overflow discharge associated with the bank failure was computed, it is necessary to consider the reverse flow since overflow depth of the bank protected region increases by continuous inflow from the channel. Therefore, comparison of the flood depth between channel and bank protected region is required in order to know whether the bank overflow proceeds or not. Considering the inundation characteristics of the bank protected region along with the reverse flow behavior, channel routing computation continues for the following section or next time step.

Dominant factors in generating the inflow hydrograph at the location of bank failure are parameters such as bank failure width, time, discharge coefficients, the ratio of land use, and flood depth.

This flood disaster mitigation analysis system is established in ArcGIS. It is useful for user's decision making for the on-line status through various analysis, editing, and merging of many different data set. The proposed flood disaster mitigation analysis system has capability for the on-line data process including flood routing, and has a post-processor for the reasonable visualization of various types of outputs.

6. Conclusion

For the GIS-based flood disaster mitigation analysis, dynamic wave model is developed to analyze the risk of levee breach, to compute the flow rate resulting from breached levee, to estimate the inundated depth and extents, and to provide basic data for Emergency Action Plan. The suggested model is applied to the river, then risks of levee overtopping are estimated by Monte Carlo simulation method, The stage hydrographs at inside and outside of the levee, and the inundated discharge from overbank spilling are simulated. The storage volume is agreed with the difference between the over flow volume and the returned volume. It can be seen that this model reasonably considers the simultaneous multiple inundation phenomena and the overflowing discharge interchange between inside and outside of the levee. Two- and three-dimensional flood inundation map is presented by using ArcGIS.

FDMS(Flood Disaster Mitigation System) is established by linking the flood inundation model with ArcGIS. FDMS will be extended to handle the real-time inundation risk by applying radar rainfall forecast and Kalman Filtering technique, and flood propagation in urban area considering drainage networks in the future. It is expected that the proposed model will contribute to analyze the flood hazards, to prepare the flood inundation maps and to establish Emergency Action Plan for river basins in Korea.

REFERENCES

Akan, A.O. and Yen, B.C. (1981). "Diffusion-wave flood routing in channel networks." J. of Hydraulics Division, ASCE, Vol. 107, No. HY6, pp. 719-732.

Akanbi, A.A., and Katopodes, N.D. (1988). "Model for flood propagation on initially dry bed." J. of Hydraulic Engineering, ASCE, Vol. 114, No. 7, pp. 689-706.

D'Alpaos, L., Defina, A., and Matticchio, B. (1994). "2D finite element modelling of flooding due to river bank collapse." in Molinaro, P., and Natale, L. (eds), Modelling of Flood Propagation Over Initially Dry Areas, American Society of Civil Engineers, pp. 60-71.

Evans, E.P., and Lany, P.H. (1983). "Mathematical model of overbank spilling and urban flooding." Paper No. G5,International Conference on Hydraulic Aspects of Floods and Flood Control, London, England.

Han, K.Y., and Park, J.H. (1995). "Two-dimensional model for the prediction of inundation area in urbanized rivers.",J. of Korean Water Resources Association, Seoul, Korea, Vol. 28, No. 6, pp. 119-131, (in Korean).

Han, K.Y., Lee, J.T., and Park, J.H. (1998). "Flood inundation analysis resulting from levee-break." J. of Hydraulic Research, Vol. 36, No. 5, pp. 747-759.

Han, K.Y., Lee, H.R., and Kim, S.H. (1998). "Numerical model for flood inundation analysis in a river" J. of Korea Water Resources Association, Vol. 31, No. 4, pp. 429-437.

Hromadka, T.V., and DeVries, J.J. (1985). "A two-dimensional dam-break model of the Orange County reservoir." International Symposium on Urban Hydrology, Hydraulic Infrastructures and Water Quality Control, Univ. of Kentucky, pp. 185-193.

Hromadka, T.V., and Yen, C.C. (1987). "Diffusion hydrodynamic model." Water Resources Investigation 87-4137, pp. 1-135, Water Resources Division, U.S. Geological Survey, Mississippi.

Iwasa, Y., and Inoue, I.K. (1982). "Mathematical simulations of channel and overland flows in view of flood disaster engineering." J. of National Disaster Science, Vol. 4, No. 1, pp. 1-30. Kyoto Univ.

Katopodes, N.D., and Strelkoff, T. (1978). "Computing two-dimensional dam-break flood waves." J. of Hydraulics Division, ASCE, Vol. 104, No. HY9, pp. 1269-1288.

Lee, J.T., and Han, K.Y. (1989). "A dynamic levee breach model and its applications to hypothetical and actual flood." Proc. 23rd Congress of International Association for Hydraulic Research, Ottawa, Canada, Sec. B, pp. 441-448.

O'Brien, J.S., Julien, P.Y., and Fullerton, W.T. (1993). "Two-dimensional water flood and mudflow simulation." J. of Hydraulic Engineering, ASCE, Vol. 119, No. 2, pp. 244-261.

Strelkoff, T., Schamber, D.R., and Katopodes, N.D. (1977). "Comparative analysis of routing techniques for the flood wave from a ruptured dam." Proc. Dam-Break Flood Routing Model Workshop, Water Resources Council, Washington, D.C., pp. 229-291.

Xanthopoulos, T., and Koutitas, C. (1976). "Numerical simulation of a two-dimensional flood wave propagation due to dam failure." J. of Hydraulic Research, Vol. 14, No. 4, pp. 321-331.

GIS Application for the Mitigation of Flood Disaster

Deuk-Koo Koh

Head Researcher,
Center for Hydro-informatics Research, KOWACO
dkkoh@kowaco.or.kr

1. INTRODUCTION

In Korea, flood is one of the most frequent natural disasters due to its meteorological and topographical characteristics. More than 2/3 of annual precipitation concentrates during the summer season (June to September) with frequent heavy rainfalls associated with the East-Asian Monsoon, locally called "Changma" and typhoons. Relatively short river reaches, small drainage areas, and steep channel slopes also cause the frequent flood disasters in Korea. During the last decade (1993~2002), annual average of life loss was 129 and property loss about US$1 billion.

Flood map is one of the non-structural measures to protect human lives and properties from flood disasters. Flood mapping in Korea was originated from a report, "White Book of the Comprehensive Planning for the Flood Disaster Prevention (1999, President's Task Force Team for Flood Disaster Prevention)." The report includes various flood protection and mitigation programs covering from the engineering technologies to the budgeting. Flood mapping was proposed as one of the non-structural program regarded as very new and feasible.

In 2000, the Ministry of Construction and Transportation (MOCT) committed the flood-mapping project to the Korea Water Resources Corporation (KOWACO). Thereafter,various researches have been conducted in order to support the actual flood mapping projects. The Guidelines for Flood Mapping was one of results of the researches. The guideline suggests the use of LiDAR surveying for the flood inundation simulation.

In places where the terrain is very flat, only one-meter increase of water level may result in the inundation of a very large area extending hundreds of meters away from the river channel. Accurate elevation data of the flood plain are required to represent the terrain in the inundation simulation (David, 2000). Recently, a relatively new technology called LiDAR has proven to be particularly effective in gathering this type of data both quickly and relatively cheaply.

The purpose of this study is to test the feasibility of using LiDAR data in the flood impact Analysis. This paper presents the procedure of flood impact analysis including topographic data acquisition by airborne laser scanning, use of them for the flood inundation simulation and mapping, and flood damage assessment. In the later part of this paper, the results of the flood impact analysis for the case study area are also presented to prove the feasibility of using airborne laser scanning data in the flood impact analysis.

2. METHODOLOGY

2.1 Flood Mapping

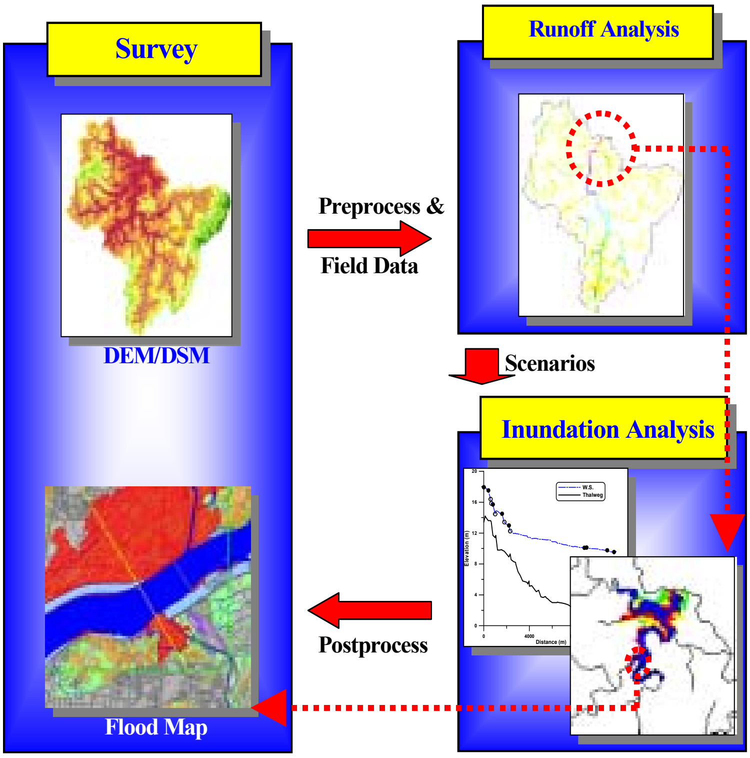
The process for generating flood map consists of four steps. The first step is obtaining the detail and accurate topographic information of the area, second is estimation of the runoff from upstream, third is inundation simulations based on the various scenarios, and the last is mapping on papers and digitally.

Either the SFM (storage function method) or Clark unit hydrograph method is used to estimate design flood. Since SFM has been used for flood forecasting and warning in major rivers of Korea for more than 30 years, it is easy to apply to the project areas in Korea.

Inundation analysis is carried out by a two dimensional unsteady flow model. The last step of flood mapping process is drawing the simulated results on the paper maps or digital maps. The flood mapping process is illustrated in Fig. 1.

2.2 Flood Damage Assessment

Flood impact analysis is very important to the effective management of land use as well as to the flood control. In general, flood damage can be evaluated by overlaying the flood map over the land use map. Flood map contains information on the extent of inundation, maximum flood depth, and detention time. GIS is a very useful tool to conduct such a task. Fig. 2 showed the process for the flood impact analysis.



<Fig. 1. Flow of flood mapping process>

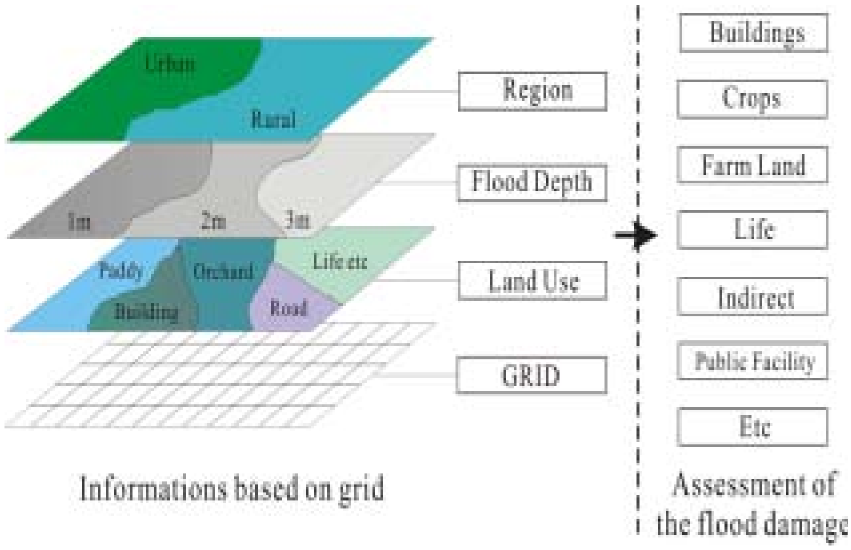


Fig. 2. Process for the impact analysis

3. CASE STUDY

3.1 Study Area

The study area is Yeoju, Gyeonggi Province, located approximately 60 km southeast of Seoul, Korea (Fig. 3). The entire study area covers an area of 8.43 km2and the population of this area is about 3,500 persons.

There are three stream channels in Yeoju. South Han (Namhan) River is the main stream that encompasses the area, and Soyang-cheon, and Ogeum-chon are the tributaries that flow into the mainstream.

There was a severe flood in this area in Aug 25, 1995. Main reason of the flood damage was the rising of water level from the Namhan River. The highest water level was recorded 10.6 m that are 1.1 m higher than the flood hazard water level. Levees were washed away and about 13,807 ha farmlands were inundated. Estimated total property loss was about 7.5 million US$ (MOCT & KOWACO, 2001).

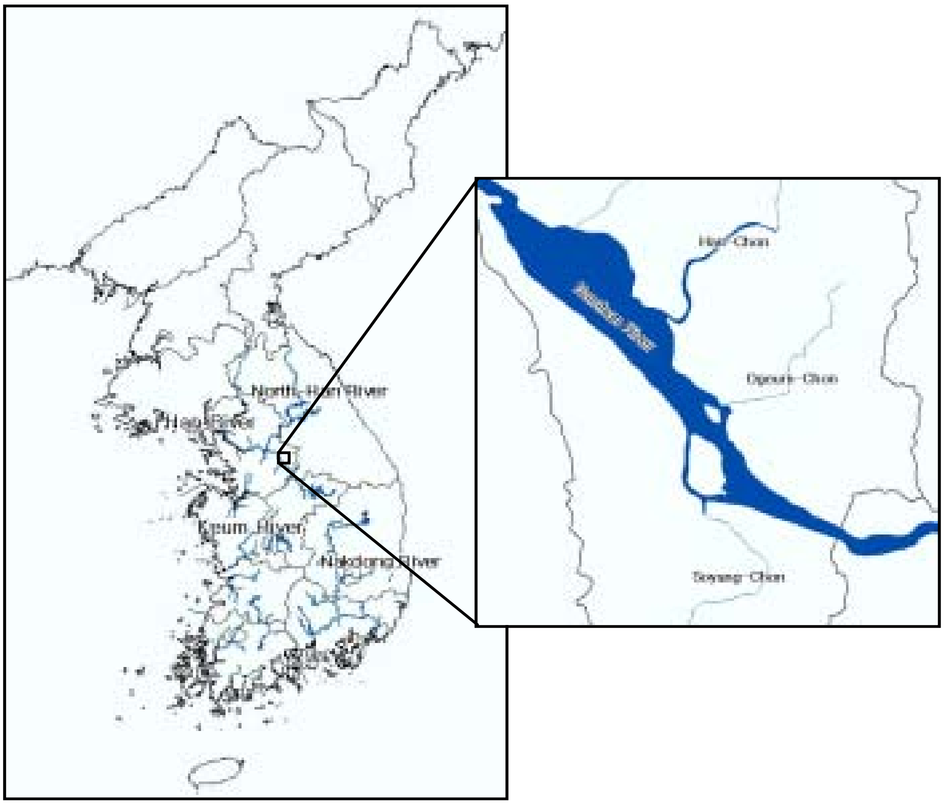


Fig. 3. Location of Yeoju and rivers around the area

3.2 Topographic Data Acquistion

Topographic data for the study area was acquired by LiDAR surveying in July, 2002. Optech's ALTM 2050 system mounted on CESSNA 208 aircraft was used (Fig. 4). Pulse repetition rate of ALTM 2050 system is 50 kHz, scanning frequency 47 Hz, scanning range 15 degrees, and has a collection mode for first and last returns, and intensity returns (IR) from 1047 nm laser. The aircraft flew at a velocity of 92.6 m/s and 800 m high above ground. This configuration results in a lateral point spacing of 60 cm, a forward point spacing of 70 cm, a footprint size of 60 cm, and a swath width of approximately 430 m.

Scanning was conducted by 60% overlapping. Through the LiDAR survey for the study area, 37,850,000 points data were acquired producing density of 4.1 points/m2.

The LiDAR data was processed primarily by Optech's REALM software. This software classifies the raw data into two classes using a proprietary algorithm. One of the classes is by first return signals and the other last return signals. Generally the first return signals represent the surface of objects such as vegetations, while the last return signals represent the ground surface, that is, DEM.

Afterward, the classified data acquired by WGS 84 UTM coordinate system were transformed into those by TM Bessel coordinate system using 7 parameters estimated by Brsa-Wolf's Equation.

Fig. 4. CESSNA 208 aircraft(left) and Optech's ALTM 2050 LiDAR system mounted on aircraft(right) applications. Australia, Canada, France, USA

3.3 Flood Inundation Simulation

FLUMEN (FLUvial Modelling ENgine) by Beffa was used to simulate flood inundation. FLUMEN is two dimensional unsteady flow model that is based on the 2-D shallow water equation and uses the finite volume scheme. Flood propagations through the inland area were simulated based on the various scenarios that include flood return periods of 100, 200, and 500 years, and conditions such as levee overtopping or levee failure.

Through the field survey at the study area, two points were selected to be vulnerable to the failure of levee as shown in Fig. 5. One is on the drainage gate located in Hyunam Levee (①) and the other is located in the junction of two rivers, Namhan River and Ogeum-cheon (②).

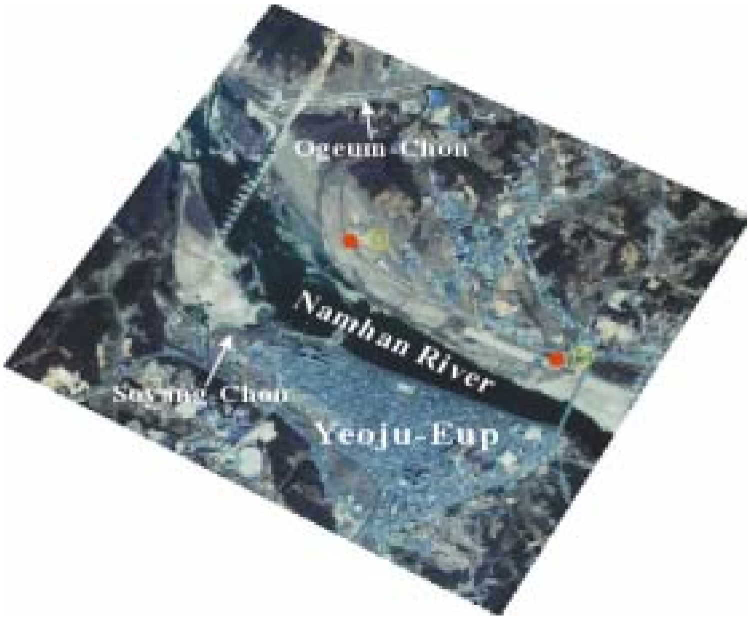


Fig. 5. IKONOS image for the study area. Red points indicate vulnerable points to the failure of levee

DEM is the most essential and important data for the flood inundation simulation using hydraulic model such as FLUMEN. However, it is necessary to manipulate DEM according to the required format by the model. It is also necessary to add breaklines to represent as correctly as possible the important ground features such as the levees, roads, buildings and so on. Breaklines were extracted using IKONOS imagery and the digital maps with 1:1,000 scales.

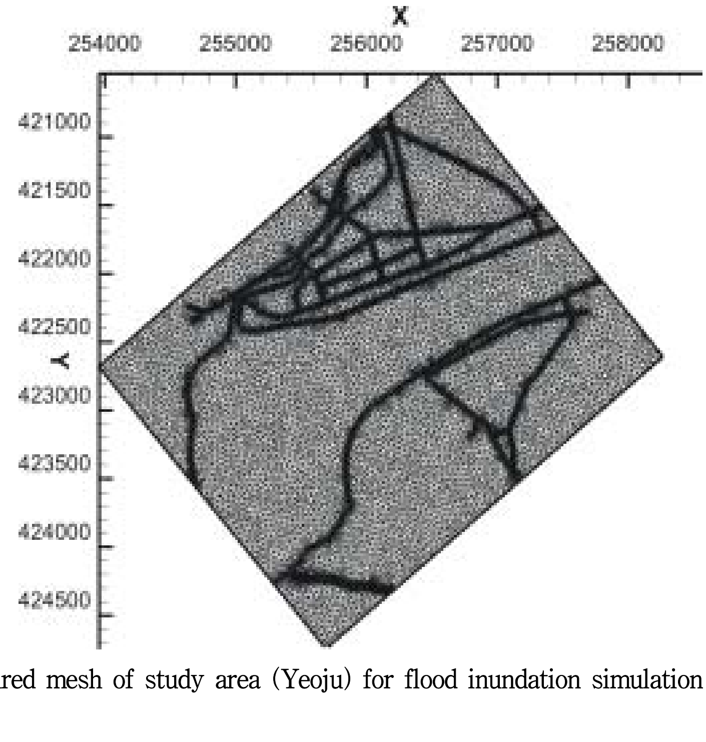


Fig. 6. Unstructured mesh of study area (Yeoju) for flood inundation simulation by FLUMEN

The elevation data for the riverbed were generated by interpolating the ground survey data. Fig. 6 is the unstructured mesh data, which is the input data for the FLUMEN generated from the DEM by LiDAR and supplementary ground surveying.

3.4 Flood Damage Analysis

In this study, the flood damage was estimated on the grid base and the grid size was 50 x 50 m. In this study, Flooding Area-Damage Curve was used to estimate the flood damages with Flood Maps. The curve was derived from the analysis of damages from the flood events during 1989-1998 and presents human life, farmland, public and private facility damage per unit area, as well as the damages per flooding depth and duration.

Table 1. Number of life loss, injured and affected people per unit area used for flood damage assessment (people/ha)

Class	Metropolis	Small Town	Suburbs	Rural Area	Forest Area
Death	0.004	0.004	0.001	0.002	0.002
Injured	0.002	0.002	0.001	0.001	0.002
Affected	1.85	1.17	0.27	0.37	0.98

Table 1 shows the number of life loss, injured and affected people per unit area (ha) by flooding while Table 2 and 3 shows household damage rate per flooding depth and crop damage rate per flooding duration, respectively.

Table 2. Household damage rates per flooding depth used for flood damage assessment(%)

Flooding Depth	0-0.5	0.5-1.5	1.5-2.5	> 2.5
Damage Rates	5.5	40.0	83.0	100.0

Table 3. Crop damage rates per flood duration used for flood damage assessment(%)

Class	8 hrs-1 day	1-2 days	3-4 days	5-7 days	> 7 days
Paddy	14	27	47	77	95
Upland	35	51	67	81	95

4. RESULTS AND DISCUSSIONS

Main issue pursued in this study was to test the feasibility of the airborne laser scanning data in the flood impact analysis.

As the first step, LiDAR DEM data with the vertical accuracy of 15cm were acquired over the study area, Yeoju, Kyeonggi Province, Korea. And then, the acquired DEM was transformed into the input data of FLUMEN.

As the second step, the flood inundation simulation was carried out by the FLUMEN based on the flood scenarios with various return period and conditions of inundation. Fig. 7 is the graphical results of the simulations for the case of 100-years return period and levee failures, while Fig. 8 is for the case of 200-years return period and levee failure. Fig. 7 and 8 show the flooded extents and depth.

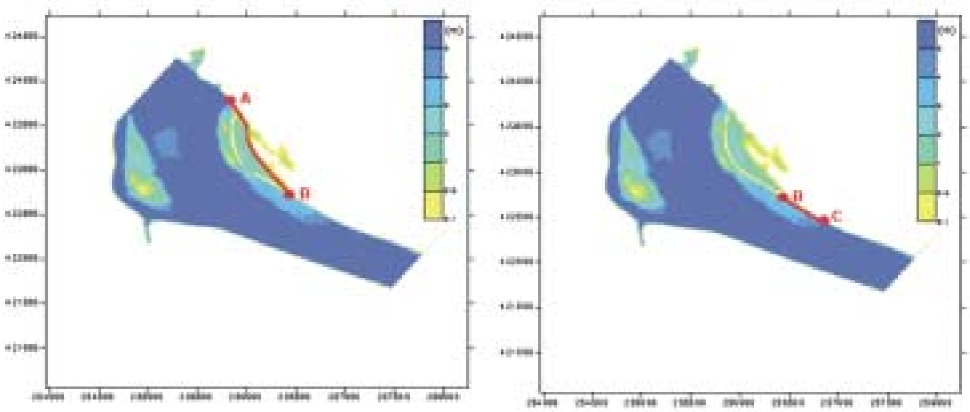


Fig. 7. Flooding depths for the case of 100-years and levee failures at (a) Location ① and (b) Location ②

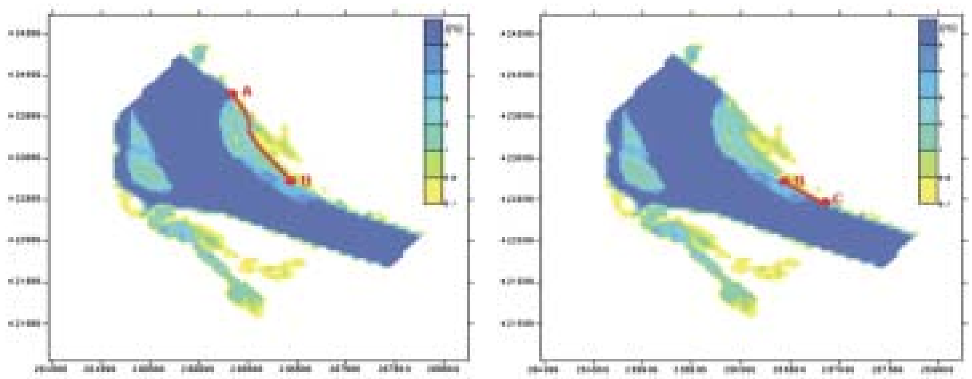


Fig. 8. Flooding depths for the case of 200-years and levee failures at (a) Location ① and (b) Location ②

As the results were generally similar to the observations during the 1995 flood event, it was conceived that the flood inundation simulation based on the LiDAR DEM is feasible.

As the last step, flood damage due to the projected flood inundations were assessed by overlaying simulated results over the land use map and consequently estimating the damages using Flooding Area-Damage Curve. Table 4 shows a sample result of flood damage assessment for the case of 100-years return period flood and levee breach.

Table 4. A sample result of the flood damage assessment for the case of 100-years return period and leeve breach(1,000 US$)

Life	Indirect Damage	Crops	Buildings	Farm Land	Public Facilities	etc	Total
22	40	18	570	51,760	490,670	37,780	580,820

The estimated total damage was about 581 million US$, of which the most severe one was the damages of public facilities. The estimation couldn't be verified since there was no relevant field data investigated in the study area. However, it was conceived, from the simplicity of this method, that this method could be used in the brief estimation of flood damages for the flood recovery or prevention works.

5. CONCLUSION

In this study, flood impact analysis for the study area, Yeoju, Kyeonggi Province, Korea was carried out using airborne laser scanning data. The final purpose of the study was to check the feasibility of this method.

During this process, acquired airborne laser scanning data on the study area, that is, the LiDAR DEM was used for the flood inundation simulation and flood damage assessment analysis.

The conclusion achieved in this study is that the LiDAR DEM can provide the excellent terrain information, in terms of both accuracy and practicability, extending its usages in the flood impact analysis.

REFERENCES

Baltasavias, E. P., (1999a). Airborne laser scanning : Existing systems and firms and other resources, ISPRS J. of Photogrammetry & Remote Sensing, Vol.54, No.2-3, pp.164-198.

Baltsavias, E. P. (1999b). Airborne laser scanning : Basic relations and formulas, ISPRS J. of Photogrammetry and Remote Sensing, Vol.54, No.2-3, pp.199-214.

Beffa C. (2003). FLUMEN v1.2 User Manual, Fluvial.ch, http://www.fluvial.ch.

Brivio, P. A., Colombo, R., Maggi, M., and Tomasoni, R. (2002). Integration of remote sensing data and GIS for accurate mapping of flooded areas, Int. J. Remote Sensing, Vol. 23, No. 3, pp.429-441.

Cobby, D. M, Mason, D. C., and Devenport, I. J. (2001). Image processing of airborne scanning laser altimetry data for improved river flood modelling, ISPRS J. of Photogrammetry and Remote Sensing, Vol.56, No.2, pp.121-138.

Kim, K. H., Yoon, C. J., Chae, H. S., and Koh, D. K. (2001). Effective generation method of the geospatial information to build flood hazard map, Proc. of Korea Water Resources Association.

Kraus, K., and Pfeifer, N. (1998).Determination of terrain models in wooded areas with airborne laser scanner data, ISPRS J. of Photogrammetry and Remote Sensing, Vol.54, No.4, pp.193-203.

Lim, K., Treitz, P., Groot, A., and St-Onge, B. (2001). Estimation of individual tree heights using LIDAR remote sensing. In Proceedings of the 23rd Canadian Symposium on Remote Sensing-10e Congrés de l'Association québcécoise de télédétection, 21-24 August 2001, Québec, Que. CASI, Ottawa, Ont. pp.243-250.

Lunne, T., Robertson, P. K., and Powell, J. J. M. (1997). Cone penetration testing in geo-technical practice, Blackie Academic and Professional, Chapman and Hall, London.

MOCT and KOWACO (2002). The report on Flood Map for Yeouju Area

Mosaic Mapping Systems Inc. (2001). A White Paper on LIDAR Mapping http://www.mosaicmapping.com

Omer, C. R., Nelson, E. J., and Zundel, A. K. (2003). Impact of varied resolution on hydraulic modeling and floodplain delineation, J. American Water Resources Association, Vol. 39, No. 2, pp.467-475.

Wehr, A., and Lohr, U. (1999).Airborne laser scanning-an introduction and overview, ISPRS J. of Photogrammetry and Remote Sensing, Vol.54, No.2-3, pp.68-82.

Geoinformation Science and Earth Observation for Municipal Risk Management: The SLARIM project

Dr. Cees van Westen

International Instititute for Geoinformation Science and Earth Observation,
ITC P.O. Box 6, 7500 AA Enschede,
The Netherlands
westen@itc.nl

Abstract

The aim of this paper is to present the first results of a research project entitled: Strengthening Local Authorities in Risk Management (SLARIM). The main objective of this project is to develop a methodology for spatial information systems for municipalities, which will allow local authorities to evaluate the risk of natural disasters in their municipality, in order to implement strategies for vulnerability reduction. The project concentrates on medium-sized cities in developing countries, which do not yet utilize Geographic Information Systems in their urban planning, and which are threatened by natural hazards (such as earthquakes, flooding, landslides and volcanoes). The methodology concentrates onthe application of methods for hazard assessment, elements at risk mapping, vulnerability assessment, risk assessment, and the development of GIS-based risk scenarios for varying hazard scenarios and vulnerability reduction options, using structural and/or non-structural measures. The methods for risk assessment that are applied depend on the availability of existing data within the study area, and range from simple loss estimations based on historic information to more complex methods based on modeling. In the development of elements at risk databases use is made of interpretation of high-resolution satellite imagery, combined with extensive field data collection, using mobile GIS. Also local communities are involved in the collection of vulnerability information, and in the evaluation of social vulnerability and capacity. Although the methodology is primarily designed to assist municipalities in the decision-making regarding vulnerability reduction strategies, the resulting databases are designed in such a way that they can also be utilized for other municipal activities.

Within the project a number of case study cities have been identified. The city of Naga in the Philippines has been selected for flood risk management, and the cities of Lalitpur in Nepal and Dehradun in India for seismic risk management. The project is carried out by research staff, PhD and Msc researchers of various disciplines at ITC, in collaboration with other partners (such as ADPC) and linked to external research and capacity building projects. In this paper an overview is given of the work done in Lalitpur.

1. Introduction

1.1 Increased urban vulnerability to disasters

The fast-growing world population is concentrating more and more into urban areas. Nowadays, almost half of the world's 6 billion inhabitants already live in cities, and in the next thirty years it is predicted that out of a total of 2.2 billion newcomers, 2.1 billion will be urban citizens, and 2.0 are expected to be born in cities in developing countries (Source: USAID, 2001).

To quote the UN General Secretary Kofi Anan:

"We have entered the urban millennium. At their best, cities are engines of growth and incubators of civilization.They are crossroads of ideas, places of great intellectual ferment and innovation...

cities can also be places of exploitation, disease, violent crime, unemployment, and extreme poverty...we must do more to make our cities safe and livable places for all" (Source: UN Press Release SG/SM/7479)

Apart from the above-mentioned problems, many of the cities in both developing as well as in developed countries are located in areas that are endangered by natural disasters, such as earthquakes, flooding, cyclones/hurricanes, landslides, volcanic eruptions, subsidence etc. Natural disasters are extreme events within the earth's system (lithosphere, hydrosphere, biosphere or atmosphere) which differ substantially from the mean, resulting in death or injury to humans, and damage or loss of 'goods', such as buildings, communication systems, agricultural land, forest, and natural environment (Alexander, 1993). Almost every day there is a disaster reported in the news. The number of reported disasters is showing an exponential increase, as are the losses and the number of casualties and people affected (Source: EM-DAT, 2004 MunichRe, 2004).

As compared to the decade of the 1960's the number of large disastrous events (especially those of hydrometeorological origin) has increased with a factor 2.2 in the last decade, and the damage has increased with a factor of 6.7 (Source: MunichRe, 2004). The relative increase in disaster losses is larger than the relative increase in population, and is caused by other factors than pure population growth. An additional factor is related to climate change, leading to increased coastal flooding due to sea-level rise, increased windstorm activity outside the tropics, more frequent heat waves, and intensification of El Nino and La Nina phenomena (Source: IPCC 2001 IFRC, 2003)

Apart from the intensification of hazard, the increase in disaster losses is caused by an increase in vulnerability of especially urban societies. There are nowadays already about 450 cities in the world with a population of over 1 million people. Many cities expand dramatically, often in an unplanned manner and confronted with lack of space. This leads on the one hand to a densification of cities and an increase in population density, and on the other hand to the occupation of unsuitable land in more hazardous conditions (e.g. steep hillslopes or active floodplains), often by the poorest. About 50 percent of the large cities in the word is located either along active earthquake zones or tropical cyclone tracks. Also in developed countries the development of highly sensitive technologies can lead to a growing susceptibility of modern industrial societies to breakdowns in their infrastructure due to natural and man-induced disasters. However, cities in developing countries suffer most from natural disasters. It is estimated that over 95 percent of all deaths caused by disasters occur in developing countries and losses due to natural disasters are 20 times greater (as a percent of GDP) in developing countries than in industrial countries (Source: Kreimer et al. 2003).

1.2 Need for urban disaster management

Local authorities are responsible for the proper management of the area under their jurisdiction, and the well being of the citizens, which includes an optimal protection against disasters. It is not acceptable anymore to have a response-oriented attitude, and concentrate only on the organization of disaster relief. Disaster prevention and preparedness are equally important component of a proper disaster management, in order to reduce the urban vulnerability.

To quote the UN General-Secretary again:

"More effective prevention strategies would save not only tens of billions of dollars, but save tens of thousands of lives. Funds currently spent on intervention and relief could be devoted to enhancing equitable and sustainable development instead, which would further reduce the risk for war and disaster. Building a culture of prevention is not easy. While the costs of prevention have to be paid in the present, its benefits lie in a distant future. Moreover, the benefits are not tangible; they are the disasters that did NOT happen. " (Source: UN, 1999)

Disaster management can be separated in several pre- and post-disaster phases (See table 1). Pre-disaster phases are risk identification, in which various types of risk are assessed in order to be able to carry out appropriate mitigation measures to reducethe risk, transferring of risk using financial means and all aspects leading to a better preparedness to predict and cope with the occurrence of hazardous events. Post disaster phases consist of disaster relief, rehabilitation and reconstruction.

Table 1: Key elements of disaster management (source: IDB, 2000)

Pre-disaster phases				Post-disaster phases	
Risk Identification	Mitigation	Risk Transfer	Preparedness	Emergency response	Rehabilitation and Reconstruction
Hazard Assessment	Physical structural mitigation works	Insurance/ reinsurance of public infrastructure and private assets	Early warning systems. Communication systems	Humanitarian assistance / rescue	Rehabilitation/reconstruction of damaged critical infrastructure
Vulnerability assessment	Land-use planning and building codes	Financial market instruments	Monitoring and forecasting	Clean-up, temporary repairs and restoration of services	Macroeconomic and budget management
Risk Assessment	Economic incentives	Privatization of public services with safety regulations	Shelter facilities Emergency planning	Damage assessment	Revitalization of affected sectors
GIS mapping and scenario building	Education, training and awareness	Calamity funds (national or local level)	Contingency planning (utility companies / public services)	Mobilization of recovery resources	Incorporation of disaster mitigation components in reconstruction

Unfortunately, until recently most of the emphasis hasbeen on the post-disaster phases, and most disaster management organizations in developing countries have been established only for this purpose. Recently, the emphasis is being changed to disaster mitigation, and especially to vulnerability reduction.

Since the International Decade for Natural Disaster Reduction in the 1990's many initiatives have been launched worldwide to assess and reduce urban vulnerability. For example, the programme on Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters (RADIUS, 2000) has had a major impact in creating awareness among local authorities in many earthquake threatened cities regarding the seismic risk and methods for vulnerability reduction. More recently, also in the field of earthquake vulnerability reduction, the Earthquakes and Megacities Initiative (EMI, 2002) is an international initiative dedicated to the promotion and implementation of earthquake preparedness, mitigation and recovery of large urban areas (i.e. megacities). In Australia, the Cities and Critical Infrastructure Project (Cities Project, 2004) undertakes research for the mitigation of the risks posed by a range of geo-hazards to Australian urban communities. Activities undertaken in several regions, such as in Asia (Asian Urban Disaster Mitigation Programme), and Central America and the Caribbean

(UNESCO-RAPCA, 2004), have demonstrated the usefulness of capacity building for urban disaster reduction.

1.3 Developments in Geoinformation science and earth observation

Geoinformation science and earth observation consist of a combination of tools and methods for the collection, storage and processing of geo-spatial data and for the dissemination and use of these data and of services based on these data. This implies the development and application of concepts for spatial data modeling, for information extraction from measuring on image data, and for the processing, analysis, dissemination, presentation and use of geo-spatial data. It also implies the development and implementation of concepts for the structuring, organization and management of geo-spatial production processes in an institutional setting.

Due to the diversity and large volumes of data needed, and the complexity in the analysis procedures, quantitative risk assessment has only become feasible in the last two decades, due to the developments in the field of Geo-Information science. When dealing with GIS-based hazard assessment, elements at risk mapping, and vulnerability/risk analysis, experts from a wide range of disciplines, such as earth sciences, hydrology, information technology, urban planning, architecture, civil engineering, economy and social sciences need to be involved.

For the average hazard and risk scientist it is difficult to keep up with the rapid developments in the field of Geo-information Science and Earth Observation. The number of new sensors and platforms, and the amount of acronyms is overwhelming. Also the change of GIS software from one version to the next, in which the methods that had been developed earlier on do no longer function, because of changes in file structure or interface, can be frustrating to many professionals. Nevertheless, GIS has become an almost compulsory tool in hazard and risk assessment, and it is the challenge to keep on using it as a tool, and not as an objective in itself.

For disaster management, and particularly for hazard and risk assessment the following recent developments in the field of Geoinformation Science and Earth Observation are considered to be important:

- DEM Generation. As topography is one of the major factors in many types of hazard and risk analysis (e.g. for flooding, landslides, forest fires, volcanic eruptions etc), the generation of a digital representation of the surface elevation, called Digital Elevation Model (DEM), plays a major role. During the last 15 years there have been important changes both in terms of data availability, as well as in terms of software that can be used on normal desktop computers, without extensive skills in photogrammetry. Nowadays DEMs are available from various sources, such as:
  - o Digitizing of conventional topomaps or photogrammetrical methods using

aerial photos;

- Nearly the entire world is now covered by a DEM with a spatial resolution of 30 meters (although outside US distributed at 90 meters) from the NASA Shuttle Radar Topography Mission (SRTM);
- ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) which is one of 5 instruments on the Terra platform, launched in 1999, and which offers stereoscopic imagery, at very low costs;
- SAR interferometry (InSAR) is gaining increasing importance as a technique for rapid and accurate topographic data collection. A number of spaceborne InSAR systems are operational, (ERS, ENVISAT, RADARSAT) or in the planning and implementation stages;
- LiDAR is an acronym standing for Light Detection and Ranging, and is an airborne method using a pulse laser to measure the distance between the sensor and the surface of the Earth. Normally LiDAR point measurements will render so-called Digital Surface Models (DSM), which contains information on all objects of the Earth's surface, including buildings, trees etc. Through sophisticated algorithms, and final manual editing, the landscape elements are removed and a Digital Terrain Model is generated. The difference between a DSM and the Digital Terrain Model (DTM) can also provide very useful information, e.g on elements at risk (buildings etc.) or the forest canopy height.

- **Higher spatial resolution**. In the last decades the use of satellite data has become a normal input into hazard and risk assessment projects. Now there is a potential value for the application of multispectral and panchromatic data with up to 1-meter spatial resolution. LANDSAT data has remained quite popular and also higher resolution imagery, such as SPOT and IRS-1C has been used for change detection and hazard mapping. Nowadays the emphasis is on the use of very high-resolution imagery, such as IKONOS or Quickbird;

- **Higher spectral resolution**. Hyperspectral remote sensing, or imaging spectroscopy, consists of acquiring images in many (>100) narrow, contiguous spectral bands, from which a continuous spectrum is obtained for each pixel, instead of only broad information in a few wide spectral bands. Hyperspectral images enable detailed spectral identification of minerals, rocks, soils and vegetation types at the surface. Spectra from airborne systems such as the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) and Hyperspectral Mapper (HyMap) have been used to successfully map soiltypes and swelling clays. Airborne hyperspectral data are available for limited parts of the world.

Spaceborne imaging spectrometers are available, such as the ASTER and MODIS on board the NASA's Terra, and the MERIS on ESA's ENVISAT. The spatial resolution of these is still rather general, with the exception of ASTER.

- **Mobile GIS**. Several methods for digital field data collection have been developed, such as MapLT, PocketGIS, and the ArcPad software from ESRI, which is the most convenient one when working with ArcGIS. The input application can be made on a desktop PC and loaded into a palmtop. The software works with vector data (shape files) and raster data (JPEG, MrSID). The software runs on laptops, tablet pen computers, palm top computers which operate in a Windows CE environment and personal data assistants (PDA) operating in Palm OS. The system is integrated with a GPS system. Elements at risk inventories can be carried out at various levels of detail, depending on the requirement of the study. In urban and rural areas the detail of inventory will also differ. Normally such an inventory is time consuming and expensive. Furthermore, such an inventory is not only made for risk analysis, but can be used in more development planning processes and can also be related to cadastral information systems (Montoya, 2002).

1.4 Risk assessment

As can be observed in table 1, the analysis of risk forms the basis for many of the other phases of disaster management. Risk is defined as the "expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular damaging phenomena for a given area and reference period" (Varnes, 1984). When dealing with physical losses, (specific) risk can be quantified as the product of vulnerability, cost or amount of the elements at risk and the probability of occurrence of the event with a given magnitude/intensity. When we look at the total risk, the hazard is multiplied with the expected losses for all different types of elements at risk (= vulnerability * amount), and this is done for all hazard types. Schematically, this can be represented by the following formula:

$$\textbf{Risk} = \sum (H * \sum(V * A))$$

Where:

H = Hazard expressed as probability of occurrence within a reference period (e.g., year)

V = Physical vulnerability of a particular type of element at risk (from 0 to 1)

A = Amount or cost of the particular elements at risk (e.g., number of buildings, cost of buildings, number of people, etc.). Theoretically, the formula would result in a so-called risk curve, containing the relation between all events with different probabilities, and the corresponding losses, which forms the basis for the phases of risk reduction, risk transfer and preparedness planning.

In order to obtain quantitative risk maps the first essential requirement is to carry out a quantitative hazard assessment. Most hazard maps still are of a qualitative nature and do not express the probability of occurrence of potentially damaging phenomena with a certain magnitude within a given period of time. In many developing countries qualitative hazard mapping is the only possibility, due to the scarcity of input data for quantitative analysis, or the absence of historical records (e.g. rainfall, discharges, earthquake catalogs). There is an important role for data collection using remote sensing and the design of databases for hazard assessment, as well as the use of various types of modeling techniques depending on the available data and the scale of analysis. Emphasis is now given to the development of quantitative hazard maps, derived by earth-scientists, based on probabilistic or deterministic modeling.

Elements at risk refer to the population, buildings, civil engineering works, economic activities, public services, utilities and infrastructure, etc., that are at risk in a given area. Each of these elements at risk has its own characteristics, which can be spatial (related to the location in relation to the hazard), temporal (such as the population, which will differ in time at a certain location) and thematic characteristics (such as the material type of buildings, or the age distribution of the population).

The next step in the analysis of risk is the quantification of vulnerability, which is achieved by making an inventory of the elements at risk and an assessment of the degree of damage that may result from the occurrence of a potentially damaging phenomenon. Emphasis is given to techniques for rapid inventory of elements at risk in densely populated areas (urban and rural), using high-resolution images, and the generation of elements at risk databases, which should be designed for multi-purposes, on the basis of cadastral databases. One other aspect is the modeling of vulnerability, using vulnerability curves in a GIS.

1.5 Loss estimation models

Risk analysis, assessment and management require a large amount of information. Relatively large volumes of multi-disciplinary and technical information have to be collected, processed, analyzed, and eventually communicated to a broad range of users under quite different conditions, ranging from planning and regulatory activities to emergency management. Modern information technology provides some of the tools to support these activities, leading to the development of risk information systems that can be used for both analyzing risk and evaluating the consequences of decisions that have to be taken to mitigate or reduce risk at both short term (emergency planning) and long term (development planning).

The spatial information of hazard and vulnerability is used in a GIS-based model for quantitative risk analysis, including the losses due to different hazards with different return periods and magnitudes. Methodologies for data handling and quantification of risks have been developed mainly in the United States over the last two decades. Within the reported methods, a basic subdivision can be made between the commercial and non-commercial ones.

Commercial catastrophe modeling techniques have been developed for earthquakes, floods, tropical cyclones, windstorms, and subsidence. They have been developed by dedicated companies or by the (re-)insurance companies, such as MRQuake, MRStorm and MRFlood (MunichRe), RiskLink (RSM), EQEHAZARD (EQECAT), CATMAP or CLASIC (AIR), CATEX (CATEX), EPEDAT(Early Post-Earthquake Damage Assessment Tool, ImageCat) and REDARS (Risks from Earthquake Damage to Roadway Systems) etc. Although most of these models have been developed in the United States, they are applied worldwide, depending on data availability. The models as well as the data are not freely available.

Non-commercial loss estimation models are those for which the software is freely available, and for which the manuals can be downloaded from the Internet. In Canada, the Natural Hazards Electronic Map and Assessment Tools Information System(NHEMATIS) has been developed by Emergency Preparedness Canada. The primary purpose of NHEMATIS is to "provide emergency planners with a tool that supports the definition and execution of elaborate models which will assist in predicting/estimating the potential impact of a natural hazard/disaster in a defined area of interest." (Source: Brun et al., 1997.) A example of a freely available method for loss estimation for building damage to Hurricanes is presented by OAS (Source: OAS, 1996)

The major achievement in loss estimation software, which is publicly available, is the HAZUS software, an interactive software released by the Federal Emergency Management Agency (FEMA, 2004) and National Institute for Building Sciences (NIBS) since 1997. Where the first version of HAZUS was only dealing with earthquake loss estimation, the recent HAZUS-MHis a multi-hazard loss estimation system, dealing with earthquakes (ground shaking, and earthquake induced hazards such as liquefaction, landslides, fires, floods, debris etc.) windstorms (hurricanes) and floods (coastal and riverine flooding). HAZUS-MH is made for ARCGIS and full datasets on the level of census tract can be obtained for the entire United States. Due to the complexity and large quantity of the input data, it has proven to be ratherdifficult to apply the HAZUS methodology in other parts of the world, where less accurate data is available. They have to be adapted for use at different levels of details, and different applications (e.g. nation-wide, provincial or municipal scale). At the municipal scale, whereas large cities often are able to attract the resources and capacity to set-up such a risk management information system, medium-size cities most often lack these possibilities.

2. The SLARIM project

2.1 Objectives of the SLARIM project

In 2002 the International Institute for Geoinformation Science and Earth Observation (ITC) launched a research project with the acronym SLARIM, which stand for Strengthening Local Authorities in Risk Management. The main objective of this research project is to develop generic methodologies for GIS-based risk assessment and decision support that can be beneficial for local authorities in medium-sized cities in developing countries. For local authorities being able to handle this tool properly implies a lot of attention in this research for user requirements, institutional issues and spatial data infrastructure, connected with the methodologies of hazard and risk assessment on the one hand and the relevant DSS based GIS applications in urban planning and management (what can local authorities actually do with this data) on the other hand.

Risk management is a typically multi-disciplinary endeavor, requiring many types of data with spatial and temporal attributes that should be made available to local authorities in the right format for decision-making. For ITC, in order to acquire the necessary expertise it is crucial that experts from different disciplines work closely together, and in combination with relevant partners.

The ultimate objective of this project is to improve the safety of communities, and consequently make them more sustainable and prosperous.

2.2 Case study cities

The methodology for the use of GIS in urban risk assessment and management is developed on the basis of a number of case studies. After carefully evaluation and visits to potential case study cities, a number of case study cities have been selected. The willingness of local authorities to participate actively in this project has been considered as one of the main criteria, besides the availability of data, and the types and severity of the hazards in the urban areas. The following cities have been selected (See figure 1):

■ **Naga city, Philippines**

The city of Naga is a medium sized city on the island of Luzon in the Philippines. It is located in an area that is frequently hit by typhoons that cause severe inundations of the city and the surrounding agricultural lands. Several types of floods affect the area, sometimes in combination: a) riverine floods from the Bicol, the mainriver in the area, b) flash-floods from the torrent Naga, and c) storm surges from the sea. In close collaboration with the municipality of Naga, a research program was initiated to investigate to what extend hydrodynamic modeling can be used as an instrument to assess the flood hazard situation in terms of inundation probability and to make a risk assessment based on the flood hazard and the elements at risk. Naga city is expanding very fast and the same trend will continue in the future since Naga is thecentre for commercial, educational and industrial sectors in the Bicol region. The annual estimated growth rate of household population within the city limits for next ten years is over 1.6% and current estimated population is over 144,000.

■ Lalitpur Sub-Metropolitan City, Nepal

The Lalitpur Sub-Metropolitan City is located in the Kathmandu valley, on the Southern side of the capital of the Kingdom of Nepal, Kathmandu. Lalitpur has a population of 163,000, in 35,000 households, according to the 2001 census. The municipality is divided into 22 wards. Lalitpur is one of the oldest cities in Nepal, supposedly founded in 299 A.D., with one of its most important periods during the Malla dynasty from 1200 1768. The old core area is famous for its cultural heritage, and has a very dense structure, with a majority of buildings with load-bearing masonry, with mud mortar and adobe. Many houses are built in a courtyard pattern, with very narrow streets. With the increase in population, and the vicinity of the capital, the city started to expand considerably, especially after the construction of the ring road in the 1980s. In the fringe area, which was developed between the core area and the ring road, the majority of buildings are masonry with brick in cement and RCC.In the last year, also rapid construction takes place in the areas, on the outer side of the ring road, where the majority consists of RCC buildings. Lalitpur, like its neighbouring cities of Kathmandu and Bhaktapur in the Kathmandu valley, are threatened by earthquakes. The last major earthquake took place in 1934, and less damaging earthquakes were reported in 1960 and 1988.

■ Dehradun, India.

Dehradun is located in the eastern part of Doon valley, at the foot of the Himalayas, in the northern state of Uttaranchal, in India. Dehradun has a total population of about 600,000 living in 45 wards. Due to its pleasant location at the foot of the Himalayas, the city is well known for its many school and colleges and the headquarters of many National Institutes and Organizations. The city has recently become the capital of the state of Uttaranchal and is experiencing a rapid increase in population. Dehradun is located near the main active thrustzones in the Himalayas, such as the Main Boundary Thrust (MBT) and Main Central Thrust (MCT). The city is located within one of the highest seismic hazard zones of the country, but has not experienced a major earthquake in recent times. The last two earthquakes that caused serious damage on the countryside, namely the Uttarkashi (1991) and Chamoli (1999) earthquakes, did not cause major damage in the city.

The plan is to extend the number of case study cities, depending on research partners and countries of origin of MSc and PhD researchers.

Figure 1: Location of case study cities for the SLARIM project.

2.3 Structure of the research project

The SLARIM research project is consisting of a number of components, which are divided along a number of work packages. The following components can be distinguished:

- **Users need assessment and organizational setting**, which investigates the requirements of local authorities with respect to information and decisions regarding natural disasters. The research will develop a methodology for the evolutionary design of a spatial decision support system for risk management that is based on a continuous monitoring of actor needs, organizational learning processes, and subsequent performance at risk management.
- **Flood hazard and risk assessment** research that focuses on the development of the science, models and techniques to develop a quantitative approach to the

analysis and assessment of flood risk. It evaluates the applicability of various hydrological and hydraulic models in developing countries with limited amount of data. The research also intends to compare the result of the modeling approach with participatory mapping using a community-based vulnerability and capacity assessment approach. The research also deals with the comparison of vulnerability curves for different elements at risk and different countries.

- **Earthquake Hazard and risk assessment**research, which focuses on the development of the science, models and techniques to analyze and assess the risks posed by earthquakes, in developing countries that have limited amounts of data. Existing approaches such as RADIUS or HAZUS are evaluated and adapted to the local conditions regarding data availability and types of elements at risk.

- **Landslide hazard and risk assessment**, which evaluates the types of GIS-based models for landslide susceptibility and hazard assessment can be used at different scales, and depending on the available input data. The research also concentrates on defining practical methods for landslide vulnerability assessment, and the combination of hazard and vulnerability into landslide risk maps, both using qualitative as well as quantitative methods.

- **Volcanic hazard and risk assessment**, which evaluates the various approaches for modeling different volcanic processes, such as lava flows, pyroclastic flows, lahars, ashfall etc. both using conventional methods as well as using GIS-based models. Another important element is the quantification of vulnerability of elements at risk in volcanic hazard zones.

- **Elements at risk mapping** focuses on the use of remote sensing data for the generation of elements at risk maps and the characterization of the elements at risk using mobile GIS. High-resolution images play an important role in the generation of building footprint maps, in combination with LiDAR data if available. One other aspect of this component is to define the most appropriate basic unit for risk assessment (e.g. individual building, homogeneous unit, census tract, ward etc.) and techniques for sampling.

- **Geographic information systems and data bases**, which focuses on the development of techniques and decision support tools using GIS to integrate, manipulate and display a wide range of risk-related information.

- **Use of Earth Observation data for disaster management**, which focuses on the use of remote sensing for base data collection for hazard and risk assessment, and damage assessment.

In the following sections an example of the results of a number of the components will be given, namely on seismic loss estimation in Lalitpur (Nepal).

3. Example: Earthquake loss estimation in Lalitpur, Nepal.

3.1 Introduction

Lalitpur is located on a relatively flat area, which used to be a former lake in the middle Himalayan mountain range, of which the surface materials are mainly consisting of alluvial terrace deposits, belonging to the Chapagaon Formation of mainly Holocene Age (Fujii et al., 2001). The terrace deposits are on top of a thick sequence of lake sediments, belonging to the Kalimati Formation, with an average thickness of 200 meters and a maximum thickness of about 400 meters.

Lalitpur has suffered from damaging earthquakes in the past, such as in 1255, 1408, 1810, 1833, 1934, 1980 and 1988. In the earthquake of 1934, which had a magnitude of 8.4, it was estimated that about 19,000 buildings were heavily damaged within Kathmandu valley, causing the death of more than 3800 people (JICA, 2002). Several areas in Lalitpur have also experienced liquefaction phenomena during the 1934 earthquake (UNDP, 1994).

Various institutions have carried out studies on earthquake hazard and risk in Kathmandu Valley. After the earthquake in 1988, a first study was carried out by the Ministry of Housing and Physical Planning (MHPP), with technical assistance from the United Nations Development Program (UNDP). In this project a regional scale seismic hazard map for Nepal was produced, and a National Building Code was established (UNDP, 1994). In 1998 this was followed by the Kathmandu Valley Earthquake Risk Management Project (KVERMP), which was implemented by the National Society for Earthquake Technology Nepal (NSET), with support from the Asian Disaster Preparedness Centre (ADPC). The aims of this project were to develop capacities and create awareness in earthquake vulnerability reduction at different levels of society, including school reinforcement, mason training, organization of an earthquake safety day, and development of an earthquake risk management plan together with local authorities (Dixit et al., 2002). The KVERMP was based on a simple loss estimation, which assumed that if the same earthquake as in 1934 would occur today, the losses would be catastrophic. A more detailed study on earthquake loss estimation was made recently by experts of the Japanese International Cooperation Agency (JICA, 2002). This study divided Kathmandu Valley into large grid cells of 500 by 500 meters, for which the number of damaged buildings were calculated using three scenario earthquakes.

In all of the previous studies, the basis of the loss estimation has always been at a rather general level. The spatial distribution of the earthquake losses is a very important basis for a proper earthquake vulnerability reduction and emergency planning at municipal level. Municipalities would need to have databases at individual building level, in order to be able to carry out proper control over building construction. This study used high-resolution satellite imagery, together with aerial photographs and field survey in the generation of a building database for seismic loss estimation in Lalitpur.

3.2 Generation of base dataset

The Lalitpur Sub-Metropolitan City Office did not yet have a GIS section, nor did they have GIS data on the building stock and other characteristics within their municipality. In the neighbouring municipality of Kathmandu, the situation was quite different. The Information Department of Kathmandu Metropolitan Office was managing a large database, which was generated in the framework of a European project. This database contained a series of large-scale topographic maps at scale 1:2,000 in digital form, containing information on drainage, roads, contourlines(1 meter resolution) and building footprints. These topomaps were in AutoCad format and also covered the urban area of Lalitpur. With some difficulties this data set was converted into a usable GIS database, consisting of separate layers for buildings, roads, contours and drainage. Especially the generation of building polygons from the segments in the building footprint layer proved to be very cumbersome. The building footprint map was prepared based on aerial photos of 1981 and 1992 and was updated in 1998. All the buildings constructed after this year as observed in the available IKONOS image from 2001 were digitized on screen to create the building data set for the year 2001. As also a CORONA image was available from 1967, this image was used to deletethose buildings that were not yet present in 1967, and generate a building footprint map for that year. An example of the various building footprint maps for a part of the city is shown in figure 2.

In the old center of the city, where most of the buildings are attached to each other and form large complexes around courtyards, the existing building footprint maps did not make a separation between individual buildings, but rather displayed entire complexes of buildings as a single polygon. To calculate the number of buildings the building footprint area of these polygons was divided by the average plinth area of a building, which was taken as 45 m2 based on samples. A total number of 26,873 buildings are estimated for the year 2001. These buildings were compared to the number of households from the census data (34,996).

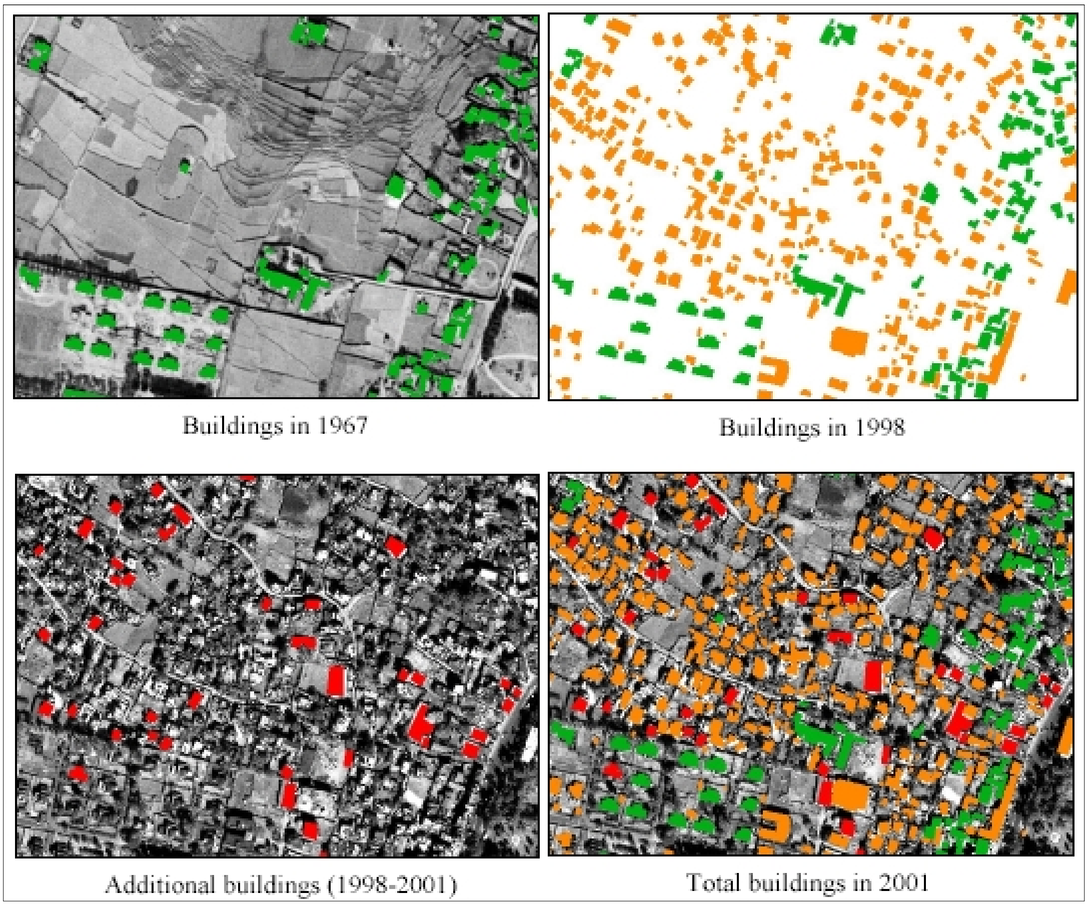


Figure 2: Illustration of the use of multi-temporal imagery for the generation of building footprint maps for different periods for a part of the city of Lalitpur.

The original digital building footprint maps did not contain any attribute information regarding the buildings within the city. In order to be able to analyze the vulnerability of buildings, transportation networks and population, information should be available on the important characteristics in relation to seismic vulnerability. Since a complete building survey would require too much time for field data collection, it was decided to use so-called homogeneous units as the basic mapping units within the city. Homogeneous units are groups of buildings with more or less similar characteristics that can be delineated from high-resolution satellite imagery, and that can be described in the field. The boundaries of the units were mostly taken along streets and roads. Before going in the field, the homogeneous unit map was made based on image interpretation, and the map was combined with the building footprint map in order to calculate the percentage built-up area and the number of buildings per unit (see figure 3). In the field mobile GIS was used to characterize the buildings within each unit according to age (based on procedure outline earlier), occupancy class, landuse type and building type, which was a combination of construction material and number of floors.

Population data were available from the latest population census in Nepal, which was held in 2001, published by the Central Bureau of Statistics (CBS) of Nepal. Information was only available at Ward level, according to age and gender. In order to calculate the population distribution per homogeneous unit, which was taken as the basic unit for the loss calculation, wardwise population figures had to be distributed over the various units within the ward. This was done by calculating the percentage of floorspace in residential buildings within each homogeneous unit as percentage of the total floorspace of residential buildings in the ward. Floorspace of residential buildings per homogeneous unit was calculated by multiplying the number of floors of residential buildings with the footprint area. The average population density within different types of buildings (residential, commercial, institutional etc.) was estimated based on 196 detailed samples of buildings carried out by a local NGO, the National Society for Earthquake Technology (NSET) and the Lalitpur Sub-Metropolitan City Office. Based on these samples estimations were made of the population amounts present in different types of buildings during different periods of the day.

Infrastructure data was collected from various institutions and by mapping the road network in Lalitpur, using Mobile GIS and a set of characteristics describing factors used in determining the vulnerability of the roads during an earthquake, such as width of the road, traffic intensity, type of road surface, and distance to buildings.

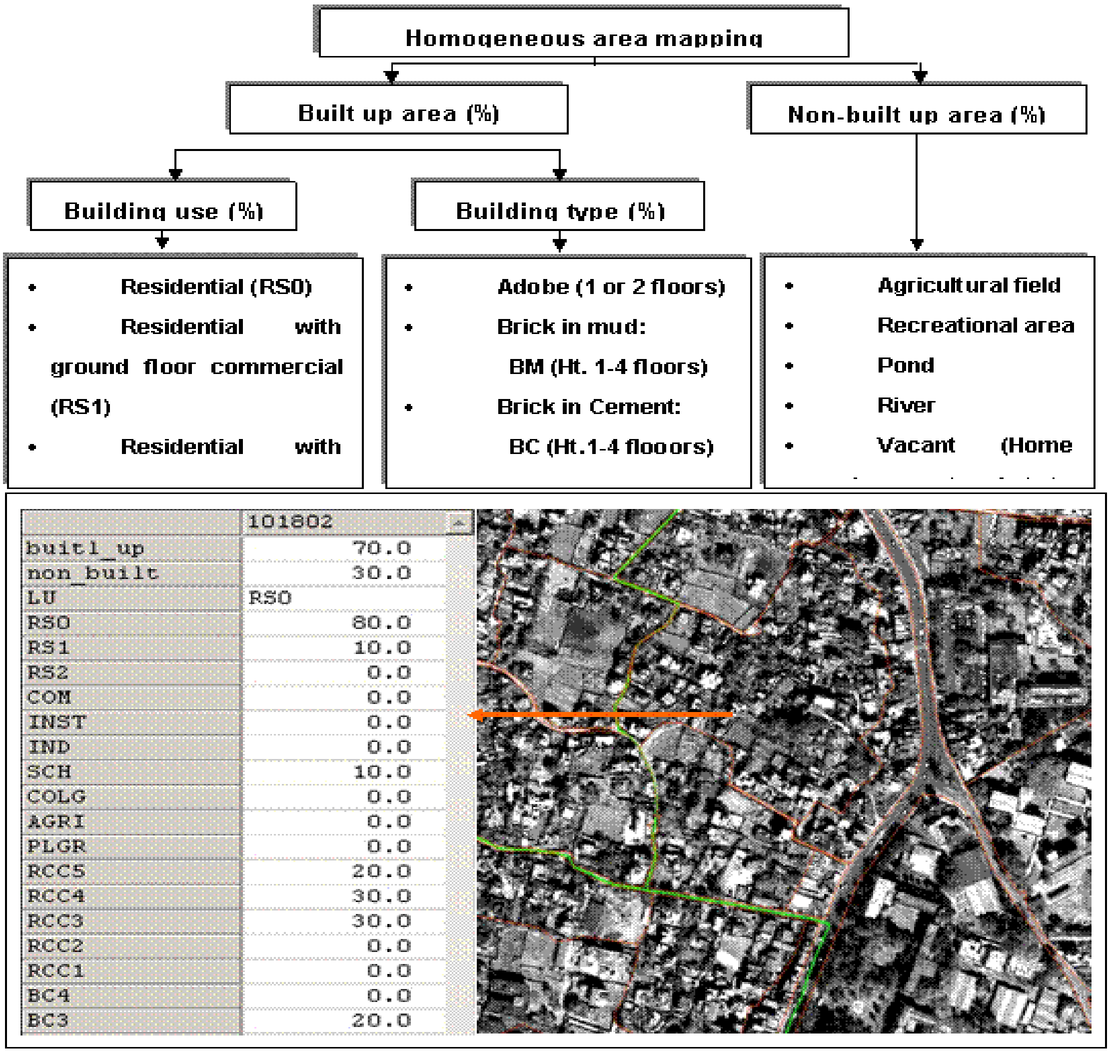


Figure 3: Above: Schematic overview of homogeneous unit mapping approach. Below: example of the resulting database.

Seismic amplification and liquefaction potential

In order to be able to analyze the seismic hazard in Lalitpur and its surroundings a sub-surface database was generated for the entire Kathmandu valley. A geological database was made (see figure 4) for storing the information for 185 deep boreholes, with depths ranging from 35 to 575 meters, of which 36 boreholes actually reached to the bedrock, and 328 shallow boreholes with depths less than 30 meters. Only the shallow borehole records contained both lithological and geotechnical information such as grain size distribution, Atterberg limits, N-values, moisture content, specific gravity, density, unit weight, angle of friction, direct shear and soil type (USCS).

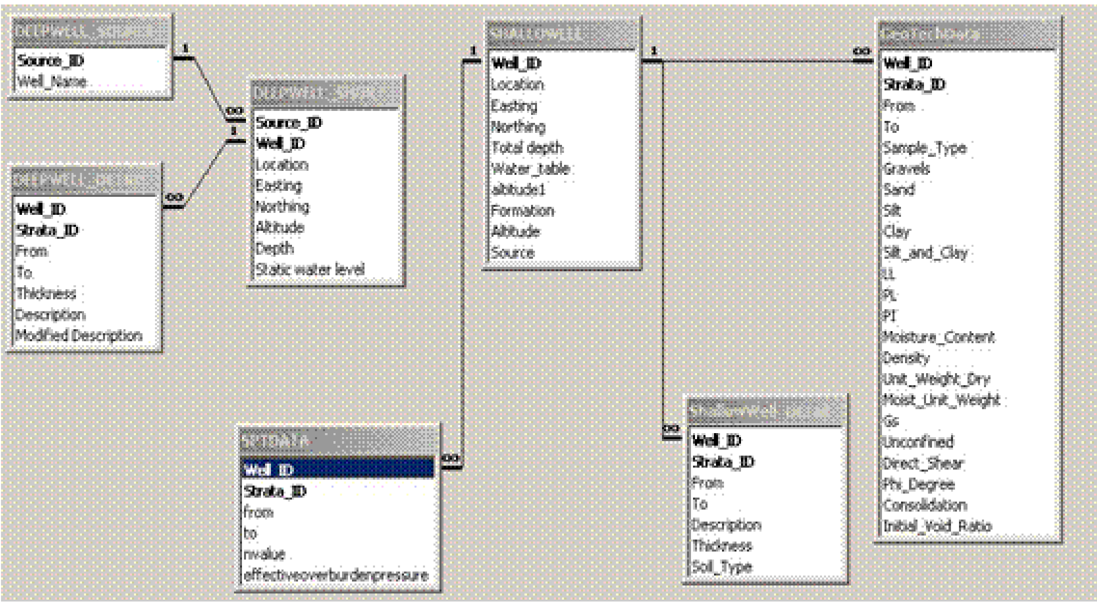
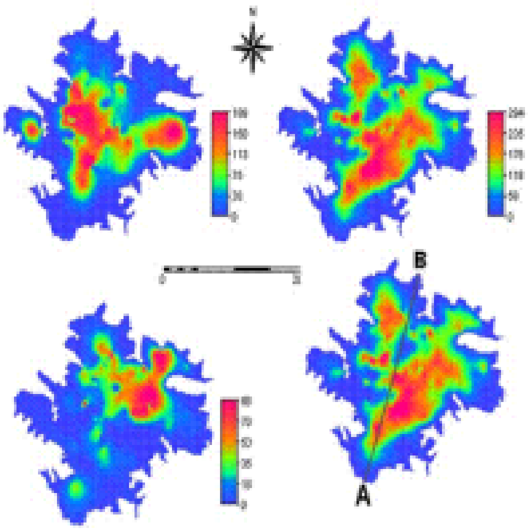


Figure 4: Structure of the geological database for Kathmandu valley.

The geological data were used in the geological software Rockworks in order to generate lithological cross sections and fence diagrams. Based on these all boreholes were divided into main stratigraphical units, for which the depth was determined and used in GIS for subsequent layer modeling. The horizontal and vertical distribution of the valley fill within the Kathmandu valley is very complex, mainly consisting of intercalations of fluvial and lacustrine deposits. In order to generate layer models for such a heterogeneous environment, a certain degree of generalization had to be accepted. In this case, the entire sediments of the basin are divided into four layers: Holocene alluvial and anthropogenic deposits, lacustrine deposits formed between 2,500,000 to 29,000 years B.P. (Yoshida and Igarashi 1984), alluvial deposits below the lacustrine sediments, and the underlying bedrock. The depth of each of the layer boundaries, including the surface elevation was used in GIS and Digital Elevation Models of each of these surfaces was obtained through point interpolation. The results are shown in figure 5.



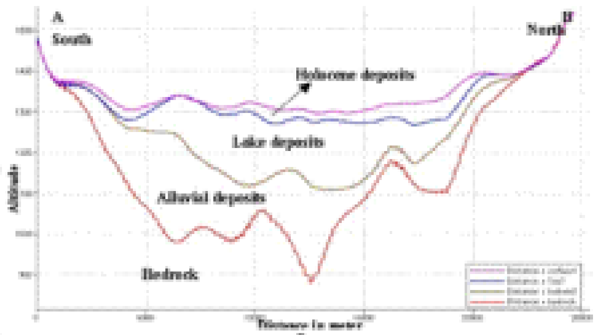


Figure 5: Left: Thickness maps of the three main material types in the Kathmandu valley. Right: Cross section

The layer-modeling concept is used in this study in order to separate between the lake deposits and the non-lake deposits so that the thickness of the different layers of the sediments could be determined and hence could be applied for the estimation of ground amplification during an earthquake

The GIS layer models were used for one-dimensional calculations of the ground response, with the help of SHAKE2000, which is derived from the original SHAKE software, used widely for soil response analysis since 1971(Ordonez, 2002). For each material type, average values for shear wave velocity, and unit weight, were used, and 5% damping was selected. Unfortunately no strong motion records are available for Kathmandu valley, so comparable records were used from other locations. Three earthquake scenarios were selected in line with the ones used in the study by JICA (2002): one comparable in magnitude and epicentral distance to the 1934 earthquake (called Mid Nepal earthquake), one located North of Kathmandu valley (North Bagmati earthquake) and a local earthquake in the valley itself. The analysis was carried out by sampling the depths of the GIS layers at regular intervals. Each of the sampling points was transformed into a soilprofile, which was entered in the SHAKE2000 program, and which was analyzed using the above mentioned scenario earthquakes. The results were calculated as Peak Ground Acceleration (PGA) as well as spectral acceleration for frequencies of 5, 3 2 and 1 Hz. These values were later linked back to the sampling points and maps were obtained through point interpolation. An overview of the method is shown in figure 6.

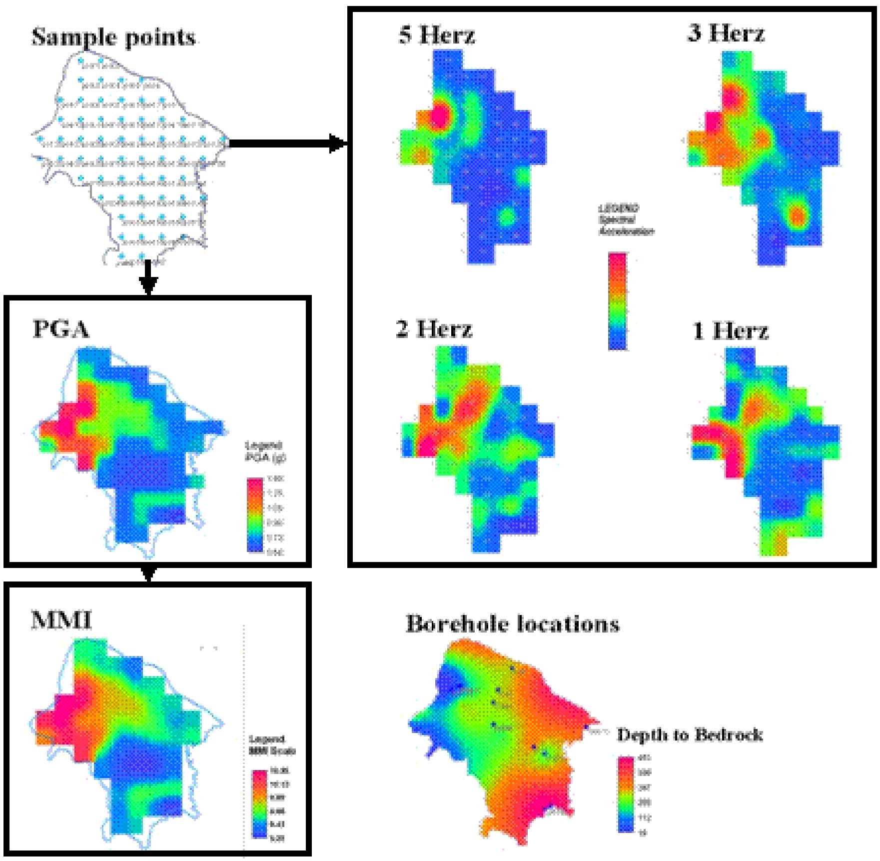


Figure 6: Schematic representation of the two methods used for soil response analysis. One resulting in PGA and MMI maps, and one resulting in spectral acceleration maps.

An analysis of liquefaction potential was made using both qualitative and quantitative methods. In the qualitative analysis the method of Iwasaki et. al (1982) and Juang, and Elton method (1991) were used and the quantitative analysis was carried out using simplified methods developed by Iwasaki et al. (1984) and Seed and Idriss (1971). The qualitative methods are based on weights, assigned to a number of factors such as Depth to water table, Grain size distribution, Burial depth, Capping layers, Age of deposition and Liquefiable layer thickness. For the Seed and Idriss method (1971) the calculation was made for an earthquake of Ms = 7.5, and PGA value of 0.1g.

Following this method, the analysis was carried out for 69 boreholes located at 40 different sites, resulting in 35 boreholes where liquefaction is likely to occur at a particular depth. The final liquefaction susceptibility map was prepared by combining the point information of the boreholes with geomorphological units in a GIS.

3.4 Building loss estimation

For analyzing seismic vulnerability, the buildings in Kathmandu valley have been divided into a number of classes indicated in figure 3 and table 2. The vulnerability curves used in the GIS analysis were derived by NSET-Nepal and JICA considering the fragility curves prepared during an earlier building code project with some modification which again was based on the damage pattern observed in the 1988 earthquake in Nepal. For each MMI class and building type, minimum and maximum values are given of the percentage of buildings that would be heavily damaged (collapsed or unrepairable) or partly damaged (repairable, and available for temporary evacuation).See table 2.

Table 2: Damage matrixes for different types of buildings in Kathmandu (The values represent percentage of buildings with the same material type. Source: NSET Nepal)

Building type	**MMI**	**VI**	**VII**	**VIII**	**IX**
	PGA (% g)	5-10	10-20	20-35	>35
Adobe+Fieldstone Masonry Buildings	Total Collapse	2-10	10-35	35-55	55-72
	Partial Damage	5-15	15-35	30	30
Brick in Mud (BM)	Total Collapse	0-6	6-21	21-41	>41
	Partial Damage	3-8	8-25	25-28	<28
Brick in Mud (BMW) and Brick in Cement (BC)	Total Collapse	0-1	1-5	5-18	>18
	Partial Damage	0-11	1-31	31-45	<45
R. C. Framed (4 storied)	Total Collapse	0-2	2-8	8-19	19-35
	Partial Damage	0-4	4-16	16-38	38-65
R. C. Framed (3 storied)	Total Collapse	0-2	2-7	7-15	15-30
	Partial Damage	0-4	4-14	14-30	30-60

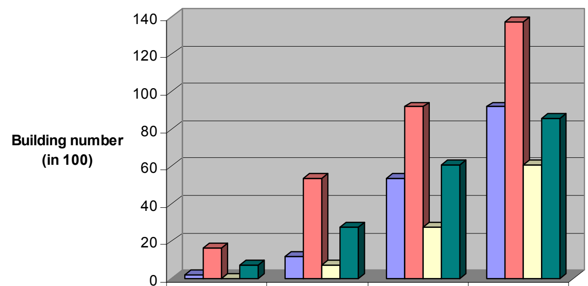
The following four types of columns for each type of the intensity (from VI to IX) were created in GIS in order to calculate the number of vulnerable buildings in the homogeneous unit.

- Partial damage min (Minimum probable number of buildings having partial damage)
- Partial damage max (Maximum probable number of buildings having partial damage)
- Collapse min (Minimum probable number of buildings having total damage)

- Collapse max (maximum probable number of buildings having total damage)

In figure 7 the results of the building vulnerability analysis in Lalitpur area are given. This table gives the total number of vulnerable buildings in different damage grades and in the four earthquake-intensities used ranging from VI to IX. For example, if an earthquake of intensity IX occurred in the entire Lalitpur Sub-Metropolitan area, a number of buildings ranging from 9,192 to 13,710 will get partially damaged and 6,104 to 8,583 will collapse and in total, 15,296 to 22,293 buildings will be partially or completely damaged.

In a next step specific damage estimations were made for three earthquake scenarios that have been defined in an earlier study (JICA, 2002), namely a large earthquake comparable to the 1934 event (Mid Nepal Earthquake), a moderate earthquake occurring northof Kathmandu (North Bagmati Earthquake) and a local earthquake caused by an active fault within the valley itself. For each of these scenarios the ranges of partially and heavily damaged buildings have been estimated, with and without the effect of liquefaction. In order to take into account the liquefaction effect, the intensities in areas with high liquefaction susceptibility have been increased with 1 on the MMI scale. For the Mid Nepal and Local Earthquakes the amount of partially damaged building ranges from 5,380 to 9,192 and heavily damaged buildings from 2,748 to 6,104. If liquefaction is also included the estimations for partly damaged buildings rise to the range 5,804 9,779 and for heavily damaged buildings between 3,034 and 6,412.



	VI	VII	VIII	IX
Partial damage min	185	1174	5380	9192
Partial damage max	1647	5388	9192	13710
Collapse min	0	737	2748	6104
Collapse max	737	2748	6104	8583

Intensity (MMI)

Figure 7: Total number of damaged buildings in different damage grades in four earthquake intensities

3.5 Population loss estimation

The number of human casualties was estimated at homogeneous unit level for the three different earthquake scenarios mentioned earlier. The data used for this calculation were the population distribution for different periods of the day and within different occupancy classes, the building loss estimation discussed in the previous section and vulnerability and casualty ratios with respect to building damage. These casualty ratios were derived from the HAZUS methodology, which uses the widely accepted ATC-13 vulnerability curves. In this study, the term casualty refers to human injury, from slight injury to highest fatality, which is instant death. The four stages of severity for casualty, which are defined by HAZUS, were also adopted here. The relation between building damage state and injury levels is given in table 3.

Table 3: Various injury levels according to building damage. Modified from HAZUS

Building damage level	Injury level (in %)			
	Severity 1 Slight injuries	Severity 2 Injuries requiring medical attention	Severity 3 Hospitalization required	Severity 4 Instant Death
Partial Damage	1	0.1	0.001	0.001
Complete damage	40	20	5	10

With these relations, the number of casualties was estimated for the three different earthquake scenarios, and for both a daytime and nighttime scenario, with a different distribution of population over the various occupancy classes. Preliminary results are shown in Figure 8 and Figure 9 for the Mid Nepal Earthquake scenario. From figure 8 it can be observed that the differences between daytime and nighttime scenarios were smaller than expected. Normally, nighttime scenarios are expected to result in higher casualty numbers. The deviation in this case might be related to the inaccuracy of the population input data, as original data was only available at ward level, and also in the distribution of population over the city in different periods of the day. Clearly more detailed information for this should be collected. It might also be caused by the fact that many of the buildings where people are during the daytime, such as schools, shops etc. are equally vulnerable, or sometime more vulnerable than the residential buildings

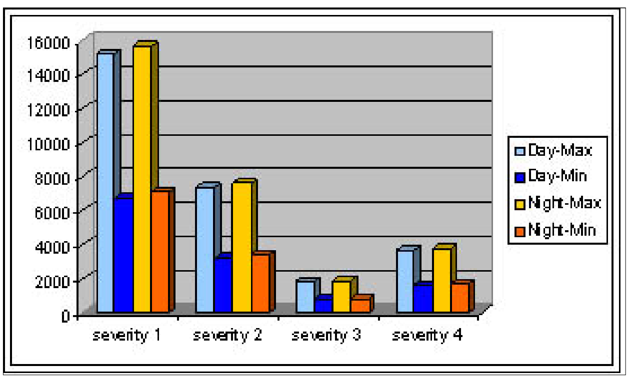


Figure 8: Casualty estimation for the Mid Nepal Earthquake scenario in Lalitpur.

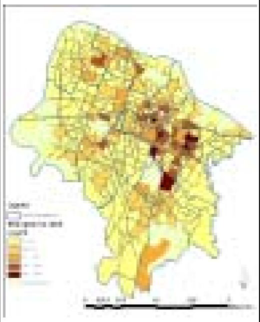
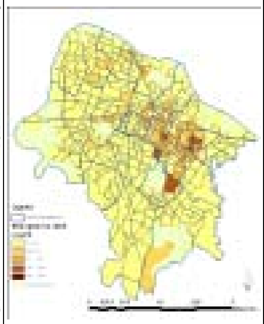
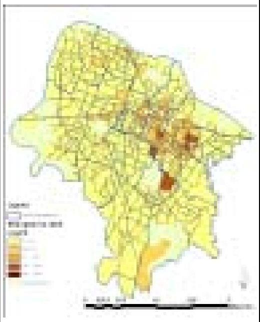
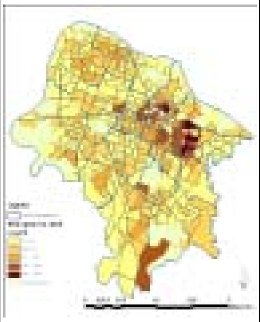
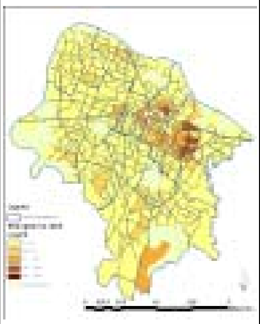
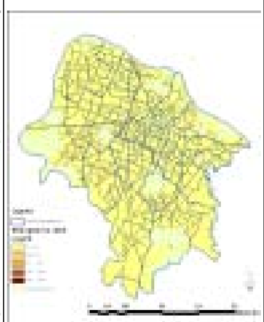
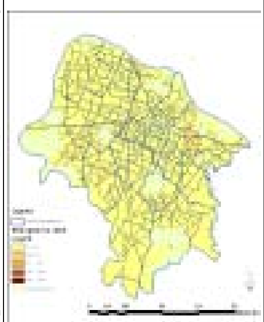
		Severity 1	Severity 2	Severity 2	Severity 4
Day Time	Maximum				
	Minimum				
Night time	Maximum				
	Minimum				

Figure 9: Various casualty levels for the Mid Nepal earthquake scenario.

4. Conclusions

The example from Lalitpur Sub-Metropolitan City in Nepal illustrates the direction of the SLARIM research project, in supporting local authorities with methods to collect and manage information used for risk estimation, analysis, assessment and finally management. The collection of basic data is of prime importance, and should be carried out by staff from the municipality in collaboration with local institutions and the local communities. The data collected thus far was mostly in the framework of rather short MSc fielddata collection campaigns, and should be further verified and extended. In the initial period of the project contacts with the Lalitpur Sub-Metropolitan City Office (LSMCO) have been established, and the results of the research was shared with their staff in a workshop. Also a user needs assessment was carried out, leading to the installation of a GIS center within LSMCO and basic GIS training of 12 of their staff. With LSMC a number of phases have been outlined, starting with the collection of base data and the development of a municipal database, leadingto the integrated use of this data for various urban planning and management activities, including disaster presentation and preparedness. One of the priority areas for the application of the municipal GIS in the framework of vulnerability reduction is thedevelopment of a building permit issuing and control system, that takes into account seismic vulnerability as one of the factors. Some other high priority GIS applications outlined by the LSMCO are the set-up of a proper addressing system for the city, which can be linked to geographic positioning using GPS, and urban heritage management. In a later phase LSMCO plans to apply it to other aspects such as solid waste management, infrastructure management, revenue management, etc. What has become clear in thecase study with the Lalitpur Sub-Metropolitan City so far is that specific GIS based Decision Support Systems for Disaster Management at municipal level can only be implemented if a municipality has experience with GIS and has developed a municipal database. Even then, such a system would be less useful for disaster prevention, as vulnerability reduction measures should be an integrated part of all common municipal activities, than for disaster preparedness.

Acknowledgements

I would like to thank the MSC students that have been involved in the studies in Lalitpur: Birendra Piya, Umut Destegul, Jeewan Guragain, Jayaweera Somasekera, Mazharul Islam and Pho Tanh Tung, as well as my colleagues involved in the research in Lalitpur: Luc Boerboom, Mark Brussel,Paul Hofstee, Erik de Man, Lorena Montoya, and Siefko Slob. Also I would like to thank the staff of the Lalitpur Sub-Metropolitan City Office, the Nepalese Society for Earthquake Technology (NSET), the International Centre for Integrated Mountain Development (ICIMOD) and the Asian Disaster Preparedness Center (ADPC) for providing support to the SLARIM research team. More information on

the SLARIM research project can be found at the following website: http://www.itc.nl/research/policy/spearhead3/vwesten.asp

REFERENCES

AIR. Website: http://www.air-boston.com/_public/html/newsitem.asp?ID=567

Alexander, D. 1993. Natural disasters. UCL Press Ltd., University College, London. 632 pp

Carter, W.N. 1991. Disaster management: a disaster manager's handbook. Asian Development Bank, Manila, 417 pp.

AUDMP (2003). Asian Urban Disaster Mitigation Project. Asian Disaster Preparedness Center (ADPC). Website: http://www.adpc.net/AUDMP/audmp.html

Brun, S.E., David Etkin, Dionne Gesink Law, Lindsay Wallace, Rodney White (1997). Coping with Natural Hazards in Canada:Government and Insurance Industry Perspectives. Website: http://www.utoronto.ca/env/nh/title.htm

CATEX. Website: http://www.catex.com/default.asp

CITIES Project (2004). Cities and Critical Infrastructure Project. Geoscience Australia. Website: http://www.ga.gov.au/urban/projects/cities.jsp

Dixit A. M., R D Welley Samant L., Nakarmi M., Pradhanang S. B., Tucker B. E. 2000. The Kathmandu Valley Earthquake Risk Management. A paper presented in the 12th World Conference on Earthquake Engineering (30 Jan-4 Feb), Auckland New Zealand

EM-DAT (2004), EM-DAT : the OFDA/CRED International Disasters Data Base.

Website: http://www.cred.be/

EMI (2002). Earthquake and Megacities Initiative. Website: http://www-megacities.physik.uni-karlsruhe.de

EQECAT.Website: http://www.eqecat.com/index.cfm

FEMA (2004). Federal Emergency Management Agency. HAZUS-MH. Website: http://www.fema.gov/hazus/

Fujii R., Kuwahara Y. and Saki H.,2001, Mineral composition changes recorded in the sediments from a 248-m-long drill-well in central part of the Kathmandu Basin, Nepal. Journal of Nepal Geological Society , vol. 25 pp 63-69.

IDB (2000). Inter-American Development Bank. Facing the Challenge of Natural Disasters in Latin America and the Caribbean. An IDB Action Plan. Washington DC, Inter-American Development Bank. Website: http://www.iadb.org/sds/doc/ENV%2DNaturalDisastersE.pdf

IFRC (2003). International Federation of Red Cross and Red Crescent societies. Climate Change Center. Preparedness for Climate Change. http://www.climatecentre.org/downloads/pdf/preparedness_climate_change.pdf

IPCC (2001) Intergovernmental Panel onClimate Change. Third Assessment Report. Climate Change 2001: Impacts, Adaptation and Vulnerability. Website: http://www.grida.no/climate/ipcc_tar/wg2/index.htm

ImageCat. Website: http://www.imagecatinc.com/reportspubs/epedatpp.pdf

Iwasaki, T., Tokida K., Tatsuoka., F. Watanabe, S., Yasuda, S., and Sato, H. (1982). Microzonation for soil liquefaction potential using simplified methods, 3rd Intl. Microzonation Conf. proceeding, 1939-1329

Iwasaki, T., Tokida K., Arakawa T. (1984). Simplified procedures for assessing Soil liquefaction during earthquakes, Soil dynamics and Earthquake Engineering, 1984, vol 3, no. 1, pp. 49-58.

JICA (2002) Japan International Cooperation Agency. The study on Earthquake

Disaster Mitigation in the Kathmandu valley Kingdom of Nepal.- Final report, Vol - I,II,III &IV.

Juang, C. H., and Elton, D.J., 1991, Use of fuzzy sets for liquefaction susceptibility zonation, in Proc. Fourth Intl. Conf. on Seismic Zonation, v. II, Standford Univ., USA. Earthquake Engineering Research Institute, P. 629-636.

Kreimer A., Arnold, M. and Carlin, A. (eds)(2003) Building safer cities. The future of disaster risk. Disaster risk management series Nr. 3. The Worldbank. Website:

Montoya, A.L. (2002) Urban disaster management : a case study of earthquake risk assessment in Cartago, Costa Rica. Promotor(s) I. Masser, N. Rengers and H.F.L. Ottens. - Enschede : ITC, 2002. - 217 p. ; 25 cm. - PhD thesis Utrecht University; Summaries in Dutch and Spanish. - ISBN 90-6164-208-6 (ITC Dissertation ; 96)

MunichRe. (2004). Topics Geo. Annual Review: Natural Catastrophes 2003. Website: http://www.munichre.com/publications/302-03971_en.pdf

OAS (1996). Estimation of Building Damage as a Result of Hurricanes in the Caribbean (A Primer). Organization of American States. General Secretariat. Unit for Sustainable Development and Environment. USAID-OAS Caribbean Disaster Mitigation Project. June 1996. Website: http://www.oas.org/en/cdmp/document/stubbs/2

Ordonez, G. (2002). A computer program for the 1D analysis of geotechnical earthquake engineering problems. Berkeley.

RADIUS (2000). Risk Assessment Tools for Diagnosis of Urban Areas Against Seismic Disasters. Website: http://geohaz.org/radius.html

RMS. Website: http://www.rms.com/Catastrophe/

Seed, H.B. and Idriss, I. M. (1971). Simplified procedure for evaluating soil liquefaction potential, Jour. of the Soil Mechanics and Foundation division, ASCE, v. 107, pp 1249-1274.

UN (1999) Report of the Secretary-General on the work of the Organization. General Assembly Official Records Fifty-fourth Session. Supplement No. 1 (A/54/1).

Website: http://www.un.org/Docs/SG/Report99/a541e.pdf

UNDP, 1994,1.Seismic Hazard Mapping and Risk Assessment for Nepal, 2.Development of Alternative Building Materials and Technologies 3.Seismic vulnerability analysis, (Appendix c) His Majesty's Govt. of Nepal, Ministry of Housing and Physical Planning, UNDP/UNCHS Habitat), Subproject NEP/88/054/21.03,1994.

UNESCO-RAPCA (2004). UNESCO Capacity Building for Natural Disaster Reduction. Regional Action Programme Central America. Website: http://www.itc.nl/external/unesco-rapca/start.html

UN Press release SG/SM/7479, (2000). Secretary-General Kofi Annan's inaugural address to Urban 21: Global Conference on the Urban Future, Berlin, July 2000. Website: http://www.un.org/News/Press/docs/2000/20000705.sgsm7479.doc.html

USAID (2001). Making Cities Work. Making Cities Work: USAID's Urban Strategy. An Initiative Launched by the Administrator and Prepared by the Urbanization Task Force. February 2001. Website: http://www.makingcitieswork.org/files/docs/MCW/MCWurbanstrategy01.pdf

Varnes, D.J. 1984.Landslide Hazard Zonation: A Review of Principles and Practice.Paris: United Nations International.

Yoshida, M. and Igarashi, Y. (1984). Neogene to Quaternary lacustrine sediments in the Kathmandu. Valley, Nepal, Jour. Nepal Geol. Soc., v. 4, pp. 73-100

Emergency Response After 9/11: The Potential of Real-Time 3D GIS for Quick Emergency Response in Micro-Spatial Environments

Mei-Po Kwan

Department of Geography
1036 Derby Hall 154 North Oval Mall
The Ohio State University Columbus,
OH 43210-1361 U.S.A.
Phone: 614-292-9465
Fax: 614-292-6213
kwan.8@osu.edu

Abstract

Terrorist attacks at the World Trade Center (WTC) in New York City and the Pentagon on September 11, 2001, not only affected multi-level structures in urban areas but also impacted upon their immediate environment at the street level in ways that considerably reduced the speed of emergency response. In this paper, we examine the potential of using real-time 3D GIS for the development and implementation of GIS-based Intelligent Emergency Response Systems (GIERS) that aim at facilitating quick emergency response to terrorist attacks on multi-level structures (e.g. multi-story office buildings). We outline a system architecture and a network data model that integrates the ground transportation system with the internal conduits within multi-level structures into a navigable 3D GIS. We examine important implementation issues of GIERS, especially the need for wireless and mobile deployment. Important decision support functionalities of GIERS are also explored with particular reference to the application of network-based shortest path algorithms. Finally, we present the results of an experimental implementation of an integrated 3D network data model using a GIS database of Franklin County, Ohio (USA). Our study shows that response delay within multi-level structures can be much longer than delays incurred on the ground transportation system, and GIERS have the potential for considerably reducing these delays.

1. Introduction

Terrorist attacks at the World Trade Center (WTC) in New York City and the Pentagon in Washington, D.C., on September 11, 2001, resulted in serious structural damage or collapse of buildings. Like other similar disasters (e.g. the bombing of the Alfred P. Murrah Federal Building in Oklahoma City on April 19, 1995), these events not only affected multi-level structures in urban areas but also impacted upon their immediate environment at the street level in ways that considerably reduced the speed of emergency response. The complex internal structure of these buildings and the restricted number of access points at the street level also render speedy escape and rescue particularly difficult in any emergency situation. When disasters occur in this kind of complex multi-level structures, a short period of time (e.g. 5 minutes) may mean significant change in the disaster environment within which trapped people have to escape and rescue personnel have to operate.

One important similarity of these multi-level structures is that they involve compartmentalized zones or areas connected by complex transport routes such as corridors. In addition, different levels of these structures are connected by a limited number of vertical conduits such as elevators and stairways. Many GIS-based analytical techniques can be applied for directing quick evacuation or rescue in these micro-spatial environments if their internal structure can be represented using navigable 3D GIS data models (Lee, 2001a,b). Further, as the horizontal and vertical conduits within multi-level structures are ultimately connected to the ground transportation system, much would be gained in emergency response through establishing a real-time 3D GIS that links together the traffic systems within these structures with the ground transportation system.

While it may be difficult to avoid enormous casualties in a major structural collapse, establishing an intelligent real-time 3D GIS that facilitates speedy escape and quick rescue in emergency situations may have the potential for considerably reducing casualties. In light of the fact that about 80 floors of both WTC towers were largely unaffected for at least 50 minutes after the plane strikes on September 11, accurate information derived from an operational real-time GIS-based Intelligent Emergency Response System and disseminated quickly to people inside the buildings and emergency personnel might have ameliorated the effects of the disaster.

In this paper, we examine the potential of using real-time 3D GIS for the development and implementation of GIS-based Intelligent Emergency Response Systems (GIERS) that aim at facilitating quick emergency response to terrorist attacks on multi-level structures (e.g. multi-story office buildings). We outline a system architecture and a network data model that integrates the ground transportation system with the internal conduits within multi-level structures into a navigable 3D GIS. We examine important implementation issues of GIERS, especially the need for wireless and mobile deployment. Important decision support functionalities of GIERS are also explored with particular reference to the application of network-based shortest path algorithms. Finally, we present the results of an experimental implementation of an integrated 3D network data model using GIS data of an area in downtown Columbus, Ohio (USA). We evaluate the benefit of using such a 3D network and concludes that GIERS built upon an integrated real-time 3D GIS have considerable potential for improving the speed of emergency response after terrorist attacks on multi-level structures in urban areas.

2. Emergency Management Information Systems

An Emergency Management Information System (EMIS) is a decision support system that integrates all phases of emergency management and response (Galloway, 2003; Tzemos & Burnett, 1995). It supports the emergency manager in planning and training for responding to emergencies in the pre-emergency phase, and in coordinating and implementing evacuation and/or rescue operations during the emergency response phase. Emergency planners use such systems to display and analyze the spatial relationships among possible event locations, shelters and other emergency management facilities and resources, transportation routes, and population at risk. An EMIS also allows the animated visualization of the temporal progression of both the hazard situation and the evacuation of the affected population from a disaster site. Response time and real-time data are important elements for an effective EMIS, which enables emergency operators to accurately evaluate and quickly implement emergency response plans so as to reduce the risk to the affected population.

Since most existing EMIS are designed and developed for handling emergencies in 2D environments, there are serious limitations when applying these systems to disasters that affect multi-level structures (e.g. multi-story buildings and subway stations). In order to respond to emergencies that occur in 3D micro-spatial environments, it is necessary to know which rooms and floors are affected, the current occupancy pattern, and which routes inside the structure are feasible and safe for reaching them. In addition, multi-level structures may also have several basement layers, with underground subway, gas, water and electricity lines that considerably increase the risk and complicate the tasks of emergency response (Cahan & Ball, 2002). An intelligent emergency response system, under the overarching framework of EMIS, therefore needs to incorporate 3D GIS capabilities and functionalities for representing the 3D structure of micro-spatial environments (e.g. internal structure of buildings) and conducting GIS-based analyses to provide real-time navigation guidance both for reaching the disaster site and for negotiating within a multi-level structure under emergency situations. In the rest of the paper, we focus mainly on the response phase of emergency management. The next section describes a system architecture and outlines some essential components and functionalities of a GIS-based intelligent emergency response system (GIERS).

3. System architecture of GIERS

A GIS-based Intelligent Emergency Response System (GIERS) is a spatial decision support system that aims at facilitating the coordination and implementation of quick emergency response operations such as evacuation and rescue. It not only incorporates important geospatial data about the emergency situation at hand, but also has spatial analytical and modeling capabilities to facilitate better planning anddecision making (Birkin, Clarke, Clarke, & Wilson, 1996). A GIERS is an intelligent system in the sense that it has reasoning capabilities for dealing with dynamically changing and uncertain disaster environments. It uses techniques in artificial intelligence (e.g. neural networks and agent-based modeling) to solve ill-structured problems and to provide decision support when facing uncertainty.

In order to enable quick emergency response and effective reduction of the risk to the population, a number of functionalities are critical to a GIERS. These include the collection and dissemination of data in real-time, as well as the capability to analyze disaster events, to model and simulate possible trajectories of change, to formulate alternative decision scenarios, and to communicate decisions and desirable actions effectively among all affected persons and emergency personnel (see Kwan 2003 for a discussion of these functionalities). Further, a GIERS needs to provide information and decision support to emergency operations at a suitable spatial scale and resolution. These functionalities in turn need to be built upon the foundation of several important components in the context of responding to terrorist attacks on multi-level structures in urban areas. They include a navigable 3D GIS, a real-time geographic database, a suite of decision support functionalities, and a distributed information architecture that is implemented through wireless and mobile communications technologies.

A possible system architecture of a GIERS is shown in Fig. 1. It illustrates that a GIERS is part of an Emergency Management Information System (EMIS), and that it integrates the ground transport component based on an Intelligent Transportation Systems (ITS) with the route systems of the multi-level structures in an urban area through a series of Intelligent Building Systems (IBS). Both ITS and IBS were originally developed for purposes other than emergency response, but they can play an important role in GIERS because they have deployed advanced real-time data collection and dissemination technologies that will be particularly useful for acquiring and conveying knowledge about a disaster environment.

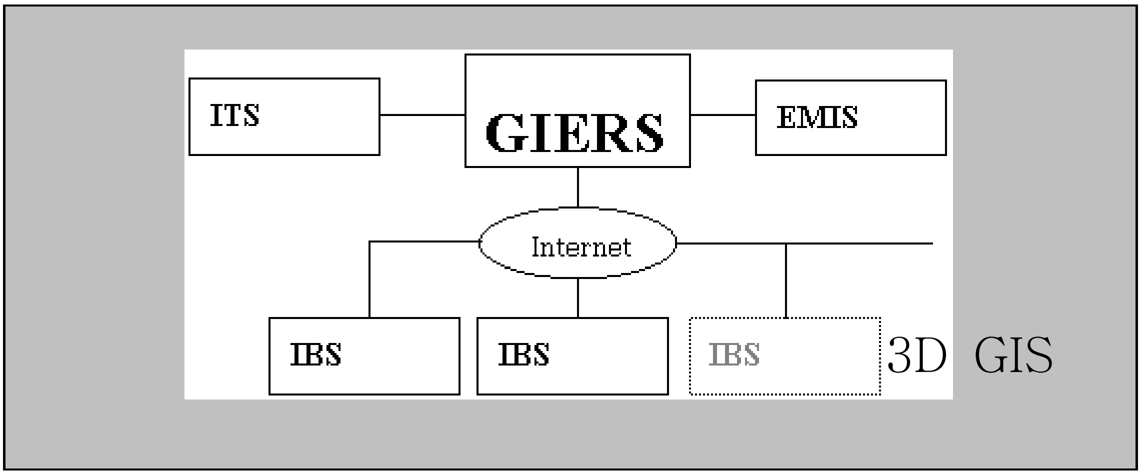


Fig. 1: System architecture of a GIERS

(a) Intelligent Transportation Systems - An important component of a GIERS is an Intelligent Transportation System (ITS), which uses advanced communications and transportation technologies to achieve traffic efficiency and safety. ITS were originally designed and developed as an innovative application of advanced computer, communications,and sensor technologies in transport and traffic management (Choy, Kwan, & Leong, 2000; Kwan, 1997). The ITS component of a GIERS is based on a geographic database that stores and manages information about the transportation network (such as attributes ofits links and its topology). Its real-time traffic detection component acquires and updates dynamic traffic information such as route condition and traffic delays in real-time using various types of sensors (Choy, Kwan, & Leong, 2000). It performs search for optimum routes and provides navigation guidance to emergency vehicles for quickly reaching disaster sites. The ITS component of a GIERS is therefore responsible for several important functions with respect to the transportation element of an emergency response situation, including data acquisition, data transmission, and control-rescuer equipment interaction (Frenzel, 2001).

(b) Intelligent Building Systems - Another important component of a GIERS deals with the internal structure of multi-story buildings such as their internal horizontal and vertical routes. This component will be useful for identifying feasible and safe routes within a multi-level structure and for providing navigation guidance for rescue personnel. It is based upon a set of interconnected Intelligent Building Systems (IBS) (Fig. 2). These systems were originally developed to provide a productive and cost-effective environment through optimization of a building's four basic components structure, systems, services and management and their interrelationships (Bushby, 1997; Carlson & Giandomenico, 1991). Each IBS is composed of numerous sensors, effectors and control units that are interconnected. Sensors used include temperature and light-level detectors, movement or occupancy sensors, pressure pads, smoke or gas detectors, and fire detectors. Devices being controlled by the system include heating, lighting, ventilation, alarms, automatic doors, and vertical transportations (e.g. escalators and elevators). An IBS optimizes operations across building control systems. For example, in the case of fire, the fire alarm communicates with the security system to unlock the doors. The security system communicates with the heating, ventilating and air conditioning (HVAC) system to regulate the flow of air to prevent a fire from spreading (Fig. 2).

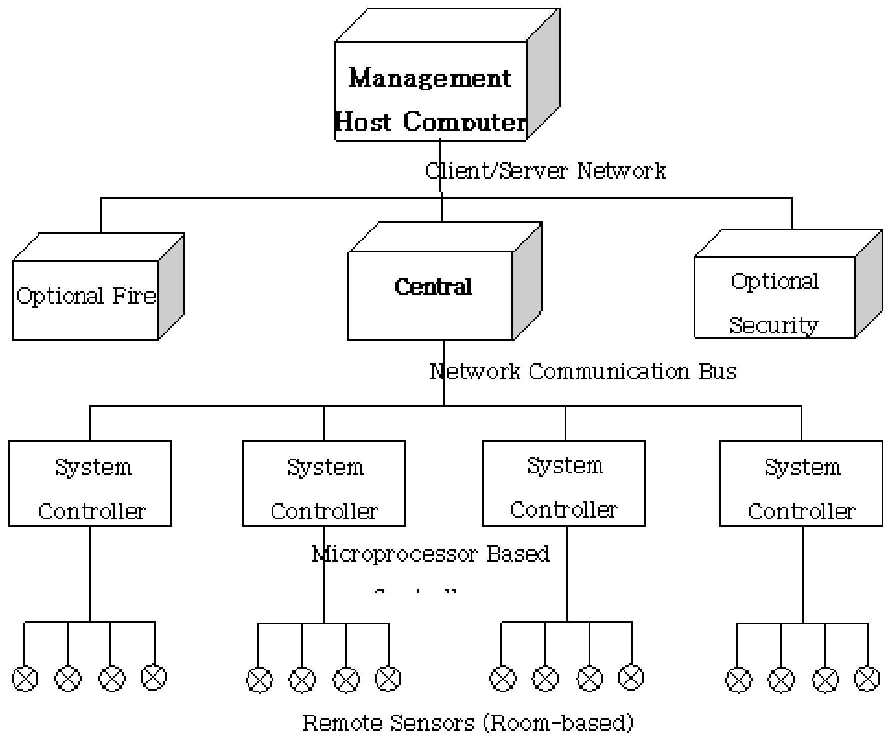


Fig. 2: Architecture of an Intelligent Building System (IBS) (Adapted from Carlson and Giandomenico, 1991)

Because an intelligent building consists of a network of room-based embedded agents covering the entire building (Reyes, Barba, Callaghan, & Clarke, 2001), the physical and logical unit of an IBS is asingle room. A building is regarded as a combination of different types of rooms, compartments, and connecting conduits (e.g. rooms, corridors, elevators and stairways). In addition, the control functions of an IBS are assigned and allocated based on roomunits because human behavior is often associated with a particular type of room (Sharples, Callaghan, & Clarke, 1999). Each room contains sensors and output devices, which are monitored and controlled by an IBS and are connected together via a communications protocol - like BACnet (Bushby, 1997) or Universal Mobile

Telecommunications System (UMTS) (Reyes, Barba, Callaghan, & Clarke, 2001) - to transfer the sensed data among the control systems. Using Intranet and Internet network technologies to access information and to control multiple building subsystems, an IBS is able to communicate with different agencies and organizations such as the police, fire stations, shopping malls, banks, and other IBS systems. A Web-enabled IBS can be accessed to control or monitor important systems or events from any PC with an Internet connection.

In order to provide the real-time data necessary for emergency response operations in multi-level structures, the data-acquisition system of an IBS needs to be extended to includespecific types of sensors that can detect and communicate critical real-time data such as the presence and number of occupants and the disaster situation (e.g. temperature). All of the sensed data are transmitted by Web-enabled technologies to a GIERS control center for analysis and compilation for its ultimate use. The GIERS control center is set up to acquire, process and communicate information about various emergency environments in real-time. Using Internet GIS technologies, mobile emergency response crews can access real-time information about the disaster situation and environment. The leaders of rescue teams can also transmit instructions to coordinate rescue operations among rescuers in action over a disaster site.

4. Mobile and wireless implementation of GIERS

Some important lessons about the deployment and implementation of GIERS in real world situations were learned from the WTC experience. After the WTC attacks, critical emergency response and information infrastructure was seriously disrupted. Affected facilities include New York City's Emergency Operations Center at 7 WTC, the switching facility of a major phone company in WTC, and part of the mobile phone infrastructure at the site (Cahan & Ball, 2002; Kant, 2002). Further, as emergency crews undertake rescue operations in a disaster site, they are mobile and cannot rely on wired connections for information and decision support from a real-time GIERS. To remain operational even in a disaster situation, a GIERS needs to be built upon a highly flexible and distributed system architecture, where the 3D GIS database and decision support functionalities remain accessible to emergency personnel through multiple channels via wireless and mobile communications technologies. These include notebook computers as well as various handheld and mobile devices with wireless communications capability. These channels and devices, as well as the information architecture that describes the data flows across the system are shown in Fig. 3.

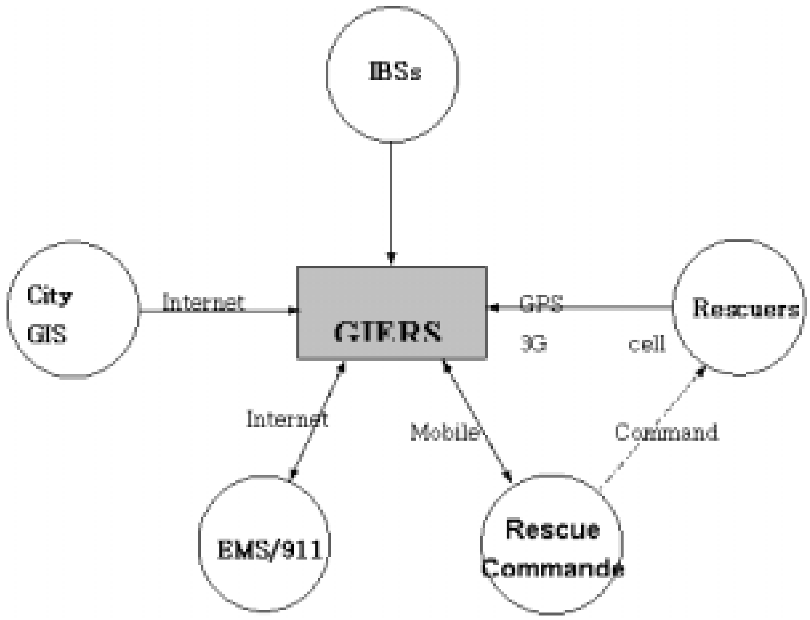


Fig.3:The information architecture of a GIERS

First, a GIERS uses the sensed data obtained from a series of IBSs to identify event locations (e.g. fire) based upon sensor locations or sensor identities; to identify current occupancy pattern and the number of users in each room from access control systems such as the SmartCard system; and, finally, to implement quickly and accurately emergency response plans. All of the sensor data obtained through IBS are transmitted through hard-wired or wireless networks to the central unit of a GIERS. This unit then incorporates the IBS data into a real-time 3D geographic database that allows for GIS-based analysis and visualization.

To be operational and effective, a GIERS requires detailed knowledge of both the disaster situation with respect to the internal structure of a building and its current occupants. While the information on the building's structure, control systems and occupancy is transmitted from a series of IBSs connected to a GIERS, reliable information on occupancy and their locations within the building cannot be obtained solely with conventional sensors in IBS - especially in the cases where a building does not have an advanced access control system. An additional source of the locational information of current building occupants, as conceived in our information architecture, is transmission via their 3G (third generation) cell phones. These phones are currently under development in order to meet the Phase II requirements of the U.S. Federal Enhanced-911 (E911) mandate, which requires wireless carriers to provide the 911 caller's location to the appropriate public safety answering point (PSAP). Under this Federal mandate, all cell phones are required to have the capability to announce their location (location notification) and communicate this information effectively through an emergency E911 call center (Fig. 3). Cell phone carriers are developing location notification capability for their cell phones either through an embedded GPS receiver or a proprietary location system they designed and developed. Some carriers use the signals from their cellular network and triangulation to identify the position of a cell-phone user (Frenzel, 2001).

Further, emergency and rescue crews operating within multi-level structures under a disaster condition will be equipped with GPS receivers and other mobile or handheld communications equipment that interact in real-time with the rescue command center of a GIERS. These GPS receivers provide location information that is transmitted via cell phones or mobile GIS devices. In addition, these locational devices are equipped with mobile GIS software (such as ArcPad) and can generate on-screen geo-referenced maps to support rescuers'operations on-site (e.g. providing navigational guidance). The location information generated by these GPS is in turn transmitted back to the rescue command center in real-time for the purpose of locating emergency crews and disaster events and conditions within the multi-level structure. However, there are limitations in using GPS within a multi-level structure due to a degradation or loss of signal in certain areas of a building. Although there is currently some development in the location-based service (LBS) sector that seeks to provide better coverage of location information inside buildings, and the network-based or hybrid positioning technology used by most LBS providers can achieve a positional fix faster and easier than conventional GPS-based technology, the problem of loss-of-fix in LBS-derived location data cannot be entirely eliminated. Much future research is still needed to address this problem (Kwan, 2001).

Fig. 3 provides an overall picture of this information architecture. It describes the communication and data flow among the mobile and non-mobile components of a GIERS across the systems. In summary, a GIERS can access geographic data about the urban environment - including the transportation network, land parcels and building footprints - via Internet GIS technologies and infrastructure operated by city/municipal GIS department. Real-time information about individual units within multi-level structures such as current room use is transmitted from a series of Intelligent Building Systems (IBS) through a hard-wired or wireless network. A GIER can also acquire additional data about the locations and conditions ofthe disaster environment within a building through fire and heat sensors, as well as other access control detectors. When an IBS fails or has been destroyed by a disaster, other real-time data on the disaster may be obtained from emergency crews with GPS receivers and mobile and wireless communications devices. The collected data is analyzed and transmitted to the emergency response command center for supporting spatial decisions pertinent to various rescuer operations, including the search for optimal routes for reaching certain units in a multi-level structure or for evacuating the affected population. Through this distributed and wireless information architecture, information about the current condition of the disaster environment can be collected and disseminated in real-time to support emergency operations.

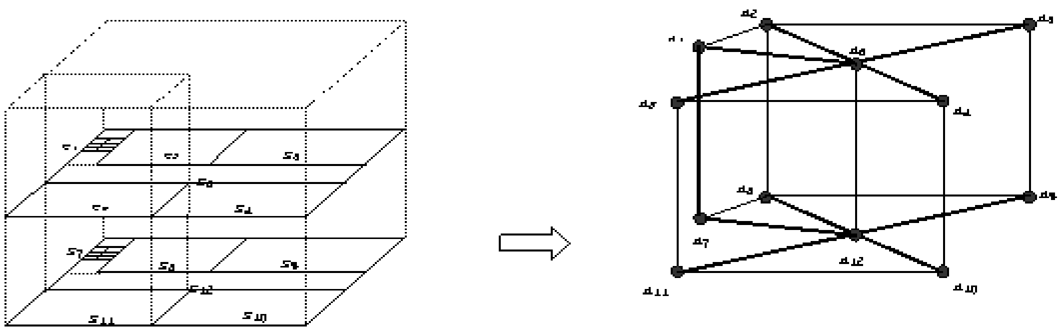
5. Network-based functionalities of GIERS

A critical element of a GIERS is its decision support capabilities, which in turn depend on a suite of analytical, modeling and simulation functionalities.These include interactive 3D geovisualization (Kwan, 2000; Kwan & Lee, 2003), multidimensional GIS modeling (Raper, 2000), rule-based methods, agent-based modeling, pattern recognition and spatial data mining algorithms (Abler and Richardson, 2003; Galloway, 2003; Miller & Han, 2001). These will be especially useful in emergency situations because the limited human knowledge and ability to deal with highly unstructured and complex problems may be assisted through these methods. Another important area is the capability to simulate current disaster situation and generate alternatives using all the information available at the moment. Simulation models also need to be developed for evaluating the propagation of risk to the adjacent areas of the disaster site, and to predict how a disaster situation will evolve and affect additional population and areas. Further, the real-time 3D GIS of a GIERS also needs to incorporate various types of geographic information, especially remotely sensed images or elevation data collected through laser-based light detection and ranging (LIDAR) technology before and after a terrorist attack (Bruzewicz, 2003). It should be able to represent a variety of less structured phenomena associated with the consequences of different kinds of terrorists attacks, and be highly editable and adaptable to real-time changes in the disaster environment.

Given that the notion of lifelines is important in the emergency management literature, and that lifelines are physical or virtual networks that are vital to the well-being of everyday life (Platt, 1995), network-based analytical capabilities are essential in a GIERS. These capabilities include finding the fastest route to reach a disaster site based on real-time traffic conditions, providing navigation guidance to emergency personnel operating inside a multi-level structure, finding the most effective and safest route for evacuating the affected population, and assessing the risk of various rescue or evacuation plans (Cova & Church, 1997; Kwan, 2003). Conventional 2D GIS and emergency response systems, however, do not allow for these kind of network-based analytical tasks when multi-level structures are involved in a disaster situation. This limitation is not only due to the unavailability of data about the internal structure of buildings, but also due to a lack of navigable 3D GIS data models that support network functionalities. For instance, the 3D GIS data models developed in recent years, such as those by Billen & Zlatanova (2003) and Coors (2003), are not navigable and therefore cannot be used to perform path-finding or routing algorithms that are important to emergency operations. To determine the optimal route for rescue and evacuation in a multi-level disaster environment in real-time, a GIERS therefore needs to be built upon a 3D network data model, which integrates the 2D GIS that handles the ground transportation (ITS) with the 3D GIS that deals with the relevant micro-spatial environments (e.g. internal structure of multi-level buildings).

In what follows, we describe such a 3D network data model based upon the work of Lee (2001a,b). The data model is used to represent the internal structures of buildings and to integrate these structures with that of the ground transportation system into anavigable 3D GIS. We begin with a description of the Node-Relation Structure, and then outline the derivation of a logical network data model and a geometric network data model that can be used for network-based analysis such as optimal route algorithms. The next section discusses an experimental implementation of this network data model for evaluating its potential for improving the speed of emergency response.

The fundamental element of the 3D network data model used in this study is a Node-Relation Structure (NRS), which is a topological data model representing the adjacency, connectivity and hierarchical relationships among discrete objects in 3D space. Due to the complexities and the variety of connected objects in micro-spatial environments (e.g. rooms and corridors inside a building), the NRS is derived using two data models: the logical data model and the geometric data model (see Lee 2001a for a detailed exposition of the steps involved, and also chapter 8 of Zeiler 1999). The logical data model is used to abstract and represent the topological relationships among discrete 3D objects. It is derived through PoincaréDuality using a graph-theoretic framework and a hierarchical representational schema (Lee 2001a,b). The geometric network data model is used to represent the geometric properties of objects in 3D space (e.g. location in 3D space, distance between two rooms and length of a corridor). As distances are accurately represented in the geometric network and topological relations are represented in the logical network, the NRS allows for the implementation of network-based analysis such as shortest path algorithms (Figs. 4 and 5).



Nodes:

N = {n_1, n_2, n_3, ……, n_{12}}

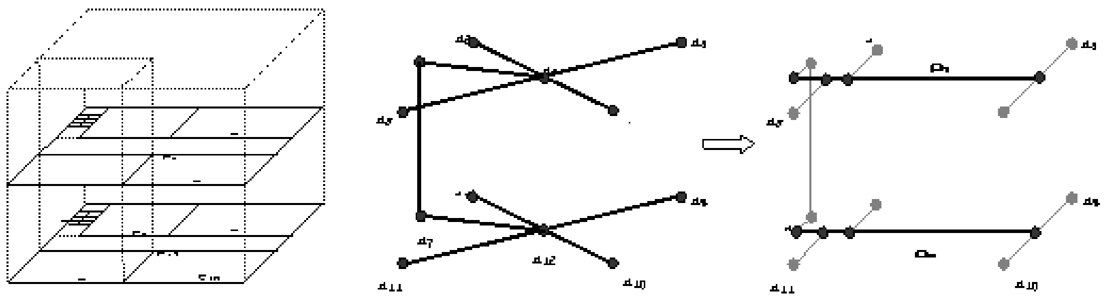
Relations:

E(G) = {ea_1, ea_2, ……, ea_n}

Edges:

Adjacency

Fig. 4: An example structure (a) and its node-relation structure (b)



(a) 3D Spatial Objects (b) Logical Network (c)Geometric Network

Fig. 5: A Node-Relation Structure (NRS) for representing topological relations among objects in 3D space

The logical data model of the Node-Relation Structure (NRS) is derived through Poincaré Duality, which abstracts the topological relations among a set of 3D objects and transforms '3D to 2D relations' in primal space to '0D to 1D relations'in dual space (Lee, 2001a). It represents adjacency relations among objects in 3D space as a dual graph, G = (V(G), E(G)). For connectivity relations in the NRS, the graph H = (V(H), E(H)) is a subgraph of the graph G = (V(G), E(G)) because of V(H) V(G) and E(H) E(G). Because the logical data model is a dual graph, which consists of sets of 0-cells (nodes) and 1-cells (edges), the graph structure of the duality of 3-complexes can be formalized using graph theory (Fig. 4b). Finally, the connectivity relationships between 3D objects in each floor within a building are represented as sub-networks and consolidated to a single node in the higher level, and as the relationships between different levels of subnetworks.

The logical data model is a pure graph that represents the adjacency, connectivity and hierarchical relationships among the internal units (e.g. rooms and corridors) of a building. It does not represent the geometric properties (e.g. size or distance) of and between these units. In order to implement network-based analysis such as shortest path algorithms in the NRS, the logical network data model needs to be complemented by a geometric network model that accurately represents these geometric properties (Fig. 5b, c). One key step in the process is to identify linear features from a simple polygon (a corridor) using Straight Medial Axis Transformation (S-MAT)) instead of abstracting a node in the logical data model (Lee, 2001a).

Based upon S-MAT, hallways are transformed into linear features, which are sub-networks consolidated into hallway nodes in the logical network (Fig. 5c). Each node representing a room of a building is projected and connected into the medial axis if there is a connectivity relation. The graph Nhi = (V(Nhi), E(Nhi)) representing the geometric network within floor i is combined with the graph Nv = (V(Nv), E(Nv)) using a UNION operation to produce the graphN = (V(N), E(N)), which is the geometric network model of the NRS. The graph Nv = (V(Nv), E(Nv)) is a subgraph of the logical network model, which represents the connectivity relations of rooms in the vertical direction. The reconstructed geometric network model generated after the transformation can be used as the 3D GIS data model for analyzing the complex spatial relations among rooms of a building and for performing network-based routing and search algorithms.

Based upon the above processes, the 3D geometric network model (Ni = (V(Ni), E(Ni))) representing the connectivity relations between the rooms of a building i is generated (Fig. 5c). The 3D geometric network, Ni = (V(Ni), E(Ni)), needs to be integrated with the 2D network of the ground transportation system for implementing a GIERS using a 3D network, R = (V(R), E(R)). The 2D street network can be represented by a graph, S = (V(S), E(S)). The first step for the integration is to define the connectivity relations between a building and the street network, which is abstracted to Connected_edges, where Connected_edges, E(C) = {(ni, nj) / ni V(Ni) and nj V(S)}. The node ni represents entrance halls of the buildings and the node nj are defined by projection p(ni, E(S)) of node ni onto edge E(S) of the street network, S. The connectivity relation is represented by a connecting network, C = (V(C), E(C)). In the final step of constructing a 3D network R = (V(R), E(R)) of a GIERS, the 3D geometric network (Ni = (E(Ni), E(Ni))), 2D street network (S = (V(S), E(S))) and the connecting network (C = (V(C), E(C))) are combined using a UNION operation because each network graph is equivalent in class. The combined network describes the connectivity relationships not only between objects in 3D space (e.g. roomsand corridors) within a building but also between buildings within the urban area.

To formalize a network structure consisting of Nodes V and Edges E, the schema of the objects is shown in Fig. 6. The primal classes of the model are Node, Edge, and Network. A node consists of an identifier and a position data in 3D (x,y,z-coordinates), and an edge consists of an identifier, start node, and end node. The class Network consists of an identifier and lists of all nodes and of all edges in a network. The database schema for attribute data of class Node and Edge is as follows:

NODE (Node_ID, RoomUse, Occupancy, Sensor_Data, Disaster_Status)
EDGE (Edge_ID, Length, Traffic_Capacity, Speed, Occupant_NO, Impedance)

Each node in the database has an identifier, room use, occupancy data, and sensed data collected by numerous sensors including temperature, smoke, gas, and fire detectors. Because the unit of IBS is a single room, the sensed data provide room-based information that is also a description of node characteristics in the 3D network. An edge has an identifier, population in each room, occupant movement, elevators/stairway capacity, corridor capacity and traffic flow impedance. Most of these data can be obtained by various types of sensors and transmitted via the communications infrastructure of an IBS in the context of a GIERS.

```
class Node {                                          class Edge {
                                Int Node_ID;
     Int Edge_ID;
                                Double x, y, z;
 Node initial_node;
                                }
                    Node end_node;

                    }

class Network {
                    Int Network_ID;
                    Node ArrayNode = new Node[];
                    Edge ArrayEdge = new Edge[];
                    }
```

Fig. 6: A network data model

6. Experimental implementation of the 3D network data model

To evaluate the potential benefit of a navigable 3D GIS for improving the speed of emergency response, we undertake an experimental implementation of a system based upon the 3D network data model described in the last section. The components of the system were constructed in the Visual Basic development environment. These components include a 3D Node-Relation Structure (NRS) Implementation Module, a relational database system accessible via Open Database Connectivity (ODBC) or ActiveX Data Object (ADO), a GIS software package accessible via Object Linking and Embedding (OLE) or ActiveX controls, and other program routines stored in Dynamic Link Libraries (DLLs) (Lee, 2001a). The data set used for our implementation is drawn from a comprehensive GIS database of Franklin County (Ohio, USA), where the study area Columbus City is located. This data set provides GIS data for the 453,536 buildings and 346,431 parcels in Franklin County. The digital street network we use contains 47,200 arcs and 36,360 nodes. Preparatory work in transforming and visualizing these data in 3D has generated over 1.4 GB data. For the implementation of the 3D network, we extract the Node-Relation Structure (NRS) of Franklin County Municipal Building located in downtown Columbus (Ohio) using the procedures outlined in the last section. This NRS is then connected with the street network at the building's entry points to create the final network used for the study.

Using the system and the GIS data of the study area, we evaluate the impact of three types of uncertainty responders often encounter in emergency situations on the speed of response: (a) road network uncertainty; (b) entry point uncertainty; and (c) route uncertainty within a building. Road network uncertainty is the uncertainty about the fastest route for traveling from the dispatching location of the rescuers (e.g. a fire station) to the entry point of the building hit by a disaster. This type of uncertainty exists because the shortest path (evaluated by travel time) under normal circumstances from the fire station to the disaster site may not be the shortest path under emergency situations due tothe sudden evacuation of people, the blockade by debris or unexpected traffic. It may lead to considerable delay in reaching the disaster site if the actual shortest path is not used. Entry point uncertainty is the uncertainty about which entry point of the building hit by disaster is feasible. Without prior knowledge about the feasible entry points, emergency responders may arrive at a ground-level entry point that cannot be used (e.g. blocked by debris). They may need to walk around the building in orderto use another entry point on the other side. This introduces additional delay in the speed of emergency response. Route uncertainty within a building is the uncertainty about the feasible and fastest route from a feasible ground-level entry point to a destination point within the building. For instance, in an attempt to reach a room without prior knowledge of which stairways are feasible and safe, rescuers may be blocked in the middle and have to go back down to the ground level and use another stairway to go up again.

To evaluate the effect of these three types of uncertainty on the speed of emergency response, the 3D network R= (V(R), E(R)) of a GIERS is implemented as a directed graph (or digraph). It is operationalized to identify the optimal route from source node a (a fire station) through an intermediate node b (the entry point of the destination building) to the destination node c (a room on the 42th floor of a building). Many individual paths Route(a, c)can be identified between node a and node c on the 3D network. The travel time for Route(a, c), RDist(a, c), can be represented as:

$$RDist(a, c) = SDist(a, c) + (a, c)$$

where SDist(a, c) is the travel time of the shortest route between the origin node a and the destination node c, and (a, c) is the sum of delay times for Route(a, c) due to the use of non-optimal routes and/or entry points. To represent the three elements of uncertainty for Route(a, c) between the fire station a and the disaster location c, the total delay time (a, c) can be expressed as:

$$\oint(a, c) = \oint(a, b') + \oint(b', b) + \oint(b, c)$$

where node b is the optimal building entry point, and node b′ is any non-optimal building entry point. The total delay in travel time (a, c) is affected by the delay due to road network uncertainty (a, b′), entry point uncertainty (b′, b), and route uncertainty within a building (b, c).

Figs. 7-10 illustrate the implementation of the system for evaluating the impact of these three types of uncertainty on response time. The study area for this experimental case is an area in downtown Columbus, Ohio (USA), located in the east of Scioto River. We assume that a 250-pound high-explosive bomb exploded on the 42th floor of Franklin County Municipal Building (labeled "Disaster Site" in Fig. 7), and that the shock also caused minor damage on some other floors as well as part of the stairways inside the building. Fig. 7 shows the shortest routes under normal traffic conditions (in red) between the disaster building and the fire station located at 405 Oak Street. Suppose that traffic is blocked at two locations on South High Street and Mound Street (indicated by two red dots in Fig. 7) nearby the disaster building. Because of these unexpected traffic blocks, the usual shortest path from the fire station to the disaster building is no longer the optimal route. Instead the route in blue in Fig. 7 becomes the new shortest path (in terms of travel time). If emergency responders do not have prior knowledge about this new optimal route, they will try to access the disaster site following the usual shortest path (red route). They will then, in this scenario, need to reroute twice because of the two unexpected traffic blocks (red zones in Fig. 8). The additional delay between the new optimal route (blue route) and the hypothetical detour route (purple route in Fig. 8) represents the effect of road network uncertainty on emergency response time.

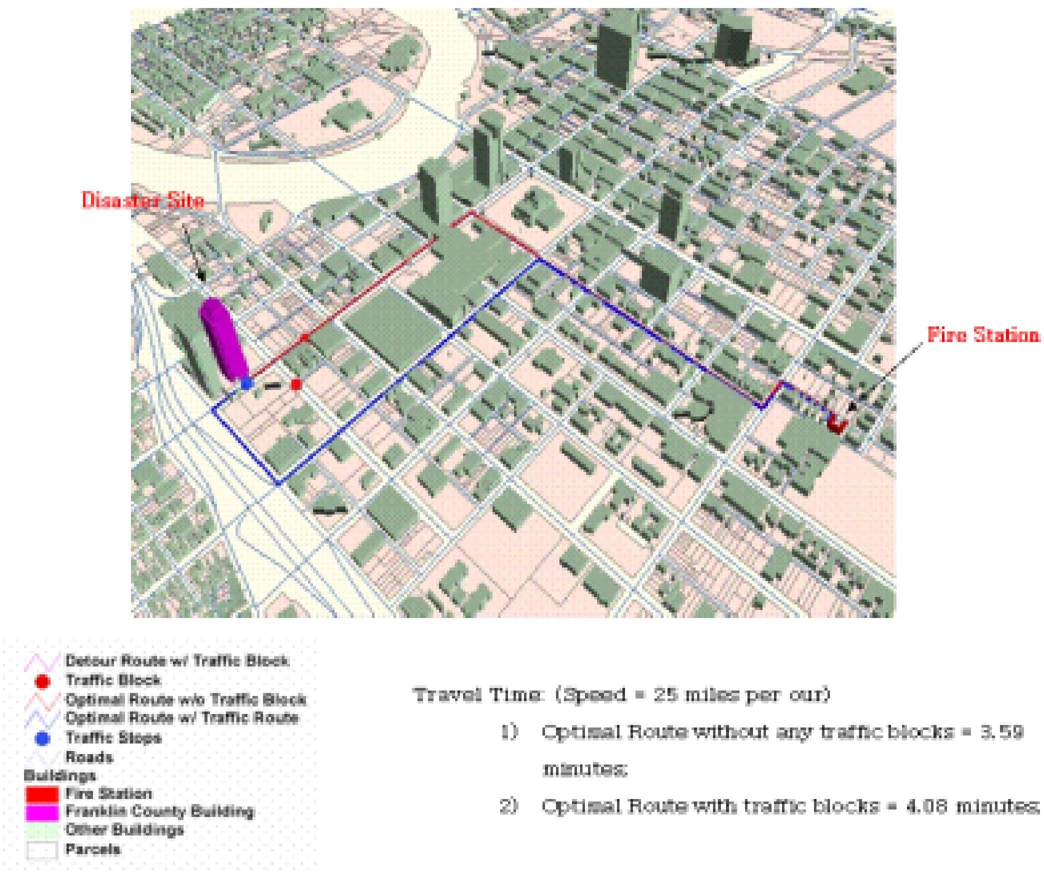


Fig. 7: The shortest path between a fire station and a disaster building (Downtown Columbus, Ohio)

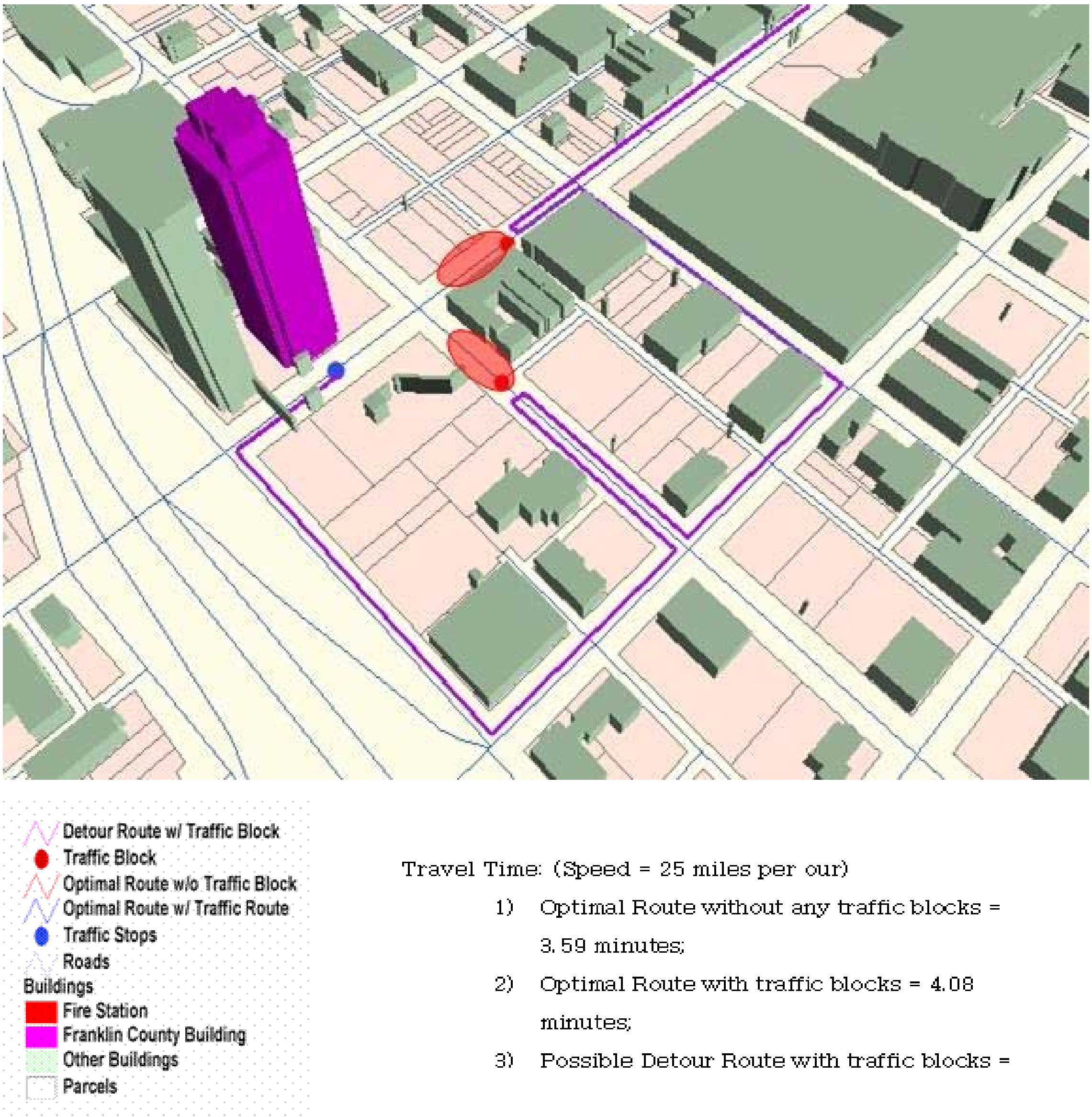


Fig. 8: A close-up view of the disaster site (Downtown Columbus, Ohio)

After arriving at the disaster building at Entrance A (Fig. 9), emergency responders discover that this entrance is blocked bydebris and cannot be used to reach the destination room (disaster site) on the 42th floor (Fig. 10). They then walk to another side of the building in order to use Entrance B (Fig. 9 and 10). These responders are, however, blocked at the 28th floor as they attempt to walk up to the 42th floor using the stairway. They then walk down to the ground level and use another stairway to go up again (Fig. 10). They are blocked on the 28th floor again and have to walk down a couple of floor and walk through some corridors to go up using another stairway (Fig. 10). The additional delay between the optimal route (green line) and the hypothetical detour route (red dotted line in Fig. 10) represents the effect of entry point uncertainty and route uncertainty in building on emergency response time.

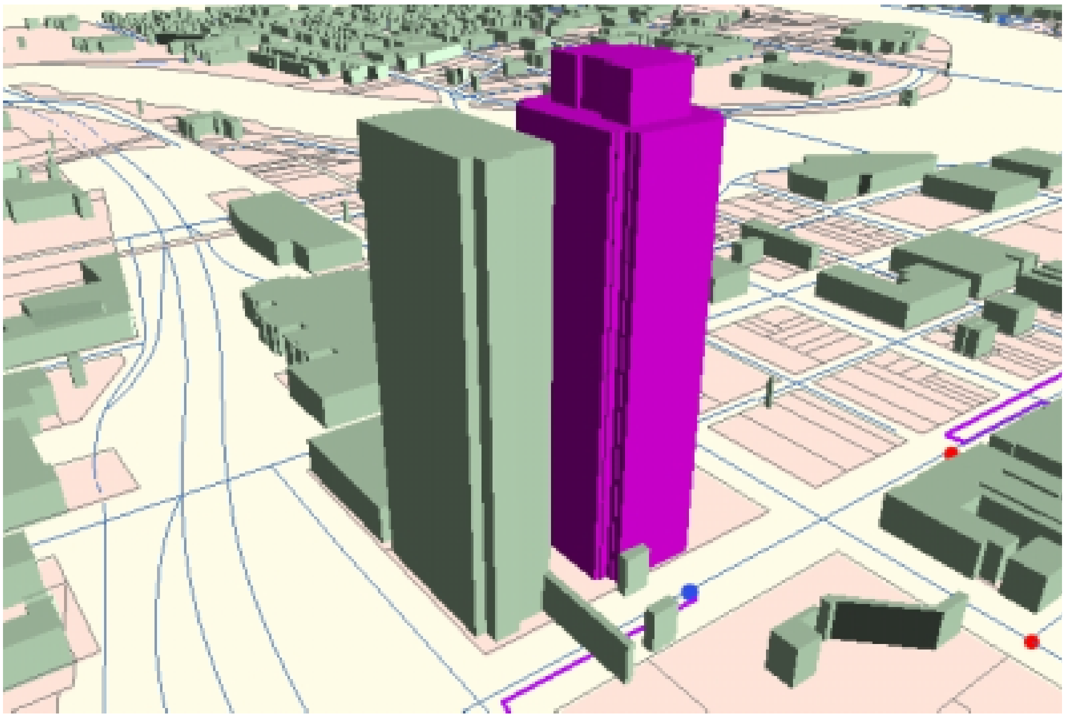


Fig. 9: Two possible entrances of the disaster building – Entrance A (visible in the Fig.) and Entrance B (not visible in the Fig. as it is on the other side of the building).

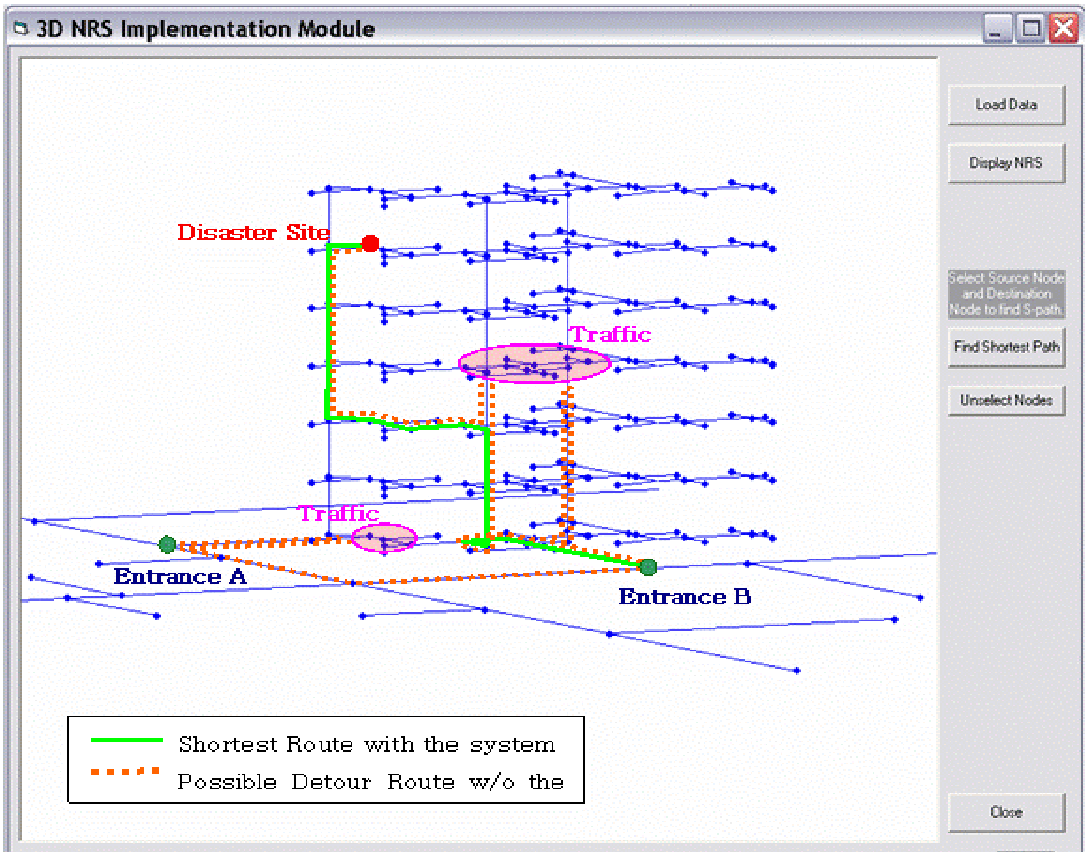


Fig. 10: The shortest path between two entrances (A and B) and a disaster site on the 42th floor of the building

In order to simulate this scenario, three travel speeds are assigned to the 3D network developed for the study: (a) 25 miles per hour for the road network; (b) 75 feet per minute for walking horizontally outside or inside the building; and (c) 40 feet per minute for going up or down vertically using the stairways inside the building. Each side of the building is assumed to be 300 feet, and each floor is 16 feet in height. Thus, the 42th floor is 672 feet from the ground and will take responders 16.8 minutes to reach from the ground level. The shortest path from the source node a to the destination node c is found using a modified Dijkstra's algorithm that operates on the 3D network.

The results of the experiment are summarized in Table 1. It shows the additional time (a, c) for traveling from the fire station (node a) to the disaster site (node c) taking into account the delays caused by the three kinds of uncertainty. The total travel time it takes to reach the destination node cwithout using the system is 39.83 minutes, while it is only 24.19 minutes when the optimal route found by the system is used. This means that emergency responders can reach the destination node 15.64 minutes earlier than when such a system is not used. In the experiment, optimal routing performed using an integrated 3D network saves more than one-third of the travel time otherwise needed for reaching the disaster site. Further, the results suggest that optimal routing using only the ground transport network as in conventional 2D GIS leads to a mere 2.18 minutes saving in travel time. This means that a 3D network that integrates the street network with the building's network brings an additional saving of 13.46 minutes. This amounts to 86% of the total travel time saved due to the use of the optimal route found by using the 3D network. This experiment demonstrates that the travel time needed to reach a disaster site inside a multi-level structure can be much longer than the time needed to travel from a source node (a fire station) to the disaster building. It shows that extending conventional 2D GIS to include the internal structures of high-rise buildings can significantly improve the overall speed of rescue operations.

Table 1: Travel times for Route(a, c) with and without using GIERS.

Source of uncertainty	Travel time without using GIERS (in min.)	Travel time using GIERS (in min.)	Delay (in min.)
Road network	6.26	4.08	2.18
Entry point	3.73	0.00	3.73
In building	29.84	20.11	9.73
Total travel time or delay for Route(a, c)	39.83	24.19	15.64

The benefit of a GIERS based uponan integrated and navigable 3D network data model would be even greater when the real world scenario is worse than that conceived in this experiment. For example, there may be more traffic blocks nearby the disaster building; the responders may have to reach the 70th floor (as in the case of the WTC disaster); and decision making without a GIERS may need considerably longer time for coming up with a desirable course of action. In addition to improving the speed of rescue operations, real-time information about the building's feasible routes disseminated to those inside may also help improve the speed and effectiveness of the evacuation process, because they can start exiting the building once they received this information. This means that evacuation can begin long before emergency responders arrive at the disaster site, and this may have the effect of saving many lives, especially if the building is becoming structurally unstable after a bomb attack or being hit by a plane.

7. Conclusion

GIS technologies and methods were useful at the WTC disaster site (Barnes, 2001; Showstack, 2001; Cahan & Ball, 2002; Cutter, Richardson & Wilbanks, 2003; Kant, 2002). There are many lessons to be learned for the development and implementation of GIS-based Intelligent Emergency Response Systems (GIERS), and in other applications of geospatial technologies on responding to the consequences of terrorist attacks on multi-level structures in the future. This paper outlines the important elements of GIERS, including 3D GIS network data models, real-time and distributed geographic databases, mobile GIS technologies, and analytical and modeling methods. The results of an experiment conducted using the 3D network we developed and GIS data of Columbus, Ohio indicate that an integrated and navigable 3D GIS has potential to contribute in significant ways to quick emergency response to terrorists attacks.

While focusing on quick emergency response systems and the usefulness of 3D network data models, this article ignores several important issues pertinent to the development and deployment of GIERS. First, successful implementation and use of GIERS depend heavily on the availability of accurate real-time information from diverse sources. As a result, not only issues of interoperability but also issues of the willingness of various government agencies to share data are important considerations (Abler and Richardson, 2003; Goodchild, 2003; Logan, 2002; Thomas et al., 2002). As apparent in the 9/11 experience, development of GIERS can be hampered by problems of interoperability and data sharing in addition to the technical difficulties associated with the development of new data models or emergency response systems.

Second, the comprehensive GIS data of GIERS themselves raise serious concernsabout issues of data security, as data assembled for emergency response operations can be used by terrorists if they can break in the system and access these data. Means for preventing access to these data by terrorists should therefore be an integral component of GIERS. Lastly, the real-time data collection systems (e.g. occupancy sensors) of GIERS raise questions about surveillance and violation of personal privacy (Armstrong, 2002; Curry, 1997; Monmonier, 2002). There is an inevitable trade-off between the need for critical information for rescue operations on the one hand, and protecting individual human rights and personal privacy on the other (Richardson, 2003). It is important to have guidelines in place before the implementation and deployment of GIERS to ensure that private information is used ethically and according to the need of a particular emergency response situation.

REFERENCES

Abler, F., & Richardson, D. B. (2003). Geographic management systems for homeland security. In S. L. Cutter, D. B. Richardson, & T. J. Wilbanks (Eds.), The geographical dimensions of terrorism (pp. 117-124). New York: Routledge.

Armstrong, M. P. (2002). Geographic information technologies and their potentially erosive effects on personal privacy. Studies in the Social Sciences, 27, 19-28.

Barnes, S. (2001). United in purpose: spatial help in the aftermath. Geospatial Solutions, 11, 34-39.

Billen, R., & Zlatanova, S. (2003). 3D spatial relationships model: A useful concept for 3D cadastre? Computers, Environment and Urban Systems, 27, 411-425.

Birkin, M., Clarke, G., Clarke, M., & Wilson, A. (1996). Intelligent GIS: location decisions and strategic planning. Cambridge: GeoInformation International.

Bruzewicz, A. J. (2003). Remote sensing imagery for emergency management. In S. L. Cutter, D. B. Richardson, & T. J. Wilbanks (Eds.), The geographical dimensions of terrorism (pp. 87-97). New York: Routledge.

Bushby, S. (1997). BACnetTM: a standard communication infrastructure for intelligent buildings. Automation in Construction, 6, 529-540.

Cahan, B., & Ball, M. (2002). GIS at ground zero: spatial technologies bolsters World Trade Center response and recovery. GEOWorld, 15, 26-29.

Carlson, R., & Giandomenico, R. (1991). Understanding building automation systems. Kingston, MA: R.S. Means Company, Inc.

Choy, M., Kwan, M.-P., & Leong, H.V. (2000). Distributed database design for mobile geographical applications. Journal of Database Management, 11, 3-17.

Coors, V. (2003). 3D-GIS in networking environments. Computers, Environment and Urban Systems, 27, 345-357.

Cova, T.J., & Church, R.L. (1997). Modeling community evacuation vulnerability using GIS. International Journal of Geographic Information Science, 11, 763-784.

Curry, M. Foucault, Michel(1997). The digital individual and the private realm. Annals of the Association of American Geographers, 87, 681699.1979. Discipline and punish: The birth of the prison, transl. Alan
Sheridan. New York: Vintage Books.

Cutter, S. L., Richardson, D. B., & Wilbanks, T. J. (Eds.) (2003). The geographical dimensions of terrorism (pp. 111-116). New York: Routledge.

Du, D.-Z., & Hsu, D.F., eds. (1995). Logical network theory. Dordrecht, Kluwer Academic Publishers.

Frenzel, L. (2001). An evolving ITS paves the way for intelligent highways. Electronic Design, January 2001.

Galloway, G. E. (2003). Emergency preparedness and reponse - Lessons learned from 9/11. In S. L. Cutter, D. B. Richardson, & T. J. Wilbanks (Eds.), The geographical dimensions of terrorism (pp. 27-34). New York: Routledge.

Goodchild, M.F. (2003). Geospatial data in emergencies. In S. L. Cutter, D. B. Richardson, & T. J. Wilbanks (Eds.), The geographical dimensions of terrorism (pp. 99-104). New York: Routledge.

Kant, E. (2002). Wireless GIS solution aids WTC rescue efforts. ArcUser, 5, 13-17.

Kwan, M.-P. (1997). GISICAS: an activity-based travel decision support system using a GIS-interfaced computational-process model. In D.F. Ettema, & H.J.P. Timmermans (Eds.),Activity-based approaches to travel analysis (pp. 263-282). New York: Pergamon.

Kwan, M.-P. (2000). Interactive geovisualization of activity-travel patterns using three-dimensional geographical information systems: a methodological exploration with a large data set. Transportation Research C, 8, 185-203.

Kwan, M.-P. (2001). Analysis of LBS-derived data for social scientists: prospects and limitations. Paper presented at the Specialist Meeting on Location-Based Services, Center for Spatially Integrated Social Science (CSISS), University of California, Santa Barbara, December 14-15, 2001.

Kwan, M.-P. (2003). Intelligent emergency response systems. In S. L. Cutter, D. B. Richardson, & T. J. Wilbanks (Eds.), The geographical dimensions of terrorism (pp. 111-116). New York: Routledge.

Kwan, M.-P. & Lee, J. (2003). Geovisualization of human activity patterns using 3D GIS: a time-geographic approach. In M. Goodchild, & D. Janelle (Eds.), Spatially integrated social science: examples in best practice. New York: Oxford University Press.

Lee, J. (2001a). A 3D data model for representing topological relationships between spatial entities in built environments. Ph.D. Dissertation, Department of Geography, The Ohio State University, Columbus, Ohio, U.S.A.

Lee, J. (2001b). A spatial access oriented implementation of a topological data model for 3D urban entities. Paper presented at University Consortium for Geographic Information Science (UCGIS) Summer Assembly, Buffalo, New York, June 21-24.

Logan, B. (2002). The lesions of 9/11. Geospatial Solutions. 12(9): 26-30.

Miller, H.J. & Han, J. Eds. (2001). Geographic data mining and knowledge discovery. London: Taylor & Francis.

Monmonier, M. S. (2002). Spying with maps: Surveillance technologies and the future of privacy. Chicago: University of Chicago Press.

Platt, R.H. (1995). Lifelines: an emergency management priority for the United States in the 1990s. Disasters, 15, 172-176.

Raper, J. (2000). Multidimensional geographic information science. London: Taylor and Francis.

Reyes, A., Barbr, A., Callaghan, V., & Clarke, G. (2001). The integration of wireless, wired access and embedded agents in intelligent buildings. Paper presented at the 5th World Multi-Conference on Systemics, Cybernetics and Informatics, Orlando, Florida, July 22-25.

Richardson, D. (2002). Building a research agenda on the geographical dimensions of terrorism: An on-going process. Transactions in GIS, 6, 225-229.

Sharples, S., Callaghan, V., & Clarke, G. (1999). A multi-agent architecture for intelligent building sensing and control. InternationalSensor Review Journal, May 1999.

Showstack, R. (2001). GIS plays key role in NYC rescue and relief operation. EOS, Transactions, American Geophysical Union, 82(40), 1.

Platt, Rutherford H. 1995. Lifelines: An emergency management priority for the United States in the 1990s. Disasters 15:172-176.

Raper, Jonathan. 2000. Multidimensional geographic information science. London: Taylor and Francis.

Thomas, D.S. K., Cutter, S.L., Hodgson, M., Gutekunst, M., & Jones, S. (2002). Use of Spatial Data and Geographic Technologies in Response to the September 11 Terrorist Attack. Quick Response Research Report #153. Boulder, Colorado: Natural Hazards Research and Applications Information Center, University of Colorado. URL: http://www.colorado.edu/hazards/qr/qr153/qr153.html

Tzemos, S., & Burnett, R. (1995). Use of GIS in the Federal Emergency Management

Information System (FEMIS), In Proceeding of 1995 ESRI User Conference, Redland, California.

Zeiler, M. (1999). Modeling our world: The ESRI guide to geodatabase design. Redlands, CA: ESRI Press.

Fire Emergency Rescue Service Based on GIS: Daegu Metropolitan City FGIS

Jin-Taek Kim
Information & Communication Part of
Daegu Metropolitan City Fire Department
kjt119@daegumail.net

1. Introduction

Nowadays, various kinds of disasters caused by world climate environment change and complication of city culture are bringing about much loss of life casualties and damages of property. According to the statistics by the National Emergency Management Agency(NEMA), in the year 2003, there were 280,869 incidents of disasters with 391,837 casualties and 217,868 million KRW property damage [3]. Among this, 14,516 incidents occurred in Daegu Metropolitan City with 18,972 casualties and 12,605 million KRW property damage. And among this, traffic accident accounted for 12,807 cases and fire accounted for 1,004 cases, respectively, 88.2% and 6.9%, of total cases of disasters [3]. The government is making every effort to prevent these kinds of disasters that brings about a great social loss. The previous management system categorized disasters into natural and human-made, and was managed by various governmental offices and laws. In June this year, the government established the NEMA in order to build a more systemized disaster management system.

NEMA classifies disasters into 8 categories (fire, forest fire, collapse, explosion accidents, traffic accident, pollution, ferry, ocean accidents) and manages these disasters through the steps of prevention, preparation, response, recovery. Furthermore it is committed to building an information communication system and integrating the management of information to enhance its countermeasure efficiency. Especially, location information is one of the essential elements that must be gained in regards to its disaster management and the Agency is trying to find an effective way to use Location Based Service(LBS), a foundation technology of location information, and 4S(GIS, GNSS, SIIS, ITS), a geospatial information unification technology.

Disaster management based on information systems is one of the most important topics in the e-government, and many countries are concentrating on building an emergency management system and infrastructure, such as the U.S. FEMA. In Korea, the 119 Emergency Rescue System(E-119) have been established since the mid-1990s as a part of the computerization of the fire service which began in Seoul and spread to other regions such as Daegu, Chungnam, Pusan, Cheju and so on.

In the midst of the trauma of typhoon 'Maemi' last September, the Daegu City 119 Emergency Rescue System succeeded in handling 3,800 emergency calls per hour during 4 hours and dispatched fire troops[1] in 550 cases, an amazing new record [2]. The Deagu Metropolitan City Fire Department has built this system through the establishment of ISP(Information Strategy Planning) and basis design in 1997, verification of performance by building a pilot system that controlled the disasters of 2 fire stations in 1998, and expanding the system for a unified disaster management of the entire Daegu Metropolitan City on February, 2000.

This paper presents the 119 Fire Geographic Information System(FGIS) which swiftly and accurately manages disaster information and dispatches a fire troop under the mission to save lives and protect property in disasters. Chapter 2 is studies the architecture of this system, Chapter 3, its application, Chapter 4, expectations and improvements, and finally in Chapter 5, the conclusion.

2. Fire Geographic Information System Configuration

Spatial information, used in all four phases of disaster prevention, preparation, response and recovery, should be continuously improved through the latest up-to-date technology. The Daegu City Fire Department has enhanced the FGIS system through the "4S pilot project to advance the 119 Emergency Command & Control Center" conducted together with the Electronics and Telecommunications Research Institute (ETRI). In June this year, it was also the first to adopt the Mobile Telephone Position Information System which was promoted by NEMA, and is currently in trial service.

It is imperative that a system is established to support the primary emergency response, beginning from the moment a 119 emergency call is made in relation to a disaster to on-site response and initial recovery, and emergency management. Moreover, it is most important that information created in the phases of the emergency is circulated accurately and continuously. That is why the system must be systematically operated without interruption under any circumstances. In this regard, the Daegu 119 Fire Emergency Rescue System is currently operating a 24 non-stop service by physically duplexing the call registration system and GIS servers. The information created in the case of disaster is gathered systematically and utilized real-time to control emergencies. It is also saved on the database, used to make statistics and analysis data, and utilized in

1) fire troops : fire fighters, fire engines, and equipments

fire administration, for example in devising measures.

2.1 Emergency Rescue System Architecture

In order to understand the basic architecture of the FGIS, a study on the overall architecture of the 119 Emergency Rescue System, responsible for the entire emergency rescue operation, and its main work phases and functions. The Emergency Rescue System is largely divided into 4 parts, Command & Control Operation, Disaster on-site Action Information Support, Related Offices Information Connection and Administration Information Management <Figure 1>.

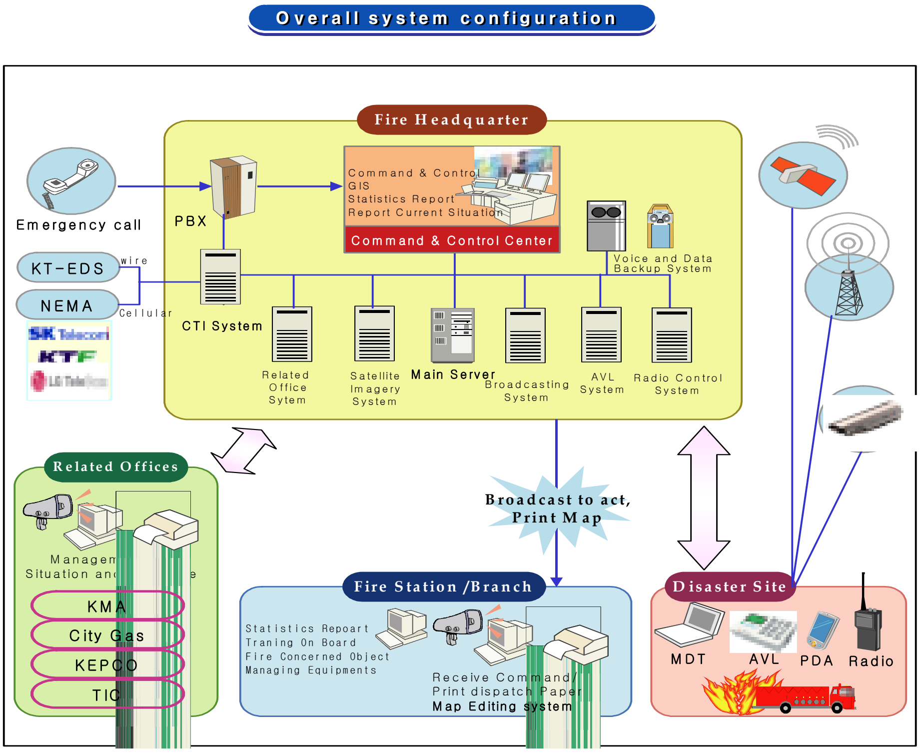


Figure 1. Emergency Rescue System Configuration

○ Command & control operation

This is a system that is operated by the 119 Emergency Control Office and various kinds of information including caller location information are used to swiftly and accurately respond to disasters. The system is composed of the following unique and active functions.

- Emergency 119 Caller location indicator
- Geographic information and Satellite imagery information provision
- CTI(Computer Telephony Integration) and disaster registration
- Automatic formation of fire troops and dispatch
- Management of disaster(fire, emergency, rescue etc.)

- AVL(Automatic Vehicle location) tracking indicator
- Reporting current situation of Emergency, and weather information of KMA(Korea Meteorological Administration), and traffic information of TIC(Traffic Information Center)

○ Disaster on-site Action Information Support

In the outbreak of a disaster, the disaster prevention organizations in the front line like fire stations and brachs swiftly turn out to the sites. On-site Action Information Support functions to provide support in accurate disaster control and prevention decision making by providing them information on the disaster situation and related offices before they arrive on site. These functions are as follows:

- Transmit Order of response and Dispatch Paper provision
- Disaster on-site information(disaster location and situation) transmission
- Disaster location and shortest route indicator
- Provision of Information on fire fighting objects and facilities
- PDA Emergency operations information support

○ Related Offices Information Connection

With the many changes and complication of our cities, the information from fire organization are no longer enough to response to disasters. The Emergency Rescue System is built to interact and share real-time information with the disaster prevention organizations in gathering latest information. In addition, a solid framework for the fire prevention system was set by building a synchronous dispatch system with the related offices. Its major functions are as follows:

- Real-time utilization of weather information from the KMA
- Linkage with the City Gas pipe lines and situation information of Gas accident
- Dispatch in connection with the Daegu City Environmental department, KEPCO(Korea Electronic Power Corporation), KGS(Korea Gas Safety Corporation)
- Connection with the TBN(Traffic Broadcasting Network)'s road situation information
- Display of TIC's traffic supervisory camera

○ Administration Information Management

In order for integrated management and administration of diverse information which are used as major data by prevention administrations including information management on facilities such as subjects of rescue and fire fighting water, disaster information and fire operation information. The administration system is as follows:

- Fire fighting Objects's information management
- Information management of Fire engine and equipment
- Information management on people who must be wirelessly paged
- Fire statistics & analysis information management

- Information management of civil appeals administration
- Training on Board with Objects's information

2.2 Geographic Information System Architecture

The Daegu Fire Geographic Information System is composed of two-dimensional and three-dimensional geographic information in order to maximize its use in disaster management and has three parts, Emergency control geographic information, satellite imagery information and map editing <Figure 2>.

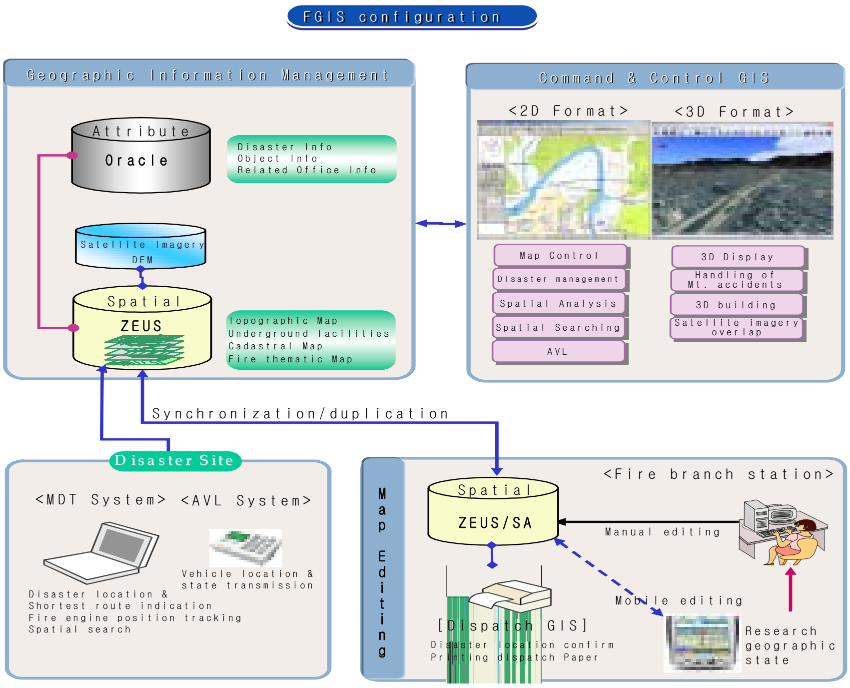


Figure 2. Fire Geographic Information System Configuration

○ Command & Control geographic information management

By using topography and facilities information based on basic data such as the digital map and satellite imagery photographs, the geographic information system supports the management and decision making of fire dispatchers during the entire process beginning from the initial stage of a disaster such as finding the location of the reporter and deciding on the area of disaster to the termination stage.

○ Satellite imagery information management

In order to complement the limits of digital maps and provide a more complete geographic information to the disaster management personnel, a database containing 1m resolution Ikonos satellite imagery photographs of inner-city Daegu and 2.5 resolution Spot satellite imagery photographs of outer-Daegu was built. In addition, to provide three-dimensional geographic information, a DEM(Digital Elevation Model) database was built. Services using such satellite imagery information include analysis of the best mountain-climbing route that can be used in case of mountain climbing accidents, 3D building modeling for three-dimensional training sessions in buildings and analysis on the spread of dangerous substances based on climate information.

○ Map-editing management

As a function to keep geographic information data on roads and buildings up to date, the editor in a fire station or branch station edits the data using the map-editing program when there is a topographical change in the precinct. Also, through synchronization and duplication phases, the consistency of information in the geographic information server at the fire headquarter and the geographic information terminal database at the fire branch station is maintained.

2.3 Geographic Information Database Architecture

The Fire Department established geographic information data on the western and northern regions in 1998 and operated a pilot system. In 1999, it built a full-fledged geographic information data on the entire city of Daegu. Maps have a significant impact on decision-making in disaster management and therefore are relatively accurate, use the latest distance data and undergo a verification process where each piece of information is checked. They have been built to ease the tension in the eyes of the fire dispatcher who has to monitor the geographic information 24 hours a day and gathering information through the system has been simplified <Table 1>.

Table 1. Fire Geographic Information Database

Category		Description	Distance	Provided by	Note
Base Map	Basic	contours, rivers, cadastral, facilities, buildings etc	1:500,1:1,000 Base map 1:500 land use map NGIS 1:5,000	Daegu City (Information Unit)	
	Roads	main roads, supplemental roads, small roads, alleys, center lines etc	1:500,1:1,000 Base map NGIS 1:5,000	〃	
Fire Them-atic Map	Fire facilities map	objects, fire fighting water, dangerous facilities, precinct etc	1:500 Base map	·	Self-built
	Lot map	lot numbers	Map of formal land price	Daegu City (Land Register Unit)	
	Related offices	related heavy-equipment companies, hospitals, police station etc	1:500 Base map	·	Self-built
	City gas	pipe lines, pressure device etc	1:1,000	Daegu City (Information Unit)	
	Underground facilities map	water supply, drainage, telecom lines etc	1:500 Base map	〃	
Aerial photograph		rivers and mountains region	1:5,000	〃	
Satellite imagery		entire city of Daegu	Ikonos, Spot	Purchased	·

3. Application

FGIS was established for the sole purpose responding disaster. In order to minimize the loss of lives and property damages, it must always be accurate and swift. Furthermore, convenience is an essential element for the tired personnel who are always at work 24 hours a day. The requests of the users have been reflected into the system and it has been developed through completely business analysis, overcoming the previous manual operation system.

3.1 Requests of Fire Geographic Information Users

GIS has been designed to enhance convenience of workers and considering the scalability such as a future connection with related offices; its design is flexible and open in accordance with the national standard.

○ Acquisition of Swift Positional Information
- Swift indication of the location of the caller and disaster area
- Facility map view control and swift scale of map changes

○ Accurate Positional Information
- Contains topographical information such as new roads, buildings and lots
- Positional information based on largely scale data(1:500,1:1,000)

○ Intimate Positional Information
- Easy-to-read and easy-to-see information
- Reality descriptions of mountains and rivers

○ Effective interface with disaster information
- Real-time operation of map with disaster information
- Changes in disaster location and area
- Swift search of facilities related to fire operations including topographic information and fire fighting property that need to rescued
- Effective acquisition and utilization of area information(road, building, public office, dangerous article etc.)

3.2 Command & Control Geographic Information System

This system has been in operation since 1999 by the 119 Command & Control Center and has taken into consideration the requests of the users mentioned above. The major procedure of this system begins with the indication of the caller in a case of disaster and when the personnel(fire dispatcher) decides on the point of disaster, the fire fighting team situated in the nearest vicinity is selected automatically and dispatched to the disaster area. The system provides real-time disaster information such as indicating the point of disaster on the map until it is terminated and different spatial information. Such operation requires major functions such as indication of the caller's position, disaster location management, spatial search and regional information analysis, overlap of aerial photographs and satellite imagery and vehicle tracking.

○ 119 Emergency caller Location Indication

This function swiftly finds the location of the 119 emergency caller who uses wire phones or mobile phones(SKT, KTF, LGT) on the map through the Ani/Ali(Automatic Number Identification/Automatic Location Identification) module of the CTI, shows and manages the address or location of the caller on the map.

○ Disaster location Management

This function swiftly decides on the disaster point and automatically searches for the nearest fire fighting team in the area. Furthermore it shows any movement of changes in the disaster point and the disaster management area may be adjusted, connected real-time with the disaster management operation until the case is terminated.

○ Spatial Search and Regional Information Analysis

The system has a spatial search function that swiftly easily searches for building names, addresses and facilities, and provide fire dispatcher with various information on nearby hospitals, heavy equipment, related offices, gasoline station and fire fighting water(hydrant) based on spatial analysis. In particular, with its real-time connection with the pipe lines and situation information of the Daegu City Gas, a swiftly collaborative response and information support system was constructed.

○ Overlapping Aerial Photographs and Satellite Imagery Photographs

A more reality map has been designed by overlapping image data of scanned aerial photographs and the database on images of 1m resolution Ikonos imagery and 2.5m high-resolution Spot satellite imagery photographs, overcoming the limits of a numerical map and enhancing readability.

○ Fire Engine Location Tracking Function

This function receives the location information of the GPS receiver attached to fire engines through the fire UHF network and shows the location of the vehicle real-time. It leads the fire engines to the disaster area swiftly and accurately even in complicated and narrow roads. Also it makes more easy to command a fire fighting operation by arranging appropriate fire troops.

3.3 Satellite Imagery Information System

In order to complement the limits of numerical maps and provide a more complete geographic information to fire dispatcher, a database containing 1m resolution Ikonos satellite imagery photographs of inner-city Daegu and 2.5 resolution Spot satellite imagery photographs of outer-Daegu was built. In addition, to provide three-dimensional geographic information, a DEM database was built. Services using such satellite imagery information include analysis of the best mountain-climbing route that can be used in case of mountain climbing accidents, 3D building modeling for three-dimensional training sessions in buildings and analysis on the spread of dangerous chemicals based on real-time weather information of KMA.

3.4 Map Editing System

For swift and accurate information delivery of the caller, personnel and dispatched fire fighters, topographical and regional information must always be updated. However, due to limitation of the time and expense required to update a digital map, maintenance of regional information such as the current names of buildings is difficult. To overcome such obstacles, FGIS researches regional information within the precincts of each fire station and branch station, apply any changes and keep the topographical information on new roads and buildings always up-to-date. Its main features are editing functions such as input, modification and deleting of topographical information like roads and buildings and attributed information like building names, and also has additional features of spatial search question and analysis.

4. Improvements and Future Development

The application of geographic information to fire business has greatly improved the operations but its effect was most significant in enhancing the speed and efficiency of fire services by its 119 caller locating function and automatic acquisition of regional information. The situation prior to the establishment of the Fire Geographic Information System clearly explains its impact.

4.1 Past of 119 Emergency Rescue System

○ Inability to gather location information swiftly

In order to acquire information about a disaster i.e. its location, fire dispatcher had to have a long conversation with the excited 119 caller, and this made it impossible to provide fire services to callers who could not communicated.

○ Waste of fire troops

The mischievous 119 calls by children and adults led to unnecessary dispatch of fire fighters, and bring a decrease of available fire fighters in case of an emergency. Furthermore, this became a cause of considerable stress to the fire fighters.

○ Unscientific fire service and difficulty in information provision

Fire dispatcher have to plan fire troops by referring to data on geographical position of the disaster and status of fire fighting equipment in possession by the fire forces and a table of organization, and then give the order of dispatch. However unscientific process method rely on fire dispatcher's past experience had many problems such as slowly dispatch. Also, disaster location that was delivered to fire troops were transmitted in voice signals through the fire UHF wireless network, but due to network failures (interruption, cut offs, busy signals due to limited call routes) produced repetitive messages and weighted fire dispatcher with a load of work.

○ Deficiency of regional information and sharing a related office's information

Information necessary in fire operations such as the amount of water available and information on buildings, underground facilities and nearby hospitals were difficult to acquire and even if there were such data, it had to be searched for manually and taken a lot of time. Also, disaster such as gas explosion require cooperation with related offices (city gas, KGS etc.) but the only way to request their help exchanged a message by using wire lines, and simultaneous dispatch was difficult.

4.2 Improvements

○ Integrated disaster management system in the entire city of Daegu

The 119 emergency call registration and management of disasters operated by fire stations unified into fire headquarter and more systemized. This brought about a slim down of staffs and a cut down on the budget.

○ Minimization of the waste of fire troops

The results of the statistics of the number of 119 calls and mischievous phone calls are as in <Table 2>. Comparing the rate of mischievous calls in 1998 before the system was built and 2003 after the system was built, a remarkable decrease(about 70%) has been recorded and is still on the decline <Figure 3>. This means that through the system, the needless dispatch of fire forces has been minimized and the overall number of calls have also gradually decreased(27%), lightening the work load of fire dispatcher and troops.

Table 2. Number of 119 calls & mischievous calls

Category		Total calls	Mischievous calls	Rate(%)
Pre	1998	777,061	577,905	83.9
	1999	766,040	643,042	74.4
Post	2000	642,232	238,293	37.1
	2001	654,587	218,893	33.4
	2002	581,513	108,730	18.7
	2003	553,882	76,849	13.9

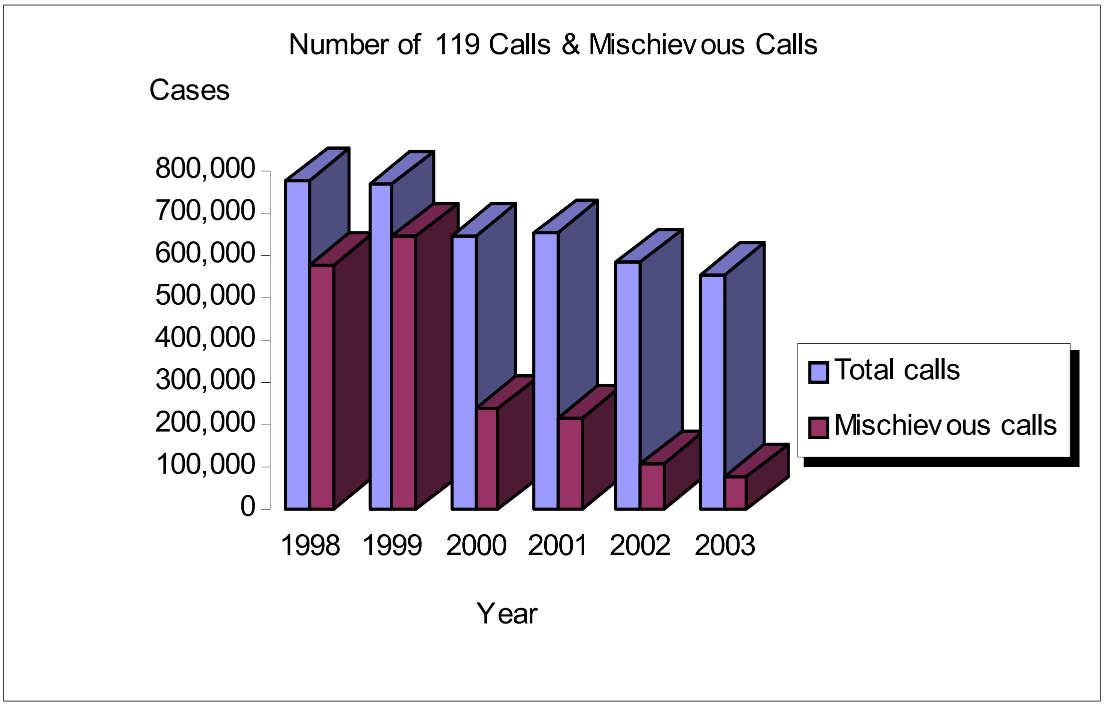


Figure 3. Trend of number of 119 calls & mischievous calls

○ Maximization of Fire Services

By providing disaster information utilizing the spatial information of the Geographic Information System to fire dispatcher who had to rely on their past experience to locate the disaster or plan a dispatch, the call registration time and the response time has greatly shortened, enhancing the initial responsive capacity of fire fighters. According to fire statistics, prior to the system, it normally took 2 to 5 minutes for fire dispatcher to locate the disaster based on the descriptions provided by the caller, but after the system, the caller's telephone number and location is indicated automatically(about 3 seconds) and took only about 40 seconds for the personnel to find the disaster location. In particular, the location information immensely contributed the fire services to 119 emergency callers who were not able to communicate.

The system also automatically planned out the most appropriate fire troops by location spatial search and a table of fire organization, and the dispatch paper with map of disaster area and information can help fire troops to response rapidly. The fire statistics report that in case of a fire, it took an average of 7 minutes(nationwide) from the time of 119 call registration to the time the fire troops arrived at the disaster site, but with the system, that time was shortened to 4 to 5 minutes.

4.3. Future Developments

The utilization of spatial information in disaster management has not only brought about great improvements, it is also enhancing the quality of fire service to our people. However, due to the fact that different organizations manage spatial information, it is in fact, difficult to establish a system that allows everyone to share up-to-date information swiftly. To resolve this problem, the central government should consider managing spatial information in relation to disaster. FGIS has taken this possibility into consideration and has connected the Daegu City Gas(pipelines, situation information) and KMA, and this year is striving to connect with the Emergency Medical Information Center(1339) for acquisition of hospital information.

Based on the recent rapid progress in computers and telecommunication technology, the system that was focused on preparation and response and recovery will be converted into prevention focused such as the disaster forecast and prediction simulation system easily. This prevents any possible disasters and even in the case of occurrence; it will swiftly response it in the initial stage. In particular, if the satellite video imagery is provided real-time, it will not only be possible to perceive a disaster but also an effective control by real-time monitoring about on-site. Related technology such as ubiquitous and telematics are the foundations upon which an on-site response information system can be established so that the Fire Command & Control Center can acquire real-time disaster information(moving picture and situation of on-site, facility of related fire activities etc.)

Therefore, the continued improvement of FGIS will lead to a high-tech three-dimensional disaster prevention system and with a swifter and more systemized management of prevention, preparation, response and recovery, advanced fire services will be available to our people.

5. Conclusion

The Fire Emergency Rescue System is the most important system among those that must be operated reliably and effectively. In particular, the geographic information system, which generally deals with spatial information such as a disaster location, requires latest and accurate data and possesses a variety of functions such as swift information management in connection with disaster-related information.

Before the FGIS at Daegu City Fire Department was established, it was difficult to acquire swiftly location of disaster on-site, there was an unnecessary waste of fire fighting forces and heavy work loads. Also, fire service could not be provided efficiently because the absence of regional information and manual connection with related offices(KEPCO, city gas etc.).

However, by the application of geographic data to fire operations, fire service has improved considerably. In particular, with quick finding of 119 emergency call locations and acquisition of regional information, the fire fighter forces are operated efficiently and an enhancement of service quality to the people has been achieved. In other words, the major effects of the system are as follows: First, the integrated emergency response system for the entire city of Daegu furnished by unifying the response system that was processed separately by each fire station before, disaster management has become not only systemized by also a labor cuts and budget decreases.

Second, the needless dispatch of fire forces has been decreased. In other words, after the system was built there was a significant decrease(70%) of mischievous phone calls compared to the time before the system was in effect, and it is still on the decline, minimizing needless dispatch of fire forces. Also, the total 119 calls have also gradually decreased(27%), lightening the work load of command & control center.

Third, maximization of service quality enhancement has been achieved. Prior to the system, locating a disaster point or dispatching fire troops depended on the individual expertise of fire dispatchers but by providing disaster information with the geographic information system the total time required to register a call and time to dispatch has shortened noticeably, increasing initial response capacity. In particular, this system has proved effective when the caller was not able to communicate over the telephone, thereby contributing to the enhancement of fire service quality.

The slogan “Prevent disaster and practice safety” is the winner of the Grand Prize in the slogan competition held by NEMA last June. It depicts that prevention of disasters should hold priority over others and it should be practiced in our daily lives. As a lot of spatial information is utilized in disaster prevention, the system will continue to improve and fire services become more advanced. However, the system must be established and developed to further focus on prevention measures in the terms of forecast, prediction and recovery simulation.

REFERENCES

Daegu Metropolitan City Fire department Headquarter, 2004, "Design paper of 1 1 9 Emergency Rescue System"

International Exposition on Government Innovation, 2004, Official Directory B-2

Ministry of Government Administration and Affairs, 2004, An Annual Report of Disasters in 2003

SPATIAL DATA INFRASTRUCTURE FOR DISASTER MANAGEMENT IN THE US

Alan R. Stevens

International Program Director
US Federal Geographic Data Committee
Global Spatial Data Infrastructure Secretariat
590 National Center, USGS
Reston, Virginia 20191, USA
+703-648-5119
astevens@gsdi.gov

ABSTRACT

The confidence that citizens have in their governance and its ability to make reliable everyday decisions as well as efforts to avert future tragedies might improve by understanding the role that geographic information and related spatial technologies play in bringing order to the chaos. Moreover, these technologies relate to the application of geographic data and information into the day-to-day decision making as well as directly assisting government and industry planning for homeland security, critical infrastructure assurance, and other public health and safety challenges.

The orderly application of these data and techniques requires the investment in a spatial data infrastructure at the local to national levels and partnerships among the governmental units, NGOs, academia, and the private sector.

Geography is the Common Language

Cities, provinces, nations, and the world are largely built and can be described in layers. Beneath ground one finds the bedrock, soils, aquifers, sewers, subways, gas pipe lines, transmission lines, etc. In the middle we might find streets and highways, land ownership, political boundaries, hydrography, water and waste treatment plants, hazardous dumps/pipelines, building footprints, farmland, forests, deserts, and a multitude of infrastructure that evolve over time. We also have several cultural layers of significance like demography, housing quality, poverty, pollution, etc. Above one might find the air quality, the atmosphere, and the planes that fly over. If a disaster disrupts any or all of these, it involves hundreds of federal, state, local and private groups with separate knowledge, jurisdiction and interest in these layers. No one group alone has all the data needed to do the job or to coordinate with others in performing critical tasks. Geography provides the common language and reference system for all response and recovery efforts.

I am not here today to tell you that geographic information and geographic information systems (GIS) are the keys to disaster prevention and remediation. That fact is well established. A common framework is critical. Agreements among those that collect, process, archive, and distribute disparate geospatial information do so using common standards and interoperable systems and techniquesand share as much as possible via the web. It is essential that, when resource managers try to integrate these disparate data sets, for whatever reason, they fit together vertically and horizontally.

Without a common framework there is no way to quickly tie together the essential information used to coordinate any unified response. A unified framework and base information have been and will continue to be critical to emergency managers and government officials responsible for response and recovery efforts regardless of the type of disaster. Imagine the confusion if the separate elements of information (roads/highways, sewer lines, water supply, gas lines, electrical transmission, building foot prints, land tenure, subways, toxic wastes, etc.) in a dense urban setting were available but in separate formats, collected via different standards, and with different reliability and at resolutions.

Spatial Data Infrastructure (SDI) what is it?

The single most important element to the success of any emergency response operation is the human contribution. Beyond that, standards for data quality and access become time critical. What are these critical ingredients to a successful emergency operation requiring geospatial data and information? They correspond to the components of a National Spatial Data Infrastructure (NSDI.)

GEODATA the actual geospatial data and information collected, processed, archived and potentially distributed by multiple agencies/organizations to meet disparate mission needs. It can be property ownership, political boundaries, land use/land cover, transmission lines, transportation/energy grids, geology, soils, surface and groundwater hydrology, demography, disease vectors, economic service areas, and many more.

META DATA standardized data elements that describe the data (content, quality, condition, resolution, scale, time of collection, other times it was collected, areas of coverage, ownership, and other characteristics of the actual data)

- o Permits structured search and comparison of data without having to spend the time examining the data itself.
- o Potential users can compare similar data collected and held by multiple organizations in one sitting and make a studied opinion as to which data best fits the user's needs.
- o Provides the end user with adequate information to take the data and use it in an appropriate context

FRAMEWORK

- o The base layers of data that most users agree is the base information that they will key their data to will most likely be different from location to location
- o Mechanisms for identifying and describing the data using features, attributes and attribute values
- o Mechanisms for updating the data periodically without complete recollection
- o Interactions among organizations for data collection and sharing

CLEARINGHOUSE A place for me to go to find out who has what data

- o Each ministry may have a clearinghouse for its data
- o Need to point to the data held by others
- o Supports uniform, distributed search through a single user interface
- o Either allows user to obtain data directly or directs user to clearinghouse worldwide where data may be obtained
- o May or may not allow a user to actually get the data

STANDARDS created and accepted locally, nationally and globally

- o Less important to build your own standards
- o More important to agree to use those standards promulgated by the

International Standards Organization (ISO)

- o Participate in and contribute to your national standard organization.
- o Promote additions/modifications to standards that facilitate your ministry's data holdings through your national standards organization.

PARTNERSHIPS fabric that allows all of this to happen efficiently and effectively

- o To identify policy barriers and recommend practices and policies to overcome these barriers
- o To reach agreements as to who is the best data stewards for the principal data sets
- o Promote data sharing
- o Reduces duplication costs of collecting the same data several times
- o Extends local/national/global capabilities in technology, skills, and sharing

What if ....?

It is bad enough to have to deal with one disaster. Not having access to data and information that can be fully and rapidly integrated is another disaster.

Without common standards and interoperable practices, many of the emergency services, relief ministries, media, NGOs, academia, and private companies would have to generate their own views of the effected area(s) to remediate the effects of any disaster and its aftermath. The goal of a National Spatial Data infrastructure (NSDI) is to allow these groups to communicate, collaborate and leverage disparate assets and specialists in real time with a maximum of efficiency and effectiveness.

One Model

The United States has one model for the building of a National Spatial Data Infrastructure (NSDI), but it is only one model. What works well in the US may not work in other nations. There are several success stories, but there are lessons to be learned from those things that need improvement in the US model.

In the early 1990s the USA established a Federal Geographic Data Committee (FGDC.) Its goal is to promote and establish an NSDI. The responsibility was assigned to the Secretary of the Department of the Interior. In the US the Department of the Interior is responsible largely for managing the public lands of the federal government. It is not similar to many nations in which the Ministry of the Interior means the federal police. The FGDC is administratively assigned to the US Geological Survey (USGS), but it facilitates the work of the Secretary of the Interior.

Today the FGDC is really two entities. On the one hand, it is a staff of about 26 people assigned or detailed to the USGS. Their job is to facilitate the work the Secretary of the Interior to build an NSDI. On the other hand, the real answer is that the FGDC is an intergovernmental committee made up of 19 federal agencies who have come together to build the NSDI.

- o Department of the Interior (co-chair)
- o Office of Management and Budget (Co-chair)
- o Department of Agriculture
- o Department of Defense
- o Department of Energy
- o Health and Human Services
- o Housing and Urban Development
- o Department of Justice
- o Department of State
- o Department of Transportation
- o Environmental Protection Agency
- o Federal Emergency Management Agency
- o Library of Congress
- o NASA
- o Archives
- o Department of Commerce
- o National Science Foundation
- o Tennessee Valley Authority
- o General Services Administration

Functions of the FGDC

Over the years and currently, FGDC's mission includes collaboration to identify institutional barriers for the components of the NSDI eg. Policies that inhibit sharing data and identifying one ministry to be responsible for a data type. After identifying the barriers, the committee works to recommend new policies that will remove these barriers and facilitate the building of an NSDI.

The FGDC also discusses, evaluates, and recommends the most effective ways to collect, process, archive, and distribute geospatial data and information. Ideally this leads to recommending data stewards -- the one best agency/ministry to collect, process and archive a given type of data. It makes little business sense for several ministries to collect the same data. It is duplicative and wasteful, particularly when governments have limited resources to support critical programs.

Another major task is to reach consensus on base framework data and mechanisms for update. The US has agreed on 7 framework data layers.

- o Transportation
- o Hydrography
- o Elevation
- o Cadastral
- o Political boundaries
- o Geodetic control
- o Ortho-imagery

For good reasons, it is unlikely that all nations or governmental components will agree on the base framework data layers. Framework data is often considered that data commonly found on maps. It is only important that your NSDI body reach consensus as to the base data layers.

Framework does not stop at identifying the base data layers. It involves a feature-based model; permanent and unique feature identification codes; reference to modern horizontal and vertical geodetic datums; seamless integrated data for adjacent or overlapping geographic areas; and it reaches into the development of the metadata model. It also has operational aspects to include transactional changes; access to previous data versions; and allows for location of data from and through the Geospatial One-Stop portal.

Agreement of metadata development and standards is another critical component of the NSDI mission. Metadata is really data about the data. It typically tells one something about the data scale, resolution, time of collection, coverage, other times the steward collected the same data, etc. It allows a user to quickly review multiple sources of data and decide which data set best fits his or her application without having to spend considerable time reviewing each data set. The metadata standard, among other things, identifies the number and types of data fields to be included in the metadata. Frequently, data providers balk at having to fill in all data fields because of the alleged amount of time required. The US metadata model calls for 22 data fields. However, it allows data stewards to fill in 8 critical fields for it to be considered fully metadata compliant.

Yet another task assigned to the NSDI is promoting clearinghouse development. The clearinghouse is a decentralized system of servers located on the internet that contain field-level descriptions of available digital spatial data. The metadata facilitate query and consistent presentation across multiple participating sites. The Clearinghouse functions as a detailed catalog service with support for links to spatial data and browse graphics. Clearinghouse sites are encouraged to provide hypertext linkages within their metadata entries that enable users to directly download the digital data set in one or more formats. Where digital data are too large to be made available through the Internet or the data products are made available for sale, linkage to an order form can be provided in lieu of a data set. Through this model, clearinghouse metadata provides low-cost advertising for providers of spatial data, both non-commercial and commercial, to potential customers via the Internet.

Incentives

Providing policies to over come barriers is important. Frequently, however, using policy is viewed by participants as forcing compliance. Another route is to cajole others into compliance by providing incentives for their full participation. The US model has developed the Community Agreements Program (CAP) Grants. The CAP provides seed funds to engage organizations in building components of the NSDI, which can include metadata documentation, national standards development and implementation, clearinghouse and web mapping, and framework development, and collaboration. The CAP is open to all U. S. organizations and seeks new participants annually. With the goal of GIS infrastructure development, the CAP program does not support GIS startups, data collection, or data purchases. Annually the NSDI allocates between $300,000 to $1,500,000 USD toward the program.

Where is the NSDI currently?

Since it started the NSDI has been successful in:

o Gathering high level support through three completely different political administrations

- o Recommending and receiving policy encouragement
- o Building an elaborate network of partnerships reaching beyond the purely federal structure into states, NGO, academia, the private sector, and communities
- o Major player in the national and international standards organizations for data standards development
- o A partner with the Open GIS Consortium (OGC) and the private sector in interoperability specifications promulgation
- o An interrelated global network of 277 clearinghouse nodes is available for users
- o Open policy for federal spatial data sharing
- o Major contributions to the development of a Global Spatial Data Infrastructure
- o Many more noteworthy accomplishments

Homeland Security Working Group

The Federal Geographic Data Committee's Homeland Security Working Group ensures that the National Spatial Data Infrastructure supports the preparation for, prevention of, protection against, response to, and recovery from (1) threats to the nation's population centers and critical infrastructure that are of natural, accidental, terrorist, or criminal origin and (2)related adverse events.

The working group has regular participation from the Departments of Agriculture, Commerce, Defense, Energy, Homeland Security, the Interior, and Transportation; the Environmental Protection Agency, Federal Communications Commission, National Aeronautics and Space Administration, and National Capital Planning Commission; and the National States Geographic Information Council.

One initiative within working group is map symbology: Use of different map symbols for the same information slows and degrades communication, especially when many organizations need to work together. The working group is compiling a set of standard map symbols to support homeland security applications, with initial efforts concentrating on emergency response. The community review of the first draft of the symbols closed in January; these symbols can be viewed through http://www.fgdc.gov/HSWG (case sensitive). Revised symbols and the working group's response to comments from the community review will be available during the summer of 2004. The group plans to submit the symbols for formal adoption through the FGDC and ANSI INCITS L1 standards processes.

Policy support:

The working group developed guidelines that provide procedures to identify sensitive information content of geospatial data sets. Should such content be identified, the guidelines help organizations decide what access to provide to such data sets and still protect sensitive information content. The geospatial data community's use of a common approach to identify data sets that have sensitive content and to provide appropriate access to such data will increase the effectiveness of individual organization's actions.

The white paper Homeland Security and Geographic Information Systems, available on the group's web site, describes how geographic information system and mapping technologies can help save lives and protect property.

For more information one can visit the working group's web site at http://www.fgdc.gov/fgdc/homeland/index.html, or contact Michael Domaratz, Co-Chair, U.S. Geological Survey, phone (703)648-4434 or email mdomarat@usgs.gov

What's next?

While it is clear that the FGDC and NSDI have come a long way in the last 14 years, there is still much to do. If the goal is to build a truly national spatial data infrastructure, it not sufficient to have federal stakeholders exclusively in the decision making positions. Typically, when a disaster hits a region, resource and emergency managers want working level data. It is not sufficient to have fully integrated data at the federal and state level only. It is essential to have city/community scale information fully integrated as well.

Geospatial One-Stop

Geospatial Information One-Stop was instituted as a part of the President's Management Agenda under the heading of Expanding E-Government. It focuses on moving to a citizen-centered way of providing information and services to constituents. Geospatial Information One-Stop will provide a geographic component for use in all E-Government activities. Geographic Information (GI) is a national asset, an essential requirement for just about every program at every level of government, and one of the key elements underlying the President's Management Reform Agenda.

Using the available tools and technical capabilities of e-government, we can expedite and improve the business of government, reform government management, eliminate redundancy, save money, increase agency productivity gains from technology, and provide citizen-centered information and services. Geospatial information is one of our most important and underutilized tools. To implement the President's e-government objectives, we need to focus on geospatial information.

Geospatial One-Stop is an important element in the overall national effort of achieving a common vision of accurate, accessible geospatial information for the nation that will transform the way government at all levels addresses the increasingly complex issues of the 21st century by using geographic information to:

Simplify and unify business processes

Respond to the information needs of citizens, producers and users of GI everywhere

Integrate and engage the coordinated effort of government at all levels, and the private sector

Align resources and foster co-investment in GI among all levels of government

Collect data once and uses it many times

Provide easy and secure access 24/7 to current, accurate GI

Enable timely and improved decision making for Homeland Security

A National Standards Effort

While specific applications of geographic data vary greatly, users have a recurring need for seven basic themes of data that are the foundation or framework for almost all applications. Framework data are characterized by a minimal number of attributes needed to identify and describe features such that they can form the foundation or framework of many applications.

To ensure its standards efforts were not viewed only from a 'federal prospective', Geospatial One-Stop, has aggressively solicited national input from all stakeholders through its Board of Directors, the FGDC and their various outreach vehicles (newsletters, conferences, email lists and existing GIS working groups). This effort was successful in encouraging involvement from the Board's constituents with Over 500 participants from Federal, State, local, tribal and the private sector sighing up to help write, review or comment on the developing draft standards.

The Portal

The portal is essentially a window or funnel to locate and view distributed geospatial data holdings from key communities or stakeholders such as the federal, state, local, tribal, acedemic and private sectors. This data coupled with geospatial data integration and services can be used to support the businesss of government with enhanced decesion making tools.

The centerpiece of the Geospatial One Stop strategy is geodata.gov . The initial implementation of the Portal designed is to facilitate publishing and searching of metadata, and enable viewing live web mapping services, is known as GeoData.Gov, and will feature intergovernmental and private sector collaboration. The National Map, led by the U.S. Geological Survey, as a starting point. It will allows easy searches for existing and planned data with a goal of "two clicks to content."

The portal is based on a distributed architecture allowing all the data to remain with the data owner. However, metadata from NSDI Clearinghouse Nodes will be harvested and copied to a centralized database for faster search and retrival. In addition a central inventory of live web map services will be published in the portal and made available for viewing.

The portal is an Internet-based organizational umbrella for federal agency data categories or channels addressing geospatial activities. Data Category teams or 'stewards' from the communities of interest are forming to actively seek and monitor available thematic geospatial data products and services, assess and promote premier thematic data products, and showcase real success stories.

Future Directions

In 2003 the FGDC staff was charged by the FGDC Steering Committee to pursue the NSDI Future Directions Initiative. The purpose of the initiative was to craft a national geospatial strategy and implementation plan to further the development of the NSDI. There were several reasons for looking at a new plan at this time:

The last FGDC/NSDI strategies were formulated in 1994 and 1997,

The organization had put out a major effort for the Geospatial One-Stop that identified several needs,

The staff Director position had transitioned from John Moeller to Ivan DeLoatch, Questions had surfaced about the interrelationships among the NSDI, Geospatial One-Stop, and the National Map, and

The high level interest in Homeland Security.

It is clear that the NSDI has come a long way in forging partnerships and streamlining mechanisms for data availability. However, one of the serious shortcomings has been that federal stakeholders exercise principal management and control. Others like states, counties, communities, NGOs, the private sector, etc. are encouraged to play significant roles. None-the-less, the federal establishment controls the vote.

If one is to build a truly national spatial data infrastructure, one needs to provide fully integrated geospatial data all the way to the ground and under it. It is critical to involve all those that collect, process, archive, use, and distribute such data in the decision making process.

Ideas and perspectives for the Future Directions Initiative were solicited and collected through interviews, Coordination Group meetings, workshops, forums, staff meetings, and conferences held between December 2003 and April 2004. Out of this a vision was formulated.

Vision Current and accurate geospatial data will be available to contribute locally, nationally, and globally to economic growth, environmental quality, sustainability, and social progress.

Three key actions were articulated repeatedly Forging Partnerships with Purpose, Making Framework Real, and Communicating the Message -- providing the structure for the goals, objectives and the strategic action plans of this initiative.

Forging Partnerships with Purpose -- It is critical to engage people that deal with digital data at all levels from the smallest to largest scales. Mechanisms need to be developed to put city/county/utility practitioners on the FGDC Steering Committee with a full voting rights. Their concerns for things like policy barriers, and intellectual property rights need to be treated along with the concerns for those that deal with smaller-scale data. A new governance model needs to be developed. Toward this end the following actions were identified.

By 2006, a governance structure that includes representatives of all stakeholder groups guides the development of the NSDI.

By 2005, options for restructuring the FGDC to make it more effective and inclusive are identified, evaluated and acted upon.

By 2005, agreements are in place to facilitate participation of the private sector and utility industry in building the NSDI.

By 2006, twenty tribes are engaged and contributing to the development of the NSDI.

By 2006, fifty state coordinating councils are in place and routinely contributing to the governance of the NSDI.

By 2006, ten non-geospatial national organizations are engaged in and contributing to the NSDI.

Making Framework Real As in forging new partnerships, data managers from states, communities, utilities need to be involved in day-to-day decision making for building a truly national SDI. Framework categories defined by the federal sector at scales of 1:25,000 and smaller, probably have little meaning to public and private utilities. Similarly, data standards defined by the federal sector probably do not co-line with cities and counties/provinces. Accordingly if the US is to build a NSDI truly to-the-ground, definitions for standards and framework need to be reconsidered. The following actions were defined here:

By 2007, nationally coordinated programs that include collection, documentation, access, and utilization of data are in place for generating the framework data themes.

By 2005, American National Standards (ANS) for framework data themes are approved, adopted, and implemented.

By 2005, FGDC member organizations use FGDCaccepted metadata standards and publish to the Geospatial One-Stop portal.

By 2006, consensus-based standards and Web protocols for access to framework data are adopted and used by Federal, state and local agencies.

By 2006, 50 percent of the 133 urban areas have data for all framework themes.

By 2008, American National Standards (ANS) for additional data themes of national significance as identified in revised OMB Circular A-16 are adopted by the Federal departments and independent agencies.

Communicating the Message To become recognized across the nation as the primary source for the availability and use of reliable spatial data. The following tasks and timelines have been generated for this goal:

By 2007, the NSDI is recognized across the nation as the primary mechanism for assuring access to reliable geospatial data.

By 2005, a comprehensive business case that demonstrates the value of geographic data to government, business and academia is compiled and articulated.

By 2005, a strategic communications plan is developed and implemented.

By 2006, training and education programs are in place to support implementation of framework standards and national initiatives to develop the NSDI.

Conclusion

The US Federal Geographic Data Committee and the National Spatial Data Infrastructure have evolved for the last 14 years. The movement has lived through three completely different political administrations because it promotes better governance doing things better, faster, cheaper. 'Collect it once; use it many times.' Making data available in a usable form to governments and the public. To live through three different administrations, is not an accident. The right policy makers needed to play leadership roles in NSDI development. The over-arching message stays the same, but the focus changes slightly to meet the needs of policy makers of the day.

This is just the US model. It is only one example. What works here may not work in other nations. The over all goal needs to fit the needs of your nation. In convincing Ministry level people, however, I am certain that they will resonate with making government more efficient and effective.

Disaster GIS Program in Japan

Kaoru Takara

Disaster Prevention research Institute, Kyoto University,
Uji 611-0011, Kyoto, Japan

Abstract

This paper describes recent GIS policies and direction of applications to disaster problems in Japan. Japanese strategy to realize "e-Government" is introduced as the long-term plan for the establishment of National Spatial Data Infrastructures (NSDI) and the popularization of GIS, followed by the GIS Action Program 2002-2005. This is a basis of the "e-Japan Priority Policy Plan" implemented strongly by the IT (information and telecommunication) Strategic Headquarters established in 2000. This paper also briefly introduces Japan's research and development policy, mainly focusing on GIS applications to disaster issues, which are summarized by the Subdivision on R&D Planning and Evaluation, Council for Science and Technology, the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

Introduction

The Japanese government has formulated a long-term planfor the establishment of national spatial data infrastructures and the popularization of GIS at the Liaison Conference of GIS-Related Government Ministries and Agencies on December 18, 1996. After that, the government has been taking some actions as indicated in Table 1.

It is notable that this series of actions was initiated immediately after the serious disaster at the Kobe earthquake on January 17, 1995. At this event of enormous damage, the governmental bodies were not able to make use of spatial information effectively. On the basis of feeling responsible for this, as well as of the rapid change of information and communication technology at that time, the government urgently formulated the long-term plan.

Table 1: GIS-related actions taken by the Japanese government

Date (Y.M.D)Action	Action
1996.12.18	Long-term plan for the establishment of national spatial data infrastructures and the popularization of GIS
1999.03.30	National Spatial Data Infrastructure Standard and Consolidation Plan
2000.10.06	Agreement on the national policy development of consolidation and popularization of GIS
2002.02.20	GIS Action Program 2002-2005
2002.02.20	Review of the 1996 long-term plan
2003.04.17	Guideline of National Spatial Information Dissemination by the Government
2003.06.26	Table of quality evaluation for spatial data
2004.04.07	Follow-up report and amendments of GIS Action Program 2002-2005
2004.06.08	Compilation of Q&A's for the Guideline of National Spatial Information Dissemination by the Government

Table 1: GIS-related actions taken by the Japanese governmentDate (Y.M.D)Action1996.12.18Long-term plan for the establishment of national spatial data infrastructures and the popularization of GIS1999.03.30National Spatial Data Infrastructure Standard and Consolidation Plan2000.10.06Agreement on the national policy development of consolidation and popularization of GIS2002.02.20GIS Action Program 2002-20052002.02.20Review of the 1996 long-term plan2003.04.17Guideline of National Spatial Information Dissemination by the Government2003.06.26Table of quality evaluation for spatial data2004.04.07Follow-up report and amendments of GIS Action Program 2002-20052004.06.08Compilation of Q&A's for the Guideline of National Spatial Information Dissemination by the Government

GIS-Related Actions in Japan

This section briefly summarizes the GIS-related governmental actions listed in Table 1.

(1) Long-term plan for the establishment of national spatial data

infrastructures and the popularization of GIS

The Liaison Conference of GIS-Related Government Ministries and Agencies formulated the long-term plan for the establishment of national spatial data infrastructures and the popularization of GIS. The first three-year term (1996-1998) was supposed to be the formation of basic infrastructures and the following items were considered:

- Standardization of National Spatial Data Infrastructure (NSDI) and its metadata
- Consolidation of digitized imageries
- Construction of advanced clearinghouse
- Clarification of the division of the roles of national and local governmental bodies and private sectors for the consolidation and updating of NSDI
- Development of the plan of consolidation of NSDI
- Arrangements of systems for the promotion of consolidation and interavailability
- Arrangements of various surrounding systems for promoting GIS

The second term (1999-2001) was for extending the basic systems formed in the first term, with strong cooperation with local governmental bodies and private sectors and popularizing the GIS nationwide. Considered were:

- Further consolidation of NSDI and metadata
- Popularization and dissemination of NSDI
- Updating of NSDI
- Technical supports to local governments and private sectors

In order to accelerate these second-term activities, the government made agreement with the related ministries and agencies on the national policy development of consolidation and popularization of GIS, considering role-sharing arrangement and cooperation between public and private sectors and international rules about GIS.

(2) GIS Action Program 2002-2005

Reviewing the above-mentioned six-year experience for the NSDI, the Japanese government has established the GIS Action Program 2002-2005, which is now under implementation. The Program is an action plan for realizing the improvement of domestic quality of life by GIS.

In parallel with this, setting up IT (information and telecommunication) Strategic Headquarters in 2000, the Japanese government established the "e-Japan Priority Policy Plan"in order:

- To form the world's most advanced information and telecommunication systems,
- To promote education and learning for human resources development,
- To expand electronic commerce, etc.,
- To comprehensively promote digitization of the administration and to activate the usage of IT technologies in public sectors,
- To assure security and reliability of the advanced IT networks, and
- To deal with cross-section themes.

Obviously this e-Japan Plan is strongly related to the GIS Action Program, which is thus supported by all the ministries and agencies as a program that can drive forward national IT strategy.

The GIS Action Program 2002-2005 aims:

- To enhance the efficiency, quickness and quality of public services in various administration sectors,
- To create new business models in the industry and to lead new greater employment opportunities
- To provide less-expensive and high-quality services in various sectors for general public by effective utilization of superior GIS contents by many people when the IT world is realized.

For this aim, the Plan defines two roles of the central government: the development of infrastructure environments (promoting consolidation and circulation of NDSI that is owned by the government and popularization of GIS) and the utilization of GIS by the government itself. It also sets two goals:

Goal 1: Overall accomplishment of infrastructure environment for GIS utilization

Goal 2: Effective utilization of GIS to realize the efficiency of administration and high-quality services in each sector in the government

The priority areas that the government is supposed to promote are:

(1) Standardization of NDSI and promotion of the efficiency of administration by the government's proactive GIS utilization,

(2) Setting up systems and guidelines in terms of the promotion of digitization

and circulation of geographic information,

(3) Promotion of digitization and provision of geographic information including:

- Promotion of digitization and provision of spatial data infrastructure,
- Promotion of digitization and provision of basic spatial data and digital imageries, and
- Consolidation of data circulation environments by upgrading and expanding clearinghouses, etc.

(4) Support of full-scale GIS popularization

- Cooperation with local government and support to region,
- Creation of new services and industries based on GIS and collaboration with related technologies, etc., and
- More activities for popularization of GIS and promotion of international cooperation

(5) Realization of more efficient and higher-quality administration services

- Collaboration with procedures of electronic application/notification, etc., and
- Realization of high-quality administration services using GIS

(6) Follow-up activities for other plans

Though the Action Program does not explicitly include disaster management applications, it is recognized that the second point of (5): Realization of high-quality administration services using GIS deals with disaster prevention/management, traffic safety, education, forestry and fishery, and the environments, etc.

GIS in Research and Development for Emergency and Disaster Management

The Subdivision on Research and Development (R&D) Planning and Evaluation, Council for Science and Technology, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) formulated the Research and development Policy for Disaster Reduction in March 2003. This section briefly introduces the Policy, mainly focusing on GIS applications to disaster issues, referring the document translated into English from Japanese.

Research and development (R&D) policies for disaster reduction in Japan were based on the "Basic Plan for Research and Development on Disaster Prevention (December

1993)" before the Kobe Earthquake (or the Great Hanshin-Awaji Earthquake Disaster) in January 1995. Review of the R&D plans at that time developed the "Promotion of Research and Development on Earthquake Disaster Prevention Based on the Great Hanshin-Awaji Earthquake (Committee on Policy Matters of Council for Science and Technology, May 1995)." In addition, the Science and Technology Agency (STA) proposed a research guideline for the earthquake disaster reduction in the "Effective R&D Organization for Earthquake Disaster Prevention Platform (The Council for Aeronautics, Electronics and Other Advanced Technologies, September 1997)."

Earthquake observations and prediction of volcanic eruptions have been conducted according to "The New Program of Research and Observation for Earthquake Prediction (August 1998)" and "The Sixth Program for Prediction of Volcanic Eruptions (August 1998)," both based on Geodesy Council (currently Subdivision on Geodesy and Geophysics, Council for Science and Technology).

In January 2001, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) was established by unifying the former Ministry of Education, Science, Sports and Culture (Monbusho) and the Science and Technology Agency (STA), due to the reorganization of the administrative bodies of Japan. At the same time, the Council for Science and Technology Policy (CSTP), Cabinet Office and the Council for Science and Technology (CST), MEXT were inaugurated as committees to handle key policies proposed by the Cabinet Office.

Based on the key strategies included in the "The Science and Technology Basic Plan (March 2001)", the CSTP, Cabinet Office developed the "Promotion Strategies by Sector (September 2001)" that indicated the research areas of emphasis, objectives of R&D, and basic promotion policies for each sector. The objectives of one of such strategies, the Promotion Strategies for infrastructure, include the development of: mechanismsof abnormal natural phenomena, real-time response systems, plans for reducing catastrophic damage in congested cities, protection systems for centralfunctions and cultural assets, and highly advanced disaster management support systems, etc.

Subdivision on R&D Planning and Evaluation (part of the CST within MEXT) has been conducting research and reviews of key tasks necessary for the R&D plan for the sectors that mainly fall under MEXT's responsibilities. In the area of disaster reduction, Committee on Research and Development for Disaster Reduction (hereafter referred to as "Committee" in short) was established under the Branch. The Committee has discussed the R&D promotion policy for the next 5 years, as a part of a whole vision of the next decade. As well as taking the "The Science and Technology Basic Plan" and the "The Promotion Strategies by Sector" into account, the Committee has also performed an analysisof current research conditions through questionnaire and interviews from institutionsthat are engaged in disaster reduction studies. The analysis has brought discussions on key tasks and promotion issues of R&D of disaster reduction research areas that MEXT should focus on.

Since the "Basic Plan for Research and Development on Disaster Prevention" was established nine years ago, there have been several events that influenced the future directions. These events include: the Great Hanshin-Awaji Earthquake that threatened the basis of urban disaster preparedness; the volcanic eruption of Miyakejima (July 2000) that emphasized the importance of long-term evacuation, recovery, and reconstruction plans; and the terrorism at the World Trade Centre in New York (September 2001) that raised the awareness for crisis management and urban safety separately from that raised by the Great Hanshin-Awaji Earthquake Disaster. In the past nine years, R&D for disaster reduction has also been affected by remarkable social changes, including aging of the society, the advancement of information technology, increasing environmental problems, and the change in public attitude seen by increasing numbers of volunteers and NPO's for disaster management.

Based on this background, hereafter, the second half of this paper describes the GIS applications to disaster prevention, reduction and management.

GIS applications considered in key subjects for Disaster Reduction R&D

The R&D Policy on Disaster Reduction (March 2003) enumerated key subjects for R&D in its Chapter II as [I] High Priority Areas in R&D and [II] Key Research and Development Subjects in Individual Fields.

[I] High Priority Areas in R&D

Enumerated as High Priority Areas in R&D, are:

(a) Development of Disaster Mitigation Strategies (Risk Management, etc.)
(b) Upgrading Hazard Maps (Identifying regional disaster risks)
(c) Understanding Failure Processes of Structures in Earthquakes
(d) Seismic Assessment and Retrofit of Existing Structures
(e) Optimization of Recovery and Reconstruction Processes
(f) Intensive Utilization of Advanced Technology for Disaster Reduction
(g) Disaster Information Management

Among these, GIS is mentioned in items (b) and (g). According to the Report of Council for Science and Technology (2003), Major R&D Tasks for the item (b) Upgrading Hazard Maps are:

- Development, dissemination and improvement of hazard maps (flood, debris disasters, storm surge, earthquake disasters, tsunami disasters, volcanic disasters, etc.)

· Development of disaster database

· Risk assessment and visualization using GIS and IT tools.

Hazard maps are very useful for local residents and visitors to assess the safety of given areas, to know vulnerable zones, and to make judgments for appropriate actions in the event of disasters. Local governments are in charge of establishing their disaster management plans, on which basis various disaster countermeasures are practiced. While there is an increasing number of local governments that develop their hazard maps, but they have not yet reached a satisfactory level. As a result, many regional disaster management plans are being developed without considering appropriate scenarios for vulnerable zones, conditions of damage occurrence, and extent of damaged areas. In such cases, local residents are unable to clearly define practical actions such as evacuation plan. It makes the effectiveness of disaster measures limited. Recent developments have made it possible to generate more detailed maps using GIS on the basis of accomplishments in understanding disaster mechanisms and development of disaster databases. Such systems should be utilized to create hazard maps that are comprehensible to local residents. Advanced and sophisticated hazard maps will allow municipalities and local residents to understand the risk of various disasters. It will help improve disaster mitigation and response capabilities of local communities.

Major R&D Tasks for the item (g) Disaster Information Management are:

· Development of information systems for appropriate collection, analysis and dissemination of disaster information.

· Research on standardization and integration of disaster information.

· Integration of disaster information and GIS.

· Development of real-time information dissemination system.

Sharing accurate information is essential in emergency under disasters. It will enable appropriate decision-making and help preventing undue expansion of disasters. It is an urgent issue to realize for national and local governments, police and fire departments, and lifelinesectors to share accurate information. Disaster information includes various classes such as real time information, damage states immediately following the event, disaster relief aids during recovery and reconstruction, etc.Since they are provided at different stages of disaster processes, it is important to collect, analyze, and disseminate information according to an appropriate time frame that range from the time of breakout to the recovery and reconstruction phase. Confusions provoked by rumors are also a matter of concern. Local governments, private sectors and local associations should be devised with a mechanism by which to share and disseminate accurate disaster informationin order to avoid confusions generated by false information. Rapid social evolutions such as shift to aged society as well as rapid globalization have caused increase in the number of handicapped people and non-Japanese speaking people. Means to provide information to those people is also required. Using advanced information technologies for collecting real time flood and earthquake data will be useful for disaster reduction. R&D in this direction should be promoted.

[II] Key Research and Development Subjects in Individual Fields.

Individual fields defined in CST (2003) are:

(1) Meteorological disasters

- Rain/Snow storm
- Wind storm
- Flood and inundation disasters
- Debris disasters
- Storm surge
- Disasters caused by climate changes

(2) Geophysical disasters

- Earthquake disasters
- Earthquake-induced geotechnical disasters
- Tsunami disasters
- Volcanic disasters

(3) Construction of disaster resilient society

- Urban fire
- Complex urban disasters
- Covering overall disaster areas

For these individual fields, key R&D subjects are summarized in the following categories:

(a) Compilation of real world data
(b) Database development
(c) Understanding disaster mechanisms

(d) Assessment of disasters
(e) Enhancement of disaster reduction capabilities

GIS plays significant roles to compile real world data (a), of course. In the item (b) Database development, it is recognized that development of databases is important both for disaster risk management and policy-making and planning for post-disaster recovery and reconstruction. Databases should be multi-functional, combined with GIS application. They should also be available from overseas including developing countries. Various kinds of databases and its management systems can be considered. Disaster oriented GIS should be developed to be ready for free and random data updating, by organizing a systematic descriptive methods and developing application software.

For the item (c) Understanding disaster mechanisms, we need various kinds of observation data as well as microscopic and macroscopic models of disaster-prone areas. Field surveys, remote sensing and socio-economical data are necessary to develop GIS-based information support systems that will assist evaluate performance of risk management models for the areas. Spatial information and its analysis are also keys to (d) Assessment of disasters. Hazard-related maps with high accuracy with the aid of GIS are important.

GIS also has a potential to play significant roles in (e) Enhancement of disaster reduction capabilities. GIS can be used for risk management systems and can be connected to the Internet for the use of the general public. Web-GIS based risk management systems could be realized in near future. It is expected to develop multi-dimensional GIS systems that contain general information of the areas concerned, hazard sources and geophysical conditions and enable two-way communication between municipal administration and citizens.

In order to construct disaster resilient society, there are research needs such as:

- Emergency-response-based risk management support systems to be developed by applying GIS.
- Pre-event policies including disaster simulation, disaster management systems, GIS-based support systems for urban planning against disasters, assistance for communities through coordination with local government and disaster preparedness plans of local communities.
- To develop and enhance GIS-based technologiesfor damage assessment, risk management, evacuation and rescue, and recovery and reconstruction.

Acknowledgments:

The author expresses sincere appreciation to Korea Research Institute for Human Settlements (KRIHS) for their kind invitation to the 9thInternational Seminar on GIS held at Seoul Education & Culture Center, Seoul, Korea, on September 8-9, 2004. He is grateful for the kind assistance provided by Mr. Jong-taek Park and Mr. Dong-Han Kim, GIS Research Center, KRIHS. He also appreciates the support of the Japanese Government, especially, by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Ministry of Land, Infrastructure and Transport (MLIT) and the Cabinet Office for providing various kinds of information relating to this article and presentation at the Seminar.

Strategies for Realizing GIS-based Disaster-free Territory

Young-Pyo Kim

Director and Senior Research Fellow
GIS Research Center
Korea Research Institute for Human Settlements
[ypkim@krihs.re.kr]

1. INTRODUCTION

Our society repeats the loss of human life and properties, and the recovery of those losses every year due to various disasters. It is impossible, with human forces alone, to perfectly prevent natural disasters, such as typhoons, floods, torrential rains, windstorms, tidal waves, heavy snowfall, drought, earthquakes, landslides, and human-caused disasters, such as fire, collapses of buildings, explosions, traffic accidents, forest fires, chemical, bio-logical and radiological accidents, as well as environmental pollution. However, the losses can be mitigated through a national level of study, effective plan and policy for the prevention, emergency measures, and recovery of disasters and accidents in advance.

The government, related organizations and experts, have exerted their utmost efforts to prepare comprehensive, scientific and analytic measures to protect nations and national land from many forms of disasters. However, still, even information management systems are not prepared yet, and further, the establishment of an effective policy on disaster prevention is not sufficient.

The rapid development of information integration and GIS analysis technology has offered an environment where data in a complex world can be managed, analyzed and simulated in a computerized environment. Also, it is used for a scientific spatial decision making support system.

Therefore, this paper seeks out the establishment of goals and strategies for realizing a disaster-free territory based on GIS, by applying a wide array of information integrations and GIS technology for the management of information on preventing disasters, decision making for solving problems concerning the current status of the prevention of disasters, and the establishment of safe territory for the prevention of disasters for effectively and rationally preparing for repetitively occurring disasters.

2. CONCEPT OF DISASTER-FREE TERRITORY

2.1 Emergency and Disaster

Before defining the concept of disaster-free territory, it is important to define several terms related to disaster. An emergency[2] is a course of events that endangers people, property or the environment.

A disaster can be variously classified according to standards, including the cause of disaster, the place of disaster, objects of disaster and direct or indirect effects of the disaster. In general, disasters are classified by natural disasters and human-caused disasters

A natural disaster means a loss incurred from natural phenomena, such as typhoon, flood, torrential rain, storm, tidal waves, heavy snowfall, drought, and earthquake. A human-caused disaster means an artificially made accident that brings forth physical loss, economic loss, or threatening to life in a relatively short time in a specific area, such as fire, collision, explosion, traffic accident, chemical, bio-logical and radiological accidents and environmental pollution accident.

In particular, the characteristics of disasters occurring in cities is that they are mutually linked. When a typhoon renders damages to big cities, where population and facilities are concentrated, it often accompanies the 2nd and the 3rd disastrous phenomena owing to the concentration of population and facilities and develops into various phenomena.

2.2 Emergency and Disaster Management

Disaster prevention is a series of procedures of preventing disasters in advance, mitigating the damage of disasters and pursuing harmoniously-made recovery at the close of disasters. Today, there are an increasing amount of 2nd and 3rd damage from disasters pursuant to natural disasters, which are more dangerous. Also, as human-caused disasters, such as fire, collision and explosion are increasing, the meaning of disasters is expanding, as to include a series of activities of minimizing disasters.

Disaster management can be classified by pre-disaster management for prevention made prior to the occurrence of disasters, emergency response and rescue, and post-disaster management for rehabilitation after disasters, on the basis of the point of time of the occurrence of disasters. The procedures of emergency and disaster management(EDM) are as follows.

---

2) Johnson, Russ. 2000. "GIS Technology for Disasters and Emergency Management", An ESRI White Paper. p.1.

① Planning

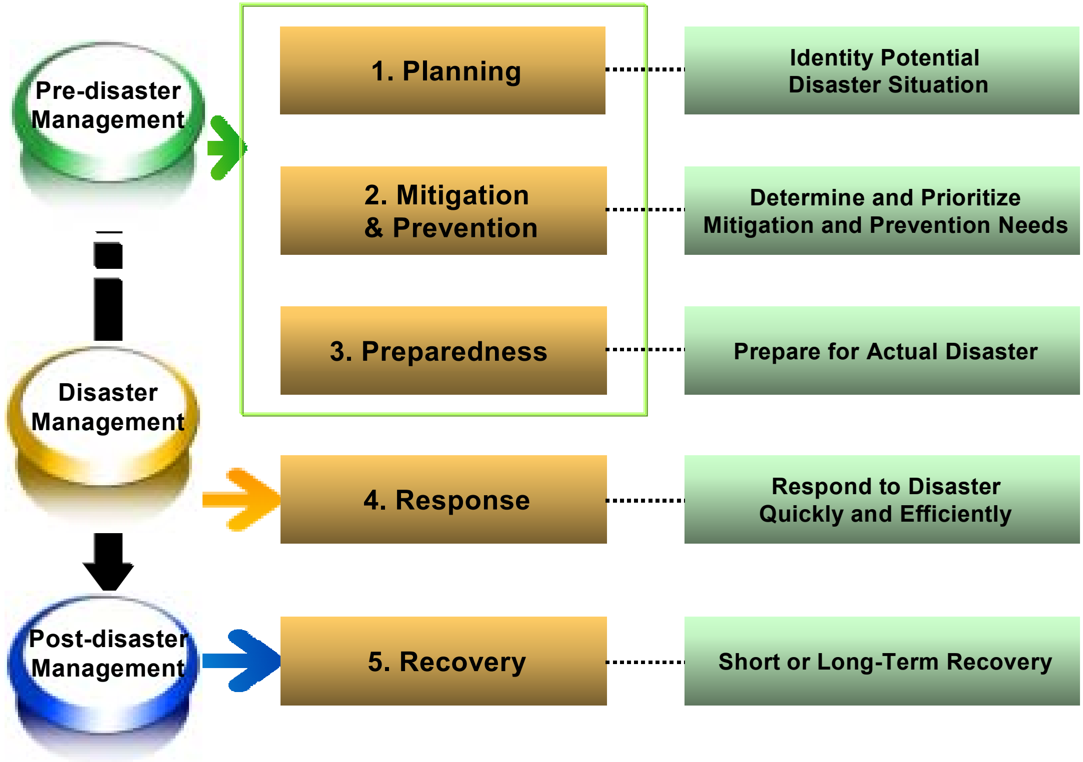
② Mitigation and Prevention

③ Preparedness

④ Response

⑤ Recovery

<Emergency and Disaster Management>



2.3 Disaster-free Territory

Disaster-free Territory(DfT) is defined as, in this paper, the safe and strong territory where we can preserve the environment and protect people's life and property from the various disasters. And DfT pursues six sigma[3] safety.

3. EMERGENCY AND DISASTER MANAGEMENT IN KOREA

3.1 Recent Disasters in Korea

3) Statistically six sigma means the frequency below 3.4 times of flaws out of 1 million trials.

In Korea, nearly 65% of the entire national land is comprised of mountains, and thus, it is highly possible to have disasters from floods of rivers around the lower parts of rivers, due to the rapid increase of outflow in the event of heavy rains within a short time. In 1998, Korea experienced disasters from floods caused by tremendous power of the typhoon "Yanni", and had 1.2 trillion Won of property losses. Also, the typhoon "Rusa" created 246 casualties and 5.1 trillion Won worth of property losses in 2002. Even in 2003, the typhoon "Maemi" caused 132 deaths and 4.7 trillion Won of property losses. The characteristics of recently occurring natural disasters are that damages are primarily caused by floods in summer, and they are repetitively occurring in especially specific areas. In addition, it cannot be overlooked that these kinds of disasters from floods can be expanded to be the 2nd disaster due to urbanization.

On the other hand, as industrialization and urbanization are speedily incarnated in Korea, facilities and structures become larger and higher, and are laid underground, however, much damage to human life has occurred due to poor construction and negligence of safety. Enlarged scale of human-caused disasters, including collapse of the Sung-Soo Bridge (1994), collapse of the Sam-Poong Department Store (1995) and the fire disaster in Daegu Subway(2003) have successively happened, and there has been more focus on the controlling of post-disasters rather than prior prevention. Only rough-and-ready management of disaster areas and unsystematic rehabilitation have been continued, whereas the fundamentals of disaster management, such as having comprehensive disaster prevention systems and plans for prevention, response and rehabilitation of disasters have been absent.

3.2 The Disaster Prevention Policy and System in Korea

1) Disasters Related Laws and Organizations

In Korea, up to May 2004, laws related to disaster prevention had been classified by 'Disaster Management Act' for human-caused disaster, 'Natural Disaster Countermeasure Act' for natural disasters, according to the cause of disaster. However, the former two acts were integrated into the new law, namely, 'Disaster and Safety Management Act', in June 2004. Based on the act, National Emergency Management Agency(NEMA) was established at the same time.

<Disasters Related Laws and Organizations>

Division	Natural Disaster	Human-caused Disaster
Related Law	Disaster and Safety Management Act (DSMA)	
	• Natural Disaster Countermeasures Act • Agricultural and Fishery Disaster Countermeasures Act	
Management Organization	National Emergency Management Agency (NEMA)	
	• Ministry of Agriculture and Forestry • Ministry of Maritime Affairs and Fisheries	
Controlling Committee	Central Safety Management Committee (Prime Minister)	

Problems of disaster prevention related policy are as follows:

- Centralized administrative characteristic and poor local financial conditions
- Shortage of expertise of disaster prevention
- Passive utilization of new technology (GIS, ICT)

2) Designated Zones and Districts Related to Disaster Prevention

The designation of local areas related to disaster prevention is to appoint regions and areas for preventing disasters in advance, targeting disaster prone areas in various laws, such as 'Natural Disaster Countermeasure Act', 'Construction Act', and 'National Land Planning Act'.

- Danger District, Special Disaster Area (Disaster and Safety Management Act)
- Disaster Danger District (Construction Act)
- Disaster Prevention Subzone, Fire Prevention Subzone (National Land Planning Act)
- Fire Warning Subzone (Fire-fighting Act)

Danger district covers areas not safe from natural phenomena, such as typhoons, floods, torrential rain, tidal waves, and heavy snowfall, and areas that can cause damage to people and properties and neighboring areas, including dangerous disaster prevention facilities. Danger areas are classified by 4 types of habitual flooding area : habitually flooded area, collapse danger area, old facilities area, and isolation danger area.

Considering the opinions of inhabitants, and situation of areas, danger levels are divided by three level, given the frequency of the occurrence of disaster, condition of damage, and degree of heavy rains.

As of 2003, a total 466 danger areas have been designated nationwide, and a total 2.4 trillion Won budget has been allotted for these areas. There are 357 habitually flooded areas, 53 collapse danger areas, 48 areas with old facilities, and 8 isolation danger areas.

3) Characteristics and Problems of Disaster Prevention Facilities

Disaster prevention facilities mean facilities with disaster preventive functions. They generally indicate facilities with active or passive measurements against disaster. The standards of division of disaster prevention facilities are as follows:

- Active disaster prevention facilities are to control the cause of disaster and effectively cope with already occurred disasters (bank, flood gate, drainpipe, retarding basin, erosion control systems, and dam)
- Passive disaster prevention facilities are facilities with possibilities of causing the 2nd disaster in the event of the destruction of facilities and facilities with little function of disaster prevention due to disaster (road and bridge, stone wall, and breast wall of rail way facilities)

Disaster prevention facilities, or urban facilities are defined in various laws, regulations, and rules. The design standard of disaster prevention facilities are not specific and only vaguely defined. In addition, the responsibility of planning, construction based on the standard of facility safety and post management lies unclear and monitoring systems are not prepared.

3.3 Disaster Information Management in Korea

Currently, the management of disaster has been concentrated on an information transmission system for measurement and rescue, in the event of the occurrence of a disaster, and the constitution of information on the occurrence possibility of a disaster is insufficient. The government does not officially produce maps of the occurrence of national land disaster, nor does it constitute a database on the possibility of the occurrence of a disaster. Moreover, as far as the NGIS constitution business is concerned, items related to disasters are all excluded.

The constitution of information supply and management systems of post-disasters are also not sufficient. As for unpredictable contingencies, damages related to that are rising, since there is no relevant prompt transmission system of informing disaster information through mass media or automatic alarming systems. In addition, performances on integrated management and computerization of disaster-related data are not appropriately prepared, and it is difficult to do integrated management since computerization works by type of disaster are dispersed by department, and there are still many works that are not yet computerized.

For the systematic prevention and the constitution of advanced national safety management information system that enables preparedness, prompt response, and rehabilitation of disaster, comprehensive systems are slated to be constituted by adopting the GIS system and the central safety management center and local safety management center and every municipality, county and district plan to disperse and share safety management information.

3.4 Information Technology Related to Disaster Prevention

The rapid development of information technology has offered an environment where data of the complex real world can be systematically managed, in particular, the GIS technology which enables management, analysis and simulation by integrating large amounts of space information, is used as a scientific spatial decision making support system in various sectors. In disaster prevention works, the GIS technology can be very usefully applied, since diverse decision making is necessary for precise forecasts and preparedness, by those the analysis and managing of spatial information related to many types of disasters should be made.

Recently, the development of 3D GIS technology that places virtual space similar to real space to a computer environment and can be combined easily with other high-tech information technology, such as GNSS (Global Navigation Satellite System), ITS (Intelligent Transport System) and SIIS (Satellite Imagery Information System) in disaster prevention sectors are pro-actively pursued.

Also, simulation technology on complex disastrous situations is considerably being developed as the operation of various data and analysis environment have developed. After modeling diverse components related to the occurrence of disasters such as hours, cost, environment and procedures, and then transforming these components into kinetic components, the technology can be used in coping with problems and effectively constituting disaster prevention systems by evaluating and understanding the model.

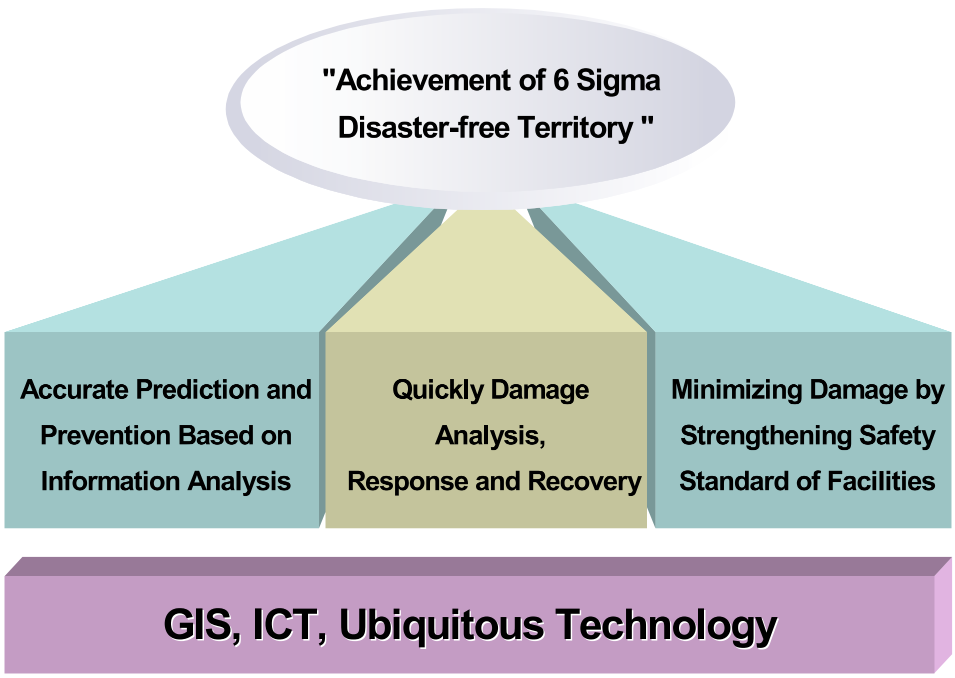
In addition, it is very meaningful to review the possibility of how to apply ubiquitous technology, which sets out as one of paradigms in the information communication industry to disaster prevention sectors. What the ubiquitous technology is aiming at is the realization of the 5-Any (Anytime, Anywhere, Anynetwork, Anydevice, and Anyservice). Anytime means the acquisition and activities of real-time information, and Anywhere means the freedom of environment, space and place. Anynetwork indicates an environment that network can be accessible anywhere, and Anydevice means the loading of ubiquitous technology to all portable devices. Anyservice supplies goods and services wanted anytime and anywhere. Since accurate forecast and measurements on the right time and space are important in disaster prevention operations, the effect of formulating a disaster prevention environment where the acquisition and transmission of real-time information, and speedy response and preparedness can be realizable by adopting ubiquitous technology to disaster prevention sectors.

4. TARGET FOR GIS-BASED DISASTER-FREE TERRITORY

To minimize the amount of damages from natural disasters and to constitute disaster-free territory which is disaster-resistant, disaster-free territory that enables comprehensive, scientific and analytic measurements should be established.

The realization of disaster-free territory is directly connected with not only people's lives and properties but also the environment. Thus, it would be effective to be implemented based on the GIS environment for enabling forecast and the preparation of measurements by accurate disaster prevention information in advance, under the target of, "Achievement of Six Sigma Disaster-free Territory". The trend of "Six Sigma Disaster-free Territory" aims at having a system that can perform flawless disaster prevention activities. It is to minimize forecast errors on the occurrence of disaster and to make safe territory where the loss of life and properties can be minimized.

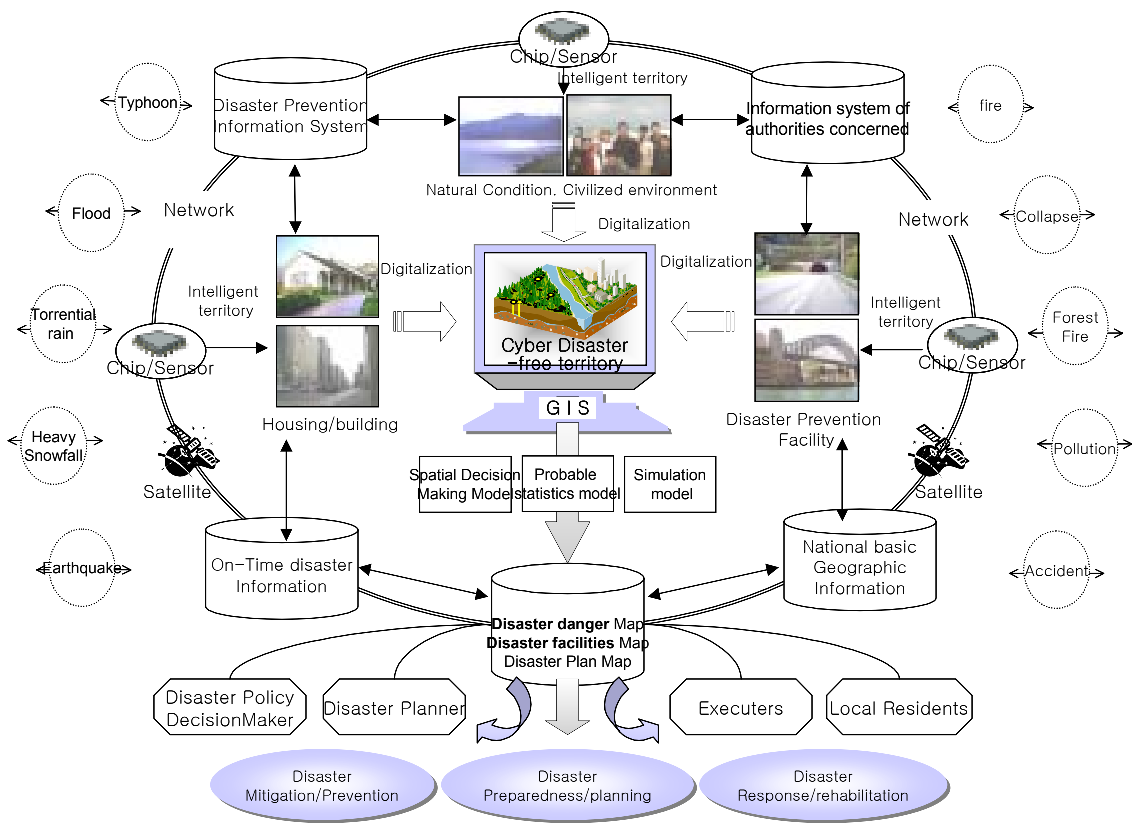
<Target for GIS-based Disaster-free Territory>



The new technology such as GIS, ICT, ubiquitous technology which are used in spatial decision making in diverse sectors, supports an environment where scientific and intelligent disaster-free territory can be attainable.

The concept of GIS-based disaster-free territory constituted under this objective is as shown in the following figure.

<Concept of GIS-based Disaster-free Territory>

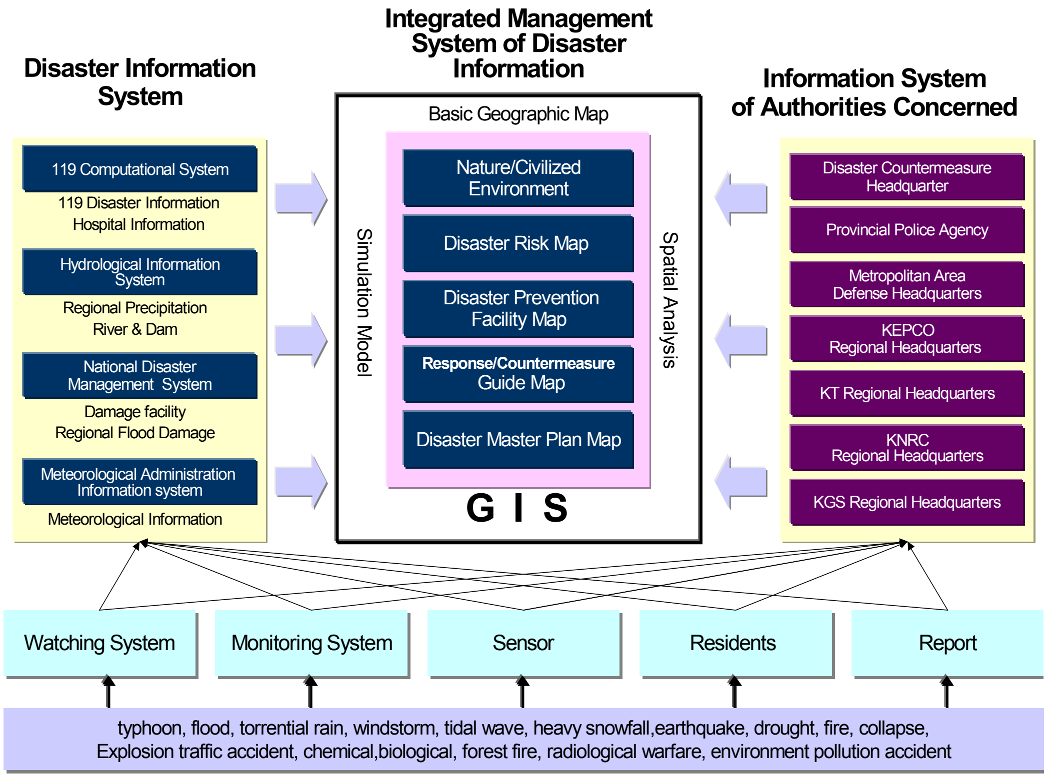


5. DIRECTIONS OF GIS-BASED DISASTER-FREE TERRITORY

5.1 Integrated Management of Disaster-free Territory Information

The first step in realizing safe land from disaster prevention lies in the constitution of accurate disaster prevention-related information and effective management. As the importance of disaster prevention has been emphasized, disaster prevention-related organizations and each local government are exerting all their might in the management of disaster prevention information. However, the information of disaster prevention that has been independently pursued can be used as effective information when it is integrated in the GIS environment.

<Integrated Management of DfT Information>

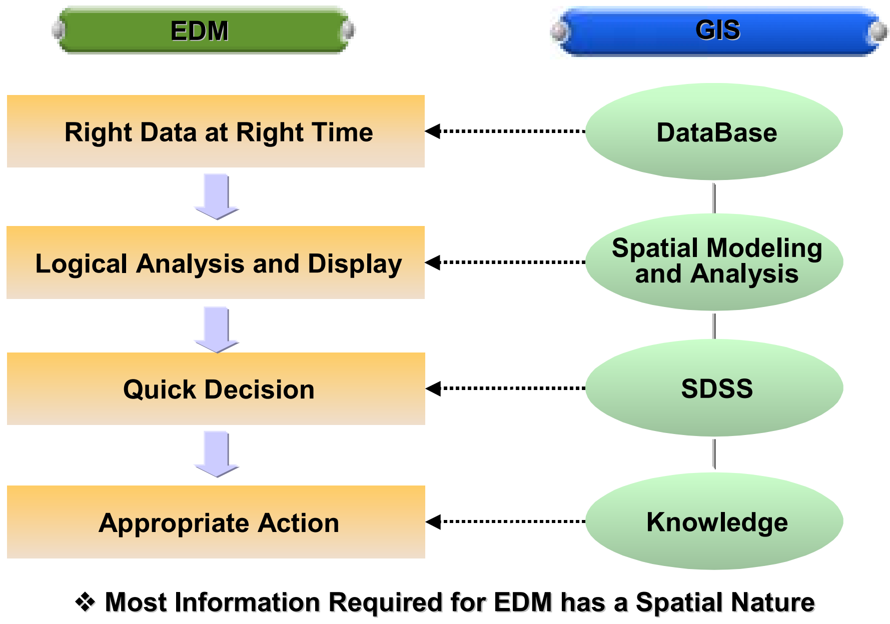


Given the characteristics of disasters, all-related conditions or facilities are linked to one another, and thus, damages are expanded. Therefore, disaster prevention information should be integrated and managed by being linked organically. Also, a system which disaster prevention information of neighboring local government, as well as other organizations, are able to use by being smoothly offered, should be prepared.

Furthermore, as for information needed for disaster-free territory operations, forecast information based on scrupulous information is important and time series information related to disaster should be managed. A system that synthetically manages information on the past, real-time and future forecasts necessary for spatial decision making for the preparation of disaster prevention planning and measurement should be implemented.

Also, for the acquisition and management of real-time and accurate information, new technologies should be adopted. In addition, since disaster-free territory operations are directly connected with national security, security facilities and major infrastructures, and fire and explosions of artificial facilities should be included and managed in disaster-free territory DB, in terms of security strategies.

<Usefulness of GIS Technology for EDM>



5.2 Base Formation for Disaster-free Territory through Digitalization of National Land

To stably and effectively perform disaster prevention operations that are performed in every land such as cities, rural villages, rivers, seashores and mountains, cyber disaster-free territories should be constituted by digitalizing real world of topography and social artificial environments. Cyber-geospace can be constituted by applying a variety of spatial information, such as topographic information and artificial satellite images to virtual buildings and 3D expression methods. By constituting virtual geospace similar to real world, comprised of a lay of lands, natural features on the earth, buildings and facilities in computers and the internet, all the infrastructure needed for disaster prevention activities can be offered. Also, it can be used as the 2nd territory, where management on the areas where past disasters have occurred, systematic planning expected in future, digital disaster prevention planning and policies by department can be performed in advance.

In the starting stage, the application of disaster prevention simulation targeting small-sized areas should be propelled, and in the stage of making the entire territory digitalized, the system that the effect of natural disasters to the entire territory can be simulated, should be established. Furthermore, the work of implementing the feature of real world into a computer environment shows large differences in digitalizing time and costs, according to how much level the similarity between reality and virtuality should be constituted, and thus, it should be made at a reasonable level.

5.3 Realization of Real-time Disaster Prevention Monitoring Systems through Intelligentialization of National Land

Currently, the development of information technology lays emphasis on ubiquitous computing technology, and the development of the Radio Frequency Identification(RFID), System on Chip(SoC), and the constitution of wireless network becomes the principle axis. Also, an intelligent environment where anyone can freely approach information, anytime and anywhere, is being pursued.

In disaster prevention operations that thoroughly manage temporal and spatial data, this kind of high-tech sensor technology can be applied for making real-time monitoring systems to the entire national land. It is like constituting an environment where every feature can give and take information like a living organism, by attaching electric chips or sensors to lay of the natural features on the earth, housing structures and various facilities. The territory can become intelligent by actively giving and taking disaster prevention state information while linking various disaster prevention facilities and disaster-related environments with wireless networks. Also, management, experts and residents can acquire real-time disaster prevention information anywhere and anytime.

If intelligent territory are constituted like this, ordinary disaster prevention management systems that enable real-time management of disaster prevention facilities, and the monitoring of an environmental state and exact forecasting of disasters, can be established.

6. STRATEGIES FOR GIS-BASED DISASTER-FREE TERRITORY

6.1 Systemization of Disaster (Prevention) Database

For prompt warning signaling and rescue in the event of disaster, information on the map of the area of the past occurrence of disasters, disaster-prone areas and disaster prevention facilities should be made as a database and systematically managed and offered.

Also, disaster information which has been independently managed by the authorities concerned should be integrated. Since various disaster information sporadically constituted in the past, should be integrated and managed organically with the GIS database, the standardization of data and transmission systems should be considered in designing database.

The disaster prevention information management systems for preventing disasters should be constituted as a database by simultaneously performing statistical analysis on information on the occurrence of disasters and spot investigation of land. The distribution of areas, types, seasonal changes of the past damages from floods, earthquakes, land slides should be thoroughly analyzed and built into a database by performing investigations on topography, geographical features, soil, ground and floodgates nationwide, and be managed by creating maps of disaster dangers through spatial analysis of all facets. Also, the way to use basic geographic information constituted by the national GIS(NGIS) and geographic information made by each authority concerned should be sought out. In additions, the disaster prevention database production projects should be adopted under the GIS umbrella.

Especially, by constituting information on disaster prevention and precisely grasping the distribution of dangerous places of the areas, disaster prevention facilities and whereabouts of activated existing materials and constituting them as database, decision makers and executors related to disaster prevention work and residents can be able to usefully avail the necessary information in starting prevention and emergent measurements against disasters.

6.2 Development of Disaster Simulation Models and Systems

One of the core components in the GIS-based disaster-free territory is supporting simulations on various situations of disaster prevention. Based on statistical data on established natural environment conditions, range of the past damages, situations of damages, information on diverse facilities, simulation models in the event of the occurrence of various disasters should be pro-actively developed.

To initiate disaster prevention simulations in a computerized environment, cyber-geospace that is similar to reality should be constituted. Since cyber-geospace constituted through the digitalization of real world, is capable of accepting all information on time, space and human levels, spatial simulations that can express and analyze conditions, such as natural disaster and human-caused disaster within the space can be realized.

Also, the development of disaster prevention simulation systems can be constituted by using computer game engines while using this cyber-geospace. Actually, as for the U.K., where 3.5 million people are expected to receive damaged by floods reaching 2080, the 3D virtual realty-based computer simulation game 'FloodRanger' has been developed and used for the preparation of flood preventing measures as one of the flood preventing projects of the Department of Trade and Industry (DTI). In a virtual space, the game 'FloodRanger', which manages cities for the coming 100 years, was applied with information such as 4 types of climate change models, actual amount of rain and tidal water and drainage capacity of land. Also, since it was created on the basis of an accurate disaster prevention scenario model, strategies for coping with floods on a real world were established. The DTI is expecting business effects of reducing trial and errors in the first test in a virtual world by using 'FloodRanger' ahead of starting the business that might require hundreds of pounds in a real world.

6.3 Realization of Disaster-free Territory Using Ubiquitous Technology

Forecasted and immediate responsed are important for disasters. Thus, information on right time and space should be freely used. By adopting ubiquitous technology, which is rapidly developing these days, to disaster prevention works, the intelligent transmission and use of national land information related to disaster prevention should be available.

In Korea, the range of national land is rather narrow, but there are various natural conditions and complex humanistic environments. Since there are many disasters occurring by region, disaster prevention fortress should be established for sensing and forecasting the status of disaster by linking intelligent land where sensors are attached to every features.

The development of ubiquitous technology is realizing situations that have been seen only in high-tech Sci-fi movies in a real world. Actually, systems that acquire real-time information by raising tiny sensors, such as smart dust, which is used by the University of California Berkeley, is in development. By using these sensor technologies, ordinary disaster prevention management systems, which enable real-time management of disaster prevention facilities and monitoring and forecasting of environment conditions, should be prepared.

Also, it fosters an environment where real-time disaster prevention information can be offered by sensor reactive systems attached to mobile phones or the PDA that executors or experts of disaster prevention and residents are always bringing with them, or even simple watches or necklaces.

6.4 Establishment of Disaster Prevention Master Plan

For implementing the GIS based disaster-free territory, above all, realizable 「Disaster Prevention Master Plan」 should be established.

In addition, the increase of investment in disaster prevention management R&D and fostering of human resources should be emphasized. Since poor investment on R&D in disaster prevention sectors, excessive budgets are consumed in losses and post-management, due to disaster. Therefore, an increase in investment on R&D in disaster management sectors should be augmented, and also experts on disaster prevention study and execution should be fostered.

For implementing successful GIS-based disaster-free territory, short-and-long term investment strategies should be established, and the way of securing funds should be prepared. To this goal, the uplift of acknowledgement on disaster prevention investments, as well as adjustment and securing of diverse tax, and expansion of public investments, should be considered. In addition, investments in the disaster prevention sectors should be expanded, as well as the way of investing budgets by setting up appropriate priority of business.

7. CONCLUSION

The world to come will be a ubiquitous world, where anyone can achieve information easily and rapidly, anytime, anywhere through an wireless network. The constitution of disaster-free territory for formulating safe life and environment must be established by real-time disaster prevention management and monitoring systems, through the systematic management of disaster prevention information, the constitution of cyber-geospace, the development of disaster prevention simulation model and the realization of intelligent territory.

To achieve six sigma disaster-free territory, the disaster related information should be acquisited and managed systematically. Also, new technology such as GIS, ICT, ubiquitous technology should be adopted actively and utilized positively. And it is necessary to construct evaluation system on performances and policy of disaster prevention. Especially for supporting those activities, research and development on disaster prevention have to be strengthened. In addition, the comprehensive disaster prevention plan should be established.

In the Great Learning, there is a phrase which says, "An ounce of prevention is worth a pound of cure (有備無患)". The phrase fits undoubtedly in the society which goes for the safe state. The construction of disaster-free territory should be made to lead to a safe environment and society for attaining six sigma, by mobilizing GIS and high-tech information communication technology.

REFERENCE

Comfort, Louis K. 1988. "Designing Policy for Action : The Emergency Management System", L. K. Comfort (ed.), Managing Disaster, Dorham, Duke University Press, North Carolina

McLaughlin, David. 1985. " A Framework for Integrated Emergency Management", Public Administration Review, Vol. 45(Special Issue)

Johnson, Russ. 2000. "GIS Technology for Disasters and Emergency Management", An ESRI White Paper.

Young-Pyo Kim, Shun-Hee Han, Mi-Jeong Kim. 2001. 「Cyber Territory Construction in Digital Age」. Kyonggi Korea : Korea Research Institute for Human Settlements

Young-Pyo Kim. 2003. "Cyber-geospace Construction toward the Ubiquitous World", 「KRIHS Policy Brief」. Kyonggi Korea : Korea Research Institute for Human Settlements