AN EARTHQUAKE EMERGENCY MANAGEMENT MODEL INTEGRATING REMOTE SENSING WITH GEOGRAPHIC INFORMATION SYSTEMS: LESSONS LEARNED FROM THE 1999 KOCAELI, TURKEY EARTHQUAKE

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A RESEARCH PAPER

Submitted to

THE GEOSCIENCES DEPARTMENT

In partial fulfillment of the
Requirements for the
Degree of

MASTER OF SCIENCE

GEOGRAPHY PROGRAM

February 2003

Directed by
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Abstract

An emergency management system integrating remote sensing and geographic information systems applied to emergency preparation, response, and recovery could have reduced casualties and damage after the August 17, 1999 Kocaeli, Turkey earthquake. Model system components include a horizontally and vertically distributed knowledge base, LIDAR 3D urban modeling, automatic feature extraction, hazard and vulnerability mapping, improved public presentations, damage detection, remote sensing and GIS in emergency coordination centers, mapping for emergency responders, tent city monitoring, and debris management.

Introduction

At 3:02 AM on Tuesday, August 17, 1999 a moment magnitude 7.4 earthquake struck northwestern Turkey. As of October 19, 1999 the Turkish government estimated the earthquake caused 17,127 deaths, 43,953 injuries, and created 250,000 homeless (United States Geological Survey, 2000). Approximately 214,000 residential structures and 30,500 business structures were damaged (RMS, 2000). The epicenter of the 45-second temblor was in the Kocaeli province, approximately 9 kilometers southeast of

Izmit. Most damage and deaths occurred in the towns of Yalova, Karamursel, Golcuk, Izmit, Adapazari, Duzce and the Avcilar district of Istanbul (Figure 1).

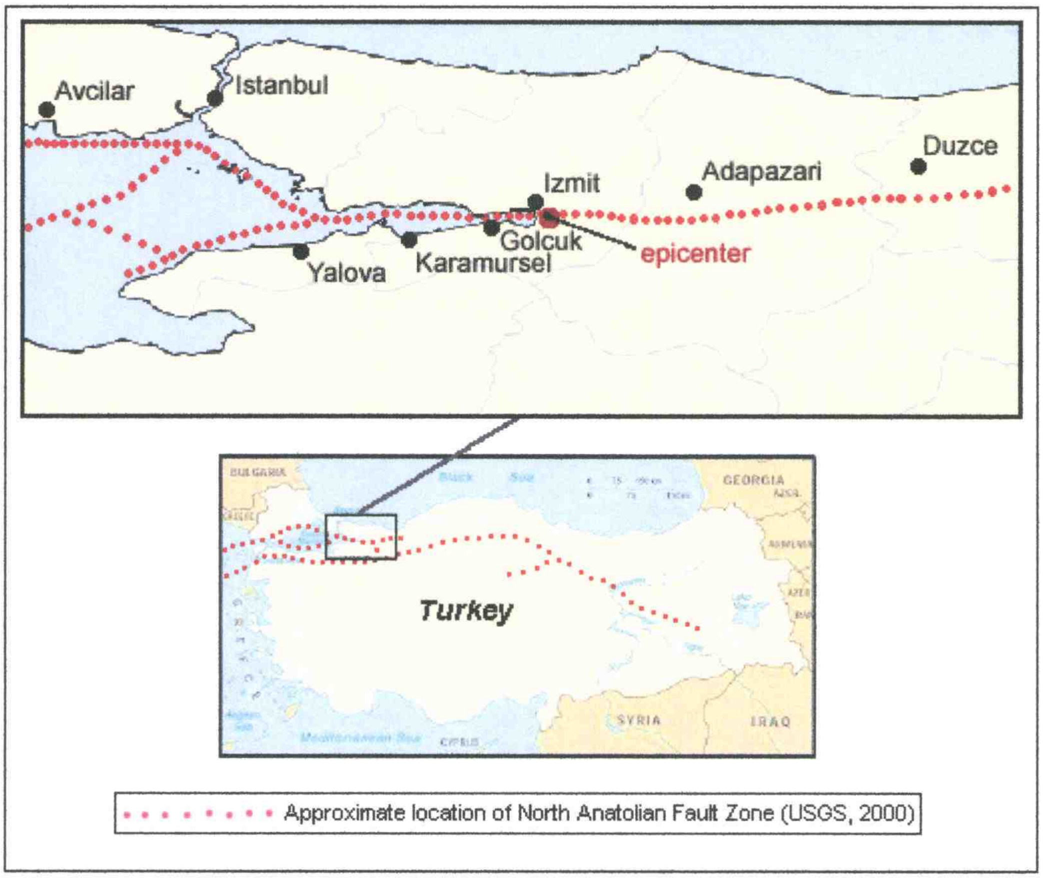


Figure 1 – Area affected by the Kocaeli earthquake

Search and rescue activities began at once and continued for eight days. Almost immediately informal groups of local volunteers searched the rubble for family members, neighbors, and strangers. But organized, coordinated emergency search and response was significantly slow in developing. In some locations there was no response from national or provincial public agencies for up to four days (Mitchell, 2000).

Several factors hindered government response. There were communication problems with affected areas, difficulties coordinating civilian and military response, inefficient information transfer mechanisms between government managers and rescue teams, a limited supply of maps for rescue workers, problems accurately locating damaged and searched buildings, and low technology levels in some emergency coordination centers.

Project Goals and Objectives

Technological advances in the fields of remote sensing and geographic information systems (GIS) have provided the tools necessary to create an efficient and effective system to prepare for, respond to, and recover from earthquakes. This paper describes a model system integrating remote sensing and GIS which could be used for earthquake emergency management, and infers how the system could have been used to reduce casualties and damage resulting from the 1999 Kocaeli, Turkey earthquake.

Project Rationale

The North Anatolian Fault Zone traverses northern Turkey (Figure 1). Devastating seismic events have been recorded along the entire zone since 29 A.D., and will continue far into the future (United States Geological Survey, 2000). Efforts to establish effective earthquake emergency management in Turkey are given impetus by the realization that, with the exception of an area a few miles south of Istanbul, the entire fault zone has experienced significant movement during the twentieth century. The probability of a magnitude 7 or greater earthquake occurring near Istanbul before the year 2032 has been estimated at 62±15% (Parsons, et al., 2000). In this historical context we cannot reasonably ask if Istanbul will experience a serious earthquake - the appropriate question is "Are we prepared?".

Remote sensing (RS) and GIS are enabling technologies which can be used to significantly reduce the human and financial cost of earthquakes and other types of natural and human-induced disasters, including wildfires, floods, droughts, hurricanes, and oil-spills. The technologies can be used to improve all phases of emergency management, including planning, preparation, response, and recovery. But we cannot wait until after a disaster strikes to enact a GIS/RS-based management system. To be effective the system must be designed, implemented, and tested before an emergency occurs.

Remote Sensing Emergency Management Applications

Remote sensing is the collection of information about a target without contact between the target and data-collection device (FEMA, 1997). As such, remote sensing data can be collected from a variety of platforms, including satellites, high or low-altitude aircraft, and ships at sea, each of which has its advantages and disadvantages. Data is gathered with passive systems such as optical photography, videography, and infrared, and active systems like RADAR, LIDAR, and sonar.

The most effective collection platform for a particular job depends on the area to be covered, required scale, type of data needed, and how quickly the imagery must be gathered. For instance, satellites can provide wide area overviews, but may not be able to provide imagery until days after a disaster. High-altitude aircraft imagery can cover wide areas, and can be captured quicker and more frequently than satellite imagery, but require specialized aircraft, are expensive when compared to medium-altitude aircraft, and are constrained by the aging fleet of high-altitude aircraft fitted for remote sensing. Medium to low-altitude aircraft can obtain imagery quickly and frequently, and are less expensive, but do not easily cover large areas.

Many types of remote sensing data can be applied to emergency management. Optical imagery, captured from the visible portion of the spectrum, is widely used. Synthetic-aperture RADAR (SAR) interferometry has been used to measure earthquake damage (Ehrismann, 1996. Aoki, et al., 1998. Estrada, et al., 2000), and to develop building inventories (Aoki, et al., 1999). High-resolution digital aerial videography can be used for natural hazard monitoring (Raper and McCarthy, 1996). Airborne thermal infrared scanning devices have been successfully used during firefighting efforts (Ambrosia, et al., 1998. Dubrasky, et al., 1998). Light detection and ranging (LIDAR) systems have been used to render urban landscape models (Hill, et al., 2000). Often the first images of a disaster come from television news helicopters, so research has been done to automatically identify earthquake damage using this technology (Mitomi, et al., 2000).

Remote sensing images can be gathered at nearly any scale, from displaying the entire globe to revealing details only centimeters in size. This flexibility allows remote sensing to be used for decision-making at every government level, from large area imagery required at national and regional levels to medium and small area imagery needed at district and local levels.

Earthquake prediction research has benefited from remote sensing. Long-term probability estimates are possible after identification of seismic zones. Landsat TM and

SPOT imagery, and SAR interferometry have been used to detect active faults on land (Yeats et al., 1996, Massonnet et al., 1993), while side-scan sonar has located seafloor faults (Prior, et al., 1979). Interferometry, a RADAR-based remote sensing technique which can detect very small changes in the topography of large regions, may improve long-term forecasts. In contrast, short-term earthquake prediction research is in its infancy, although researchers have reported using National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) data to identify ground thermal anomalies 14 days before a 1998 earthquake (Chengyu, et al., 1999).

Earthquake damage extent and severity can be estimated by change detection techniques which compare pre- and post-earthquake images. Earthquake damage was detected in the Golcuk, Turkey area with before and after image comparison using SPOT panchromatic and synthetic aperture RADAR imagery (Mansouri, et al., 2002, Eguchi, et al., 2000). Ehrismann, et al. (1996) mapped large-scale surface deformations caused by the 1995 Kobe, Japan earthquake. Surface displacement and collapsed buildings caused by the 1995 Hyogoken-nanbu earthquake were detected using interferometric RADAR technology (Okhura, et al., 1997). IRS-PAN was used to determine damage caused by Jabalpur, India 1997 earthquake (Saraf, 1998). Before and after satellite imagery of night lights has been used to locate damage areas (Hashitera, et al. 1999).

GIS Emergency Management Applications

Effective emergency management requires a variety of information be obtained, integrated, then provided to multiple sources (Van Westen, 1993; Rosenfeld, 1994; Scott, 1998). A well-designed management system allows quick decision-making, essential during emergency situations (Shibata, 1997). Two relevant GIS capabilities are data manipulation, including integration and analysis, and map creation based on that data.

A GIS strength is its ability to quickly integrate spatial and non-spatial data from a wide variety of sources, perform quantitative analyses, then display the results in easy-to-understand formats, all in much less time than a manual system (Haack-Benedict, 1998). Data can be organized into a common format which can be shared between the multiple levels of government typically dealing with a disaster (Fletcher, 2002).

GIS can produce maps in a plethora of scales, from continent-wide to displaying objects less than a meter in size. When an emergency brings together disparate agencies with differing map requirements GIS can easily map the same area with different geographic coordinates (Riche, 1998). Infrastructure maps showing locations of hospitals, schools, pipelines and utility lines can be compiled into a map atlas made readily available to emergency services (Hester and Krumm, 1996).

An advantage of using GIS for analysis becomes obvious when maps are superimposed to produce additional meaning and understanding. Vulnerability maps are created by combining hazard maps (e.g. active fault maps, seismic macro and micro-zonation maps, and soil maps) with infrastructure and lifeline maps (e.g. water supply lines, transportation routes, telecommunication and power networks, and critical facilities). Emergency planners can use vulnerability maps to readily identify facilities at risk and plan emergency response accordingly.

But GIS is more than maps. GIS can be used to integrate database information with map-based spatial information. For example, GIS can answer questions like how many people live in an area which has lost electrical power, how many emergency response units or hospital beds are within a two-hour travel time of a disaster area, or what are the estimated casualty numbers and damage costs for an earthquake at a given location and magnitude.

Network analysis is an important GIS function. It can be used to plan and manage evacuations, or to determine how emergency vehicle response time will be affected if given transportation routes are inaccessible. Transportation chokepoints at bridges, tunnels, and overpasses can be identified, and multiple what-if scenarios used to plan evacuation routes. GIS can also be used for "shortest path" analysis when dispatching emergency vehicles (Fletcher, 2002), which can then be tracked and routed by GIS in combination with global positioning systems (GPS) technologies (Scott, 1998).

Integrated Remote Sensing/GIS Emergency Management Applications

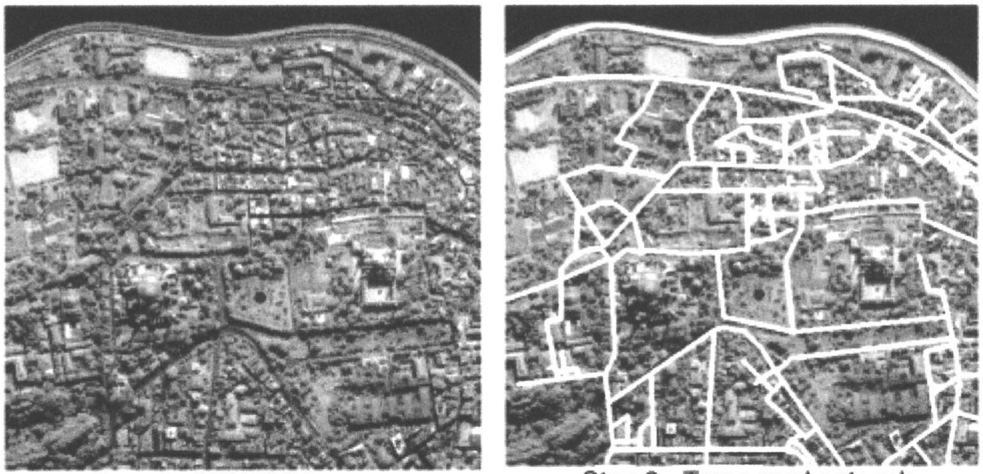
A system which integrates remote sensing and GIS is most effective when used for every phase of the emergency management cycle, from planning before the event through response through recovery, with output from one phase becoming input for the next (McKee, 1998). Before a disaster occurs remote sensing imagery can be used to create GIS layers which are combined with other GIS layers for planning purposes. After an event the system can locate, identify and analyze damage, assist in emergency response, then monitor recovery efforts. The imagery and GIS layers created during response and recovery become input for the next round of planning.

The reliability of a GIS emergency response system is primarily determined by the accuracy of its base data, which are GIS layers containing geographic features used for locational reference. Unfortunately, in some places the only existing source from which base data may be created are old maps created with imprecise techniques. The maxim "garbage in, garbage out" applies to GIS as much as it applies to any other computerized system. Symptoms of bad input become glaringly apparent when data from multiple sources cannot be superimposed because one source locates a highway where the other shows a structure. Accurate GIS base data can be created with ground-based techniques, such as mapping trucks using GPS technology, but there are time and expense factors associated with the purchase and use of this equipment.

Another approach, which may be more practical, is the creation of GIS base data from remote sensing imagery. The imagery is georeferenced, made spatially accurate with the location of every point known, then entered into a GIS system. GIS operators can create data layers for roads, lifelines, hospitals, etc., by "tracing" imagery features. Figure 2 illustrates a GIS road network created from remote sensing imagery.

If it is difficult to create GIS layers with ground-based techniques before an emergency, it can be impossible afterwards. Blocked roads, destroyed landmarks, and the need to use personnel for rescue efforts prevent accurate information from being quickly gathered over a wide area. The data gathering capabilities of aircraft and satellites becomes crucial.

For remote sensing to be useful during emergency response it must be gathered quickly and frequently, then processed and distributed to relief workers with little delay (Rosenfeld, et al., 1996. Alexander, 1991). GIS can rapidly georeference remote sensing data, combine it with data from other sources, and display it in a format which can be understood by personnel having no extensive training in image interpretation.



Step 1 - IKONOS image

Step 2 - Trace road network with GIS software

Step 3 - Separate road network from image

Figure 2 – Creating a GIS road network file from an IKONOS satellite image

Damage can be identified by image processing software that compares imagery of the same area before and after an earthquake. Damage locations are superimposed with GIS layers of building inventories, lifelines, and population density to create casualty and damage estimates used to prioritize relief efforts. GIS analysis can suggest which before and after images should be compared first, based on pre-earthquake classifications (Gamba and Casciati, 1998).

Effective emergency management requires public support. GIS using remote sensing images can be used with great effectiveness during public presentations. However, images must be at a sufficiently large scale to allow individuals to identify known landmarks, such as their own dwellings or workplaces. When someone sees their home within a hazard zone or above a fault line, the danger becomes much more personal, increasing the likelihood the individual will take or request action.

A Model System

An emergency management system integrating remote sensing and geographic information systems could have reduced casualties and damage after the Kocaeli earthquake. Detailed analysis of a complete system is beyond the scope of this paper. Instead, the discussion focuses on how current and future remote sensing and GIS technologies can be used to improve some aspects of emergency management.

Although the model system is described in terms of dealing with earthquakes, it can be used to manage many types of natural or human-induced disasters. Remote sensing/GIS systems have been used to manage floods, wildfires, hurricanes, oil spills, and recovery after the 9/11 New York City terrorist attack.

The model was designed from an academic perspective and background. But an effective and efficient system cannot be created from that limited viewpoint alone. Real-world effectiveness of the model is constrained by lack of input from those who would create and use the system, including remote sensing/GIS technologists, software developers, and working emergency managers and responders. As such, the model should be considered a starting point for discussion, not a finished product.

Data Sharing

The model system includes a horizontally and vertically distributed knowledge base through which remote sensing and GIS data and metadata flow from data providers to clearinghouses to emergency managers (Figure 3). The data sharing system will save money and time which would otherwise be spent re-creating existing data, provide an efficient data retrieval process for emergency managers, implement data and metadata standards which enhance widespread data sharing, place data security responsibilities in the hands of those most familiar with security requirements, and create an information system which will not be crippled by damage to a few components.

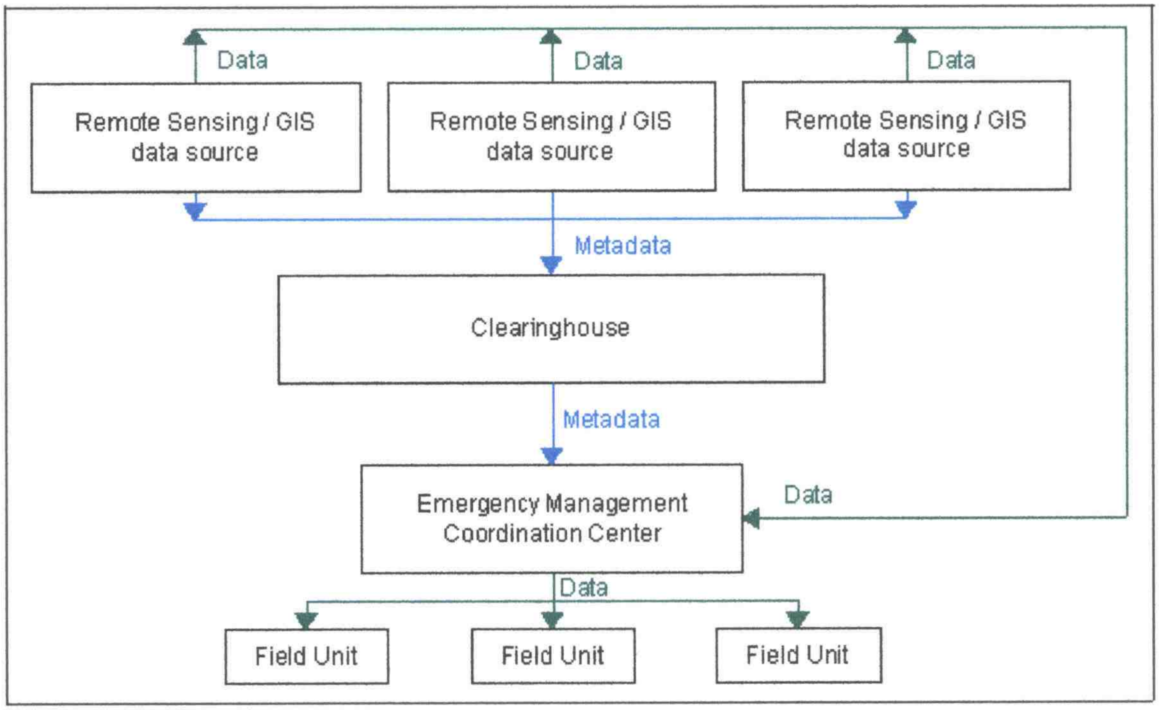


Figure 3 – Data sharing model

The data sharing process begins at the agency that created, or sponsored the creation of, the remote sensing/GIS data. This agency creates metadata describing the data, sends the metadata to multiple clearinghouses, then makes the data available through a secure Internet connection. This design eliminates central data depositories which could be crippled by a disaster. An additional benefit of leaving data with those who created it is an increased likelihood it will remain current (ESRI, 2001). Data security responsibilities remains with those who could, if necessary, modify the data to provide needed information while withholding sensitive information. For example, an electric utility company could release GIS layers locating areas without electrical power, while not releasing generator and substation locations.

Clearinghouses to which metadata have been sent will provide password-protected secure Internet interfaces and user-friendly search engines, similar to the National Geospatial Data Clearinghouse (NGDC) maintained by the United States Geological Survey (USGS). Clearinghouse visitors will use search engines to find and view metadata, then will contact the sponsoring agency for secure downloads. Metadata is used because visitors can determine if needed data exist without having to download and study large datasets (Walsh, et al., 2002).

An important model component is the creation of, and adherence to, data and metadata standards. Historically, GIS and remote sensing data have been gathered in multiple formats and scales, and require more than one type of software for display and analysis. Efficient emergency response requires the same data be used on a variety of computers and software, but time constraints may not allow data conversions to be performed after an emergency occurs.

Standardized data formats and software will allow an emergency to be managed at an unaffected location when local facilities are damaged or local emergency responders are tending to the needs of their families. When local management functionality is reestablished, responsibility can be handed back to the local center with minimum confusion and lost time.

Activities during the preparedness phase

Activities include creating and gathering remote sensing imagery, creating new GIS layers, producing hazard/vulnerability maps, and public education.

Remote sensing of the entire country will be captured during the preparedness phase. Imagery will be captured periodically, so up-to-date information is always available. Periodic updates will occur more frequently for fast-growing urban areas, and less frequently for slowly growing rural areas. Image scales, and therefore collection platforms, will vary according to how the imagery will be used. Wide-area coverage provided by high-resolution satellite imagery such as IKONOS 1-meter will be used for national and regional planning. Local planners will use highly detailed images of urban areas captured by medium to low-altitude aircraft. However, if recent trends in improved remote sensing satellites and computer processing power continue, even highly detailed large-scale images needed for local use can be affordably captured by satellite then processed on desktop computers.

The model system will make use of automatic feature extraction (AFE). AFE reduces the need for skilled, experienced photo interpreters required for time-consuming traditional methods (Hill, et al., 2000). Future improvements in AFE may allow quick, automatic, and affordable creation of GIS layers from remote sensing imagery.

Hazard and vulnerability maps will be created during the preparedness phase. An example of how this process could benefit Istanbul is vulnerable structure mapping. The amount of damage sustained by a building varies with the type and quality of construction, age, building height and stories, and soil and geological site conditions (Johnson, 2000). Superimposing a map of abandoned riverbeds beneath Istanbul with a map of buildings more than three stories in height would identify buildings which might suffer from earthquake-induced soil liquifaction.

Remote sensing and GIS will be used to identify areas in which temporary housing or tent cities could be constructed. This analysis requires reliable information on demographics, terrain, and location of lifelines (Lavakare, 2001), all of which can be stored in GIS.

Remote sensing images can be powerful tools for public education. Education is an effective way to keep earthquake awareness at high levels for decades. But educational messages are not effective if they are ignored. Public popularity of an educational message presented in a visually pleasing, entertaining format was demonstrated in Turkey by the cartoon character “Grandfather Earthquake”, who trained children on how to prepare for and respond to an earthquake event (Isikara, 2000). The fascinating perspectives and minute detail of remote sensing images combined with colorful GIS graphics can be used to create entertaining and appealing presentations.

It was widely acknowledged that poor building code enforcement significantly contributed to widespread structural collapses after the Kocaeli earthquake. Remote sensing and GIS imagery used to identify vulnerable structures during public presentations may help foster a public attitude which encourages enforcement. An additional benefit may be realized if public awareness of vulnerable areas stimulates property owners to purchase appropriate insurance, reducing the economic exposure of the Turkish government, the historical insurer against earthquake damage.

Activities during the response phase

After the Kocaeli earthquake the Prime Minister's Central Committee for Disasters in Ankara was constrained by lack of information concerning damage extent and severity. In the model system damage will be rapidly located, identified and quantified by the use of remote sensing and GIS. The findings will promptly be made available in appropriate formats to all levels of decision makers.

Remote sensing used for earthquake emergency response must be collected, analyzed. and distributed within a few hours. To meet this deadline, damage imagery will be collected digitally, instead of on film which must be developed then scanned. At the same time, data needed for post-flight image correction and fast GIS integration will be captured by GPS, recording gyroscope, and recording altimeter technologies. All data will be transmitted to ground processing centers in real time so analysis may begin immediately. The digital format will allow data to be quickly transmitted to distant processing centers if local facilities are not available.

The model system will use aerial platforms to capture post-event imagery. Currently it is often impossible to capture timely post-event satellite imagery. Because of fixed orbital return times between image acquisition sessions the appropriate satellite may not be in position until several days after an event.

Aerial platforms will be capable of capturing remote sensing in many formats, e.g. still and video, optical, thermal, LIDAR and RADAR. Powerful, high-speed computers will perform damage detection. Damage detected by LIDAR/RADAR systems will be superimposed on optical images to be used by decision-makers who do not have the extensive training needed to interpret LIDAR and RADAR.

Earthquake damage extent and severity will be estimated by change detection techniques which compare pre- and post-earthquake images. Figure 4 is an example of how Indian Remote Sensing (IRS) satellite images were manipulated by the author to locate Kocaeli earthquake damage at Golcuk, Turkey. Brightness levels on images captured August 8, 1999 and September 27, 1999 were compared. Because rubble has higher reflectivity than non-rubble, areas brighter on September 27 indicated damage areas and rubble dispersal sites (shown in red). The blue area in the upper right-hand corner was darker on the September 27 image, indicating subsidence-related flooding along the Sea of Marmara coast.

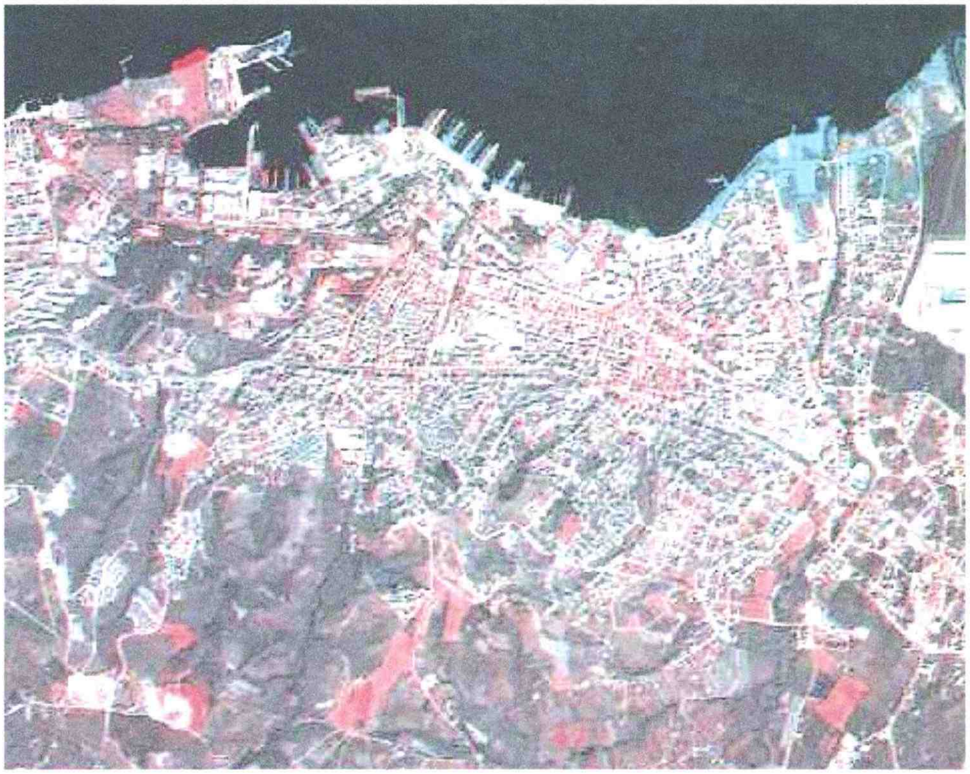


Figure 4 – Change detection used to identify damage and subsidence at Golcuk

Future advances may allow LIDAR 3D models (Figure 5) to be used for damage detection. LIDAR 3D circumvents an optical imagery problem which occurs when soft-story collapse cannot be detected because the sensors see only building rooftops. Effective emergency response requires imagery be gathered as soon as possible after an event, making LIDAR an attractive tool because it can be gathered at night and through cloud cover or smoke, when optical sensors are ineffective.

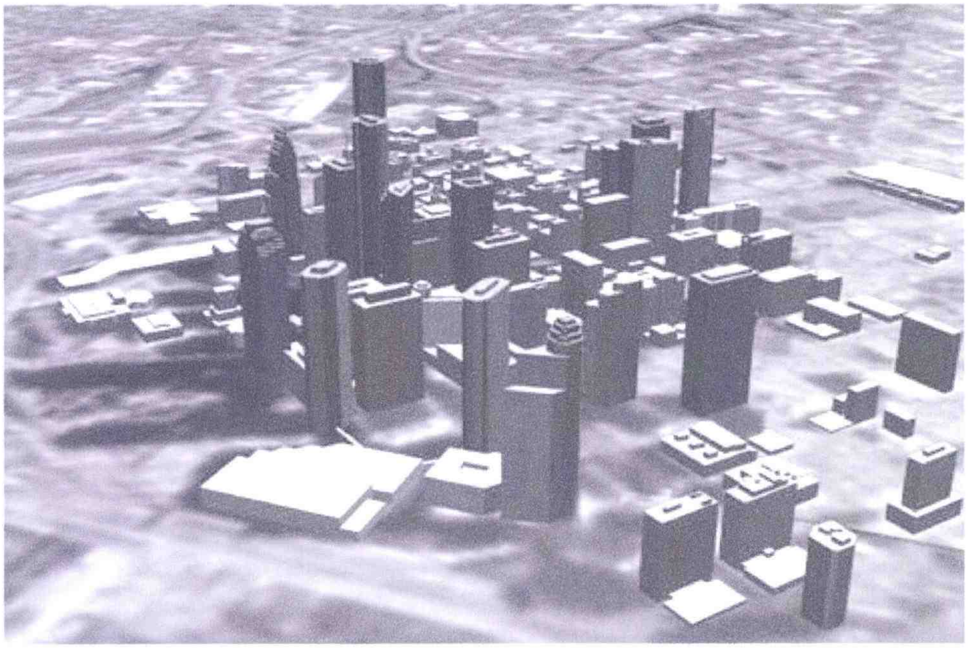


Figure 5 – LIDAR-generated rendition of Houston, Texas (Hill, et al., 2000)

Processed remote sensing imagery will be combined with GIS, then used by emergency managers in coordination centers and in the field. Uses include locating available and unavailable transportation routes, tracking searched and unsearched buildings, and routing GPS-equipped emergency vehicles. Figure 6 is an example of an

IKONOS satellite image of Istanbul overlain with pertinent emergency management information.

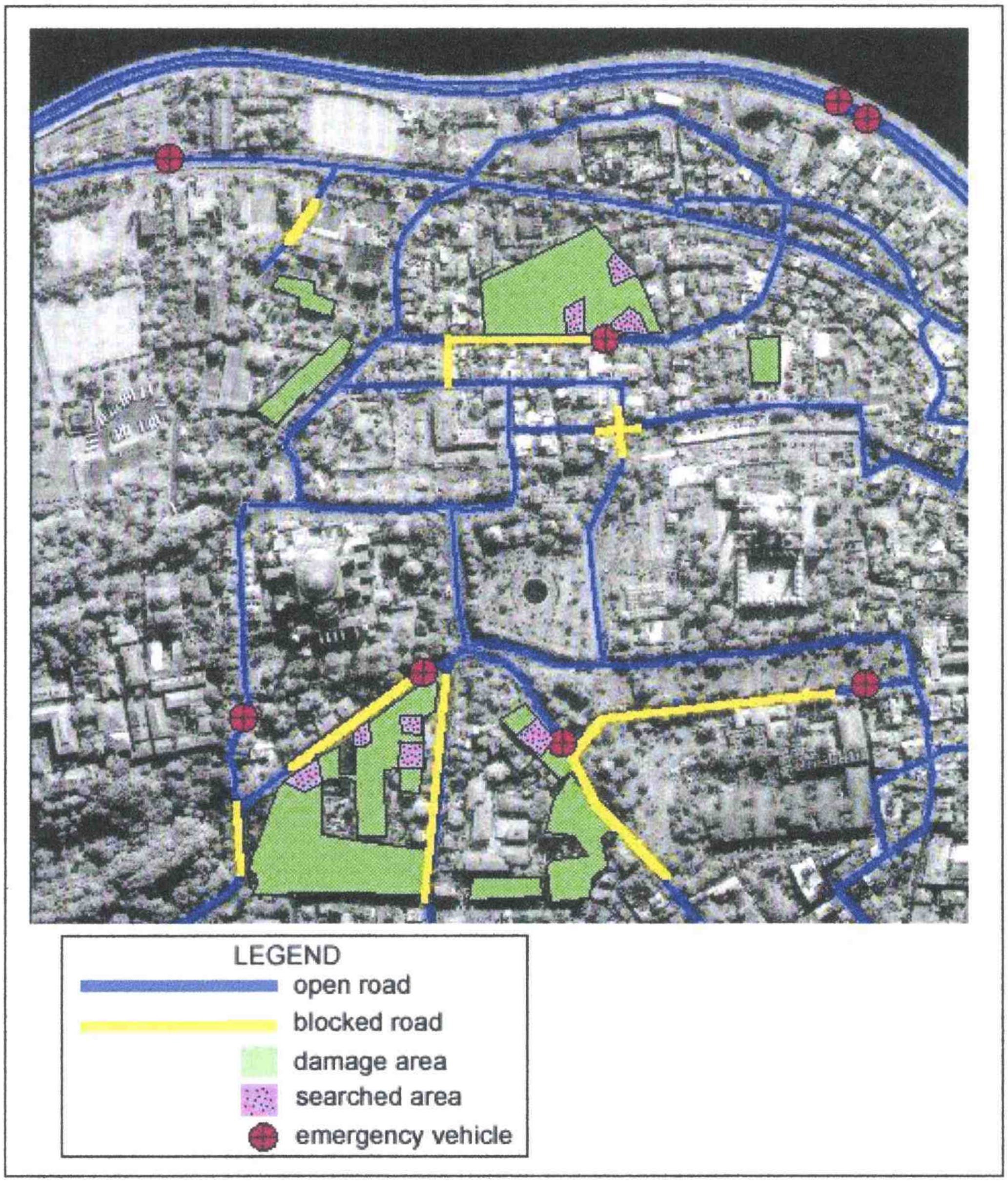


Figure 6 – IKONOS Istanbul imagery with GIS overlay

Representatives from different branches of the government and military will work together in coordination centers, viewing the same information and participating in decision making together. This process would have alleviated a problem experienced after the Kocaeli earthquake in which the government had coordination and communications problems with the military for two days after the event (Mitchell, 2000).

GIS will be used to produce maps combining remote sensing imagery with other information. GPS coordinates will be used on all mapping, as recommended by The United Nations International Search and Rescue Advisory Group (INSARAG) (Berthlin and Hornung, 1999). After the Kocaeli earthquake maps were not available to field workers (Petal, 2000), police, or international rescue teams. On Friday, August 20 an Israeli rescue unit in the Cinarcik area had to ask directions to a rescue site ('Turkish Daily News, August 21, 1999). Similar situations were reported to have occurred to German and American teams. Mr. Dewey Perks, task force leader for Virginia Task Force One, an American search and rescue team, told of police escorting the team to two incorrect locations (Perks, 2000).

Remote sensing and GIS information will be saved in formats easily transferable to computers used by international rescue teams. This information will be made available via secure Internet download or CD. After the Kocaeli earthquake there was little or no formal mechanism to transfer information from the government to international rescue missions (Turkish Daily News, August 23, 1999). There were numerous complaints from international search and rescue teams regarding lack of information from government authorities.

Activities during the recovery phase

Remote sensing and GIS will be used during the recovery phase to monitor authorized tent cities and temporary housing sites, locate unauthorized tent cities, and track debris collection and dispersal.

Remote sensing will be used to monitor authorized tent cities to determine if available space is being used efficiently, and to locate unauthorized tent cities. After the Kocaeli earthquake the Red Crescent could not support spontaneous, unauthorized tent cities, providing assistance only at authorized locations. Remote sensing imagery can distinguish between organized and spontaneous tent cities because in organized cities tents are in rows and roads are graded (Carlson, 2000). Figure 7 shows a suspected tent city in the Golcuk area.

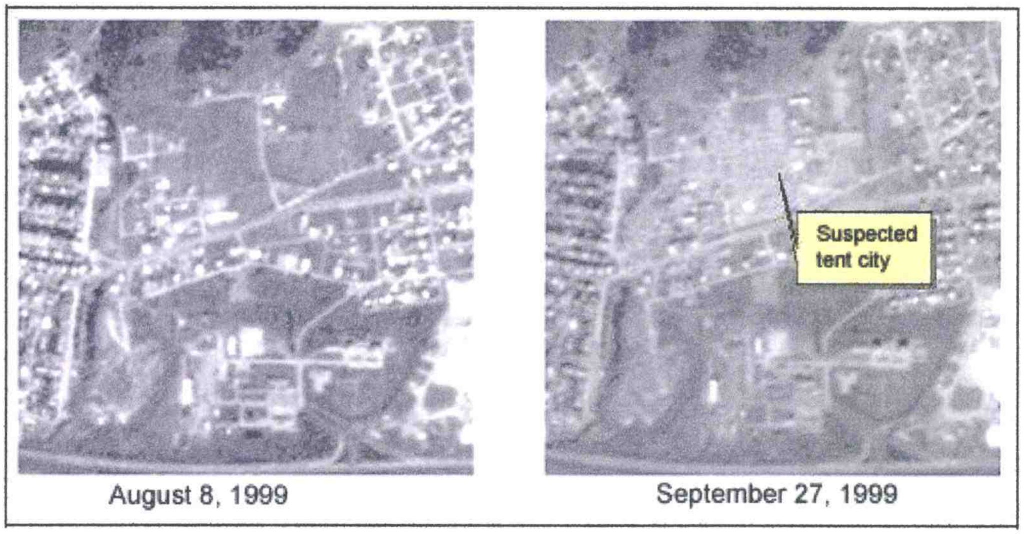


Figure 7 – IRS 5-meter satellite imagery shows a suspected tent city (Gaston, 2002)

Debris removal will be monitored with GIS, a procedure performed by the United States Army Corps of Engineers (Bruzewicz and McKim, 2002). Debris dispersal can also be tracked and managed. In Figure 8 (an enlargement of the upper left-hand corner of Figure 4) the large red area clearly delineates Kocaeli earthquake debris dumped into the Sea of Marmara. This debris will become unstable during future earthquakes, so land use laws prohibiting building of vulnerable structures should be enacted and enforced.

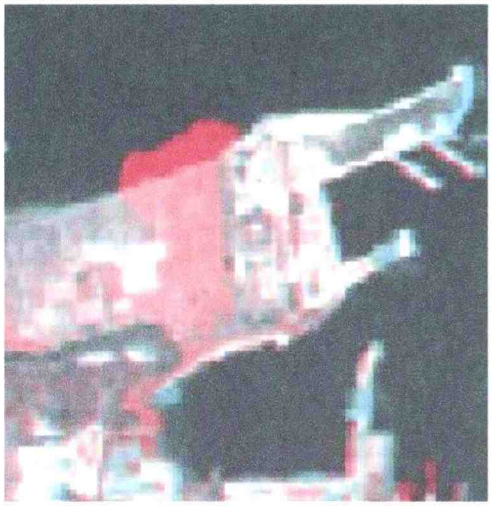


Figure 8 – IRS 5-meter imagery captured on September 27, 1999 shows debris (red) dumped into the Sea of Marmara (black)..

Potential Impediments to Model Implementation

System creation will require significant capital outlays for remote sensing platforms, imagery-capture missions, computers and software to store and analyze remote sensing and GIS data, communications and presentation equipment for coordination centers, and equipment for field responders. International funding sources such as the United Nations, World Bank and the insurance industry, should be explored (Rosenfeld, 1994).

System costs can be minimized by proper planning and design. However, failure to involve representatives from all relevant segments of the GIS, remote sensing, and emergency management communities in the design process can lead to an inefficient, perhaps unusable, system. Emergency management involves many diverse stakeholder communities including remote sensing analysts, geospatial software designers, national and regional strategic decision makers, local tactical decision-makers, and both national and international emergency responders. These groups have different missions, perspectives, and priorities, and may not be aware of how their actions impact other groups. Meetings should be held to allow communication between these groups so ideas and information can be exchanged. Attendees can learn about tools both available and in development that can improve emergency management. System developers can use feedback from these meetings to better focus their efforts.

High resolution georeferenced remote sensing data and detailed GIS coverages can contain highly sensitive information, causing security concerns from government, military, and private businesses. In an ideal world all remote sensing and GIS data would be instantly accessible. But we do not live in an ideal world, so data access must be controlled. One approach would be creation of a government agency to oversee distribution of government owned remote sensing imagery. An example of such an agency is the Regional Scientific Response Center (RSRC) of the National Mapping Division (NMD) of the United States Geological Survey (USGS). The RSRC integrates classified government assets with commercial and public domain data to create data sets for hazard response. Data sets from many sources, such as USGS, United States Environmental Protection Agency, United States Army Corps of Engineers, Federal Emergency Management Agency, and state and local governments are integrated and made available to RSRC partners and the public.

The emergency management model described in this paper cannot function if data is too tightly controlled. Communication and cooperation between those concerned with security and those concerned with emergency management is mandatory. An example of this cooperation occurred recently in the United States. At the request of United States Navy staff, the Puget Sound LIDAR Consortium (PSLC) disabled Web access to LIDAR topography because of national-security concerns. Further discussion revealed LIDAR topography was not significantly more useful than other geospatial data widely available on the Web, so the PSLC agreed to institute guestbook tracking of geo-registered data downloads.

Suggestions for Future Research

Research should determine the content, format, and timeliness of GIS and remote sensing data required to support emergency management strategic and tactical decision-making. Questions to be addressed would include: What are the information needs at all levels of decision-making, including the Prime Minister's office, Governors' offices, and local emergency managers? At what level of detail should information be presented? In what format should information be presented (e.g. large-screen video, paper maps)? How soon after an event occurs should information be available? What is the optimum rate at which information should be updated?

The availability of LIDAR-derived 3D models of urban areas would allow much more accurate automated damage detection than is now possible. Future LIDAR systems, combined with computerized automatic feature extraction, should have the capability of producing a 3D post-event model within a few hours. The model should render structures less than one story in height, an improvement over current capabilities of three stories. Comparison of before and after models would identify damage to structures, overpasses, elevated freeways, etc..

Improved automatic feature extraction (AFE) methods would enhance rapid creation of georeferenced GIS layers from post-event remote sensing imagery. AFE might allow accurate damage detection in areas for which before/after comparison cannot be done because no pre-event imagery exists.

Timely satellite imagery of any disaster would be available if a network of high-resolution, multi-wavelength satellites was accesible. Similar in concept to the network of GPS satellites which currently exists, the "disaster network" would always have one or more satellites positioned over any given point on the globe. These satellites would begin image acquisition almost immediately after an earthquake, transmitting data to processing centers in near real-time. Methods for international cooperation to finance and manage a satellite network such as this should be explored.

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