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Improved earthquake response via simulation and integrated space- and ground-based technologies: the TREMOR proposal

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ABSTRACT

Earthquakes occurring around the world each year cause thousands of deaths, millions of dollars in damage to infrastructure, and incalculable human suffering. In recent years, satellite technology has been a significant boon to response efforts following an earthquake and its after-effects by providing mobile communications between response teams and remote sensing of damaged areas to disaster management organizations. In 2007, an international team of students and professionals assembled during the International Space University's Summer Session Program in Beijing, China to examine how satellite and ground-based technology could be better integrated to provide an optimised response in the event of an earthquake. The resulting Technology Resources for Earthquake MOnitoring and Response (TREMOR) proposal describes an integrative prototype response system that will implement mobile satellite communication hubs providing telephone and data links between response teams, onsite telemedicine consultation for emergency first-responders, and satellite navigation systems that will locate and track emergency vehicles and guide search-and-rescue crews. A prototype earthquake simulation system is also proposed, integrating historical data, earthquake precursor data, and local geomatics and infrastructure information to predict the damage that could occur in the event of an earthquake. The backbone of these proposals is a comprehensive education and training program to help individuals, communities and governments prepare in advance. The TREMOR team recommends the coordination of these efforts through a centralised, non-governmental organization.

INTRODUCTION

On May 12, 2008, a major earthquake measuring 8.0 on the Richter scale rocked the Sichuan province of southwest China. The impact of the earthquake on human life and the Earth was massive. Approximately 70,000 people were killed, and more than five times that many were reported injured or missing. Fifteen million individuals were evacuated from their homes, some never to return to their ravaged cities. Property damage was estimated at USD 10-15 billion, with estimated economic losses totalling USD 86 billion. In some areas, the landscape was permanently altered by rifts and landslides; new lakes were formed where before there were none. (USGS, 2008a; French, 2008; RMS, 2008)

As devastating as this event was, earthquakes are unfortunately not uncommon. Figure 1 illustrates the propensity of major earthquakes to occur in all the world's continents. Countries surrounding the Pacific Rim are most likely to experience the violent shaking that result from shifts in the Earth's tectonic plates; however, countries in the Mediterranean region, as well as southern and western Asia are also highly susceptible. Developing countries, which often have limited infrastructure and emergency resources, are among the hardest hit when an earthquake strikes.
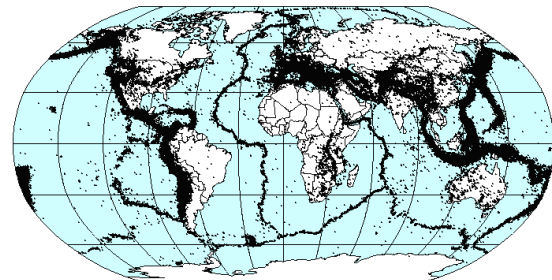

Figure 1: Global occurrence of earthquakes (DTAM, 2002).

Just 6 months prior to Sichuan, a magnitude 7.7 earthquake occurred in Chile on November 14, 2007, killing 2, but destroying or damaging thousands of homes, and displacing 15,000 people (USGS, 2008b). Three months prior, a magnitude 7.9 earthquake in Peru resulted in 519 deaths and widespread infrastructure damage, including the destruction of over 58,000 homes and 14 hospitals (UN, 2007). In the last 30 years, earthquakes have accounted for nearly 640,000 deaths and billions of dollars in property damage and economic losses (USGSc, 2008). Figure 2 shows the number of deaths caused by earthquakes and their secondary effects from 1980 to 2008. The large peak in

2004 corresponds to the December 2004 South-East Asia tsunami, which was caused by a massive offshore earthquake in the Indian Ocean. Even in cases where earthquakes cause minimal loss of life, they can still result in significant property damage and economic loss. For example, an earthquake that occurred in Japan only one month after Sichuan killed 12 people, but resulted in insurance payouts of more than 4.9 billion yen (USGSd, 2008; JCN, 2008.
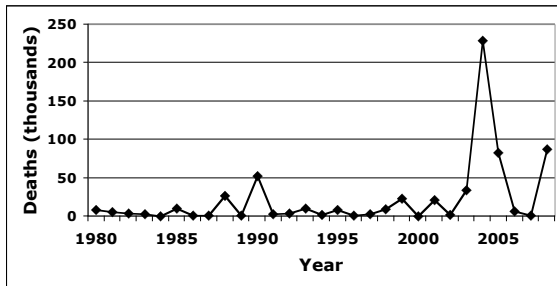

Figure 2: Estimated global earthquake-related deaths (1980-2008) (USGSc, 2008).

Following the Sichuan earthquake, and other natural disasters in Southeast Asia, UN Secretary-General Ban Ki-moon called for a "new path out of disaster" focused on mitigating the impacts of such events through improvements to response and pre-planning (Ki-moon, 2008). In the wake of the Sichuan earthquake, the United Nations International Strategy for Disaster Reduction (UN/ISDR) noted the need to develop an earthquake early-warning system (UN/ISDR, 2008). Although the reliable prediction of earthquakes is not yet feasible, it is possible to mitigate their effects through other means. Ki-moon calls for actions such as improving disaster education and developing steps for community-based preparedness, evacuation, and mitigation in advance of natural disasters.

One year prior to Ki-moon's address, in the summer of 2007, a group of 36 students and professionals from 11 different countries convened in Beijing, China as part of the International Space University's annual Summer Session Program to examine different ways of reducing the devastation and human suffering resulting from major earthquakes. The team considered all phases of earthquake disaster management and prepared the Technology Resources for Earthquake Monitoring and Response (TREMOR) report (ISU, 2007). Several papers based on the TREMOR report have since been published that focus on different aspects of the solutions proposed (Christensen *et al.*, 2008; Fletcher et al., 2007; Harrison *et al.*, 2008).

This paper examines in greater depth the integration of space and terrestrial resources to improve earthquake response efforts through a two-tiered organizational structure. The importance of education and outreach with respect to earthquake preparation and response is also discussed.

TREMOR MISSION

The TREMOR project's mission statement was "to develop an integrated terrestrial and space-based system for mitigating the effects of earthquakes, and improving response". A gap analysis conducted by the team revealed numerous barriers that prevent more efficient response to earthquakes. This is despite the presence of many organizations and government agencies throughout the world with the specific mandate of disaster management, and despite a variety of advanced technologies that have been employed to assist response efforts. Coordination of response efforts between organizations, effective pooling of financial and human resources, integration of multiple technologies, and education of governments, local response personnel and the general population, were all found to be in need of significant improvement.

The team's findings resulted in a three-part proposal that considers how space and terrestrial assets may be integrated to improve each of the four phases of the disaster management cycle (planning, mitigation, response, and recovery). Figure 3 shows the interaction between the three prototype systems that constitute the proposed TREMOR solution.
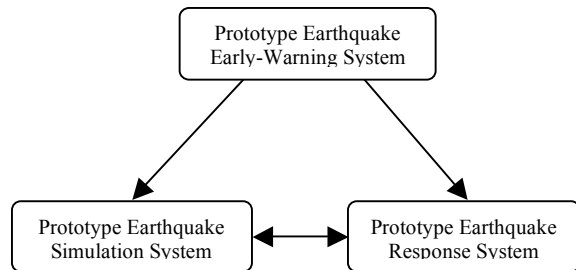
Figure 3: Schematic diagram showing the three parts of the TREMOR framework.

The Prototype Earthquake Early-Warning System is based on the integration of historical data and earthquake precursor phenomena observed by ground and space instruments (Fletcher et al., 2007). If the likely location and magnitude of an impending earthquake is known in advance, response efforts can be better coordinated using the Prototype Simulation and Response Systems. Information from the Early-Warning System is used by the Simulation System to estimate the potential damage resulting from the earthquake and hence the optimal allocation of response resources. The early warning data initiates the deployment of the Response System so that response efforts can be planned in advance. There is a two-way flow of information between the Simulation and Response systems. Simulation results enhance the planning of response activities, and data on the effectiveness of the eventual response goes back to the Simulation System so that its accuracy can be gauged and improved for future events. The Simulation and Response Systems can function even without the Early-Warning System. These systems are described more fully in this paper and align in many ways with the steps proposed by UN Secretary-General Ban Ki-moon.

It is envisioned that these prototype systems would be managed by a centralised organization that could facilitate the necessary multilateral agreements to ensure that essential technology and training are made available to local personnel. To this end, the proposed TREMOR Foundation would be a non-profit, non-governmental organisation with an international headquarters and local branch offices in earthquake-prone countries.

EARTHQUAKE RESPONSE PROTOTYPE

The response to a natural disaster must occur immediately and efficiently in order to save as many lives as possible. The first hours and days after an earthquake are critical for search-and-rescue (SAR) teams to help trapped, stranded, or injured people. Communications systems routinely fail, however, and the coordination of rescue teams can be challenging. At present, numerous ground- and space-based technologies are used during the response phase of disaster management, such as telecommunications, remote sensing (RS), and global navigation satellite systems (GNSS). These technologies offer services over wide coverage areas and are not impacted by the earthquake itself, giving them a significant advantage over terrestrial counterparts in disaster situations. These technologies are not efficiently integrated, however, to ensure human safety and the rapid delivery of aid (Abolghasemi *et al.*, 2005; Simmons *et al.*, 2004; Garshnek & Burkle, 1999). The purpose of the Earthquake Response Prototype proposed in the TREMOR project is to significantly improve the effectiveness of response efforts following earthquakes via the integration of space-based technologies and terrestrial resources at the global and local levels.

To achieve this goal, the first task is the coordination of space assets on a global scale. Space resources that can be used to achieve disaster management objectives must be identified, and agreements reached with providers to ensure the availability of necessary services after an earthquake. Sensitive issues such as satellite monitoring using remote sensing technology will require careful consideration of international law and policies. Hence, the TREMOR Foundation will advocate for the establishment of appropriate bilateral and multilateral agreements so that the necessary resources can be put to use in countries affected by earthquakes as soon as they are needed. All of this should be achieved before an earthquake occurs.

The next stage of organization will enhance the local deployment of resources once an

earthquake occurs. TREMOR proposes the development of a portable communications unit that can be deployed to the site of an earthquake to support all disaster management-related communications and manage relevant data collected from the various satellite and terrestrial resources regarding the affected region. Centralised management at the local level will facilitate more effective dissemination of needed information to response teams, thereby enhancing the distribution and implementation of local resources. The ultimate outcome of the system is that space- and ground-based resources are successfully procured, integrated and employed to improve local response efforts following an earthquake. The deployable unit will be designed to fit within standard shipping pallets for transportation via commercial airliners, military cargo transports, trucks, or railway cars.

Local authorities would be trained in the use of the deployable unit by TREMOR personnel prior to or following an event, but all decision-making processes pertaining to a response effort would remain the government's responsibility. TREMOR's role at this stage is to act as a facilitator between the local authorities and other nations/organizations whose space-based resources can assist the response efforts. The decision-making hierarchy should be established in the preparation phase, with strategies for the delivery of rescue aid and medical care already in place, so that the space-based technologies can facilitate the necessary plans of response action. The overall organization and integration of ground- and space-based resources is illustrated in Figure 4. Communications (Com) satellites would be used for telecommunications, transmission of data and telemedicine; remote sensing satellites for mapping and damage assessment; and GNSS for tracking of supplies, emergency vehicles and rescue personnel. Additionally, some activities, such as search-and-rescue, would benefit from the integration of all these resources.

Figure 4 illustrates the connection and flow of information between the deployable communications unit and the various space- and terrestrial-based resources. Satellite

communications coupled with GNSS allows the disaster management teams operating from the mobile unit to deploy and track emergency vehicles and supplies. Remote sensing imagery and data is collected from system providers via the TREMOR Foundation and processed at an external site before being released to the on-site unit in a usable form. RS data received can be used to guide emergency personnel around damaged infrastructure when deploying emergency services and allocating supplies.
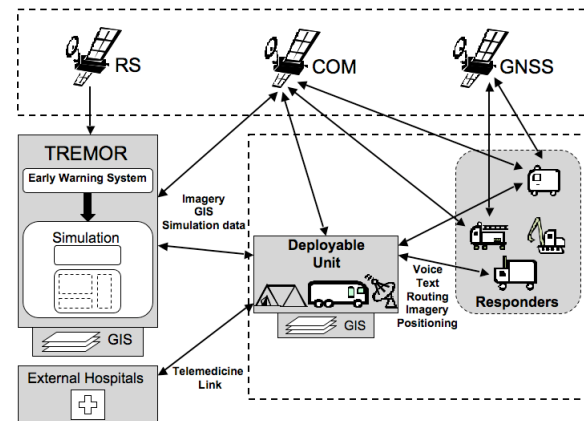

Figure 5: Coordination unit of the Earthquake Response Prototype (ISU, 2007).

In an ideal scenario, the Early-Warning System presented in the original TREMOR report would play an important role in reducing human and socio-economic losses by successfully predicting the location and magnitude of earthquakes (ISU, 2007). Upon activation, the data from this system would be an input for the response system and would offer further insight into likely response actions required. Furthermore, the outside assistance links can be put on alert and the deployable communications units could be pre-positioned on the outskirts of the anticipated affected earthquake zones for even faster deployment to the affected areas. The science of earthquake prediction remains controversial, however, (Geller, 1997) and substantial progress in this area is required before such a system is feasible. Even without an early-warning system, though, numerous preparatory actions can be taken, such as the allocation of emergency communication bandwidth, the procurement of remote-sensing satellites (through purchase, lease or special

agreements) and distribution of portable communication and tracking devices in order to guarantee availability and rapid deployment of local emergency services.

For more specific resources, links to outside assistance should be pre-established and TREMOR can play a role in coordinating these links. For example, once disaster strikes, sifting through medical volunteers to find those able to provide telemedical aid in the required language(s) and on equipment available would be time consuming and inefficient. A worldwide database of volunteers with relevant expertise could be connected through the TREMOR organization, such that telemedicine end-users such as nurses or medics could easily be connected with expert help. Registered Engineers for Disaster Relief (RedR) is an example of an organization that maintains a similar database of pre-selected and qualified engineers who are available for rapid deployment to disaster areas around the world. (RedR, 2008). When a disaster occurs, RedR accesses its database to identify and contact engineers with the relevant technical and language skills to deploy to the afflicted region on short notice.

Beyond the immediate aftermath of the earthquake, resources offered at the national level, by various relief organizations, and likely by international aid will become available. These must be aligned with local efforts and brought on-site in a coordinated manner. These might include personnel, financial support, food and medical supplies necessary to restore normal conditions. Through its experience and analysis of previous efforts, TREMOR could offer frameworks and tools for tracking the recovery effort, better allocating available resources, and reducing mismanagement.

Communication

Effective communication links between the local coordinating unit, the various on-site response teams, and the external organizations providing support is a vital element of any successful response strategy. Telecommunication systems have been plagued by numerous problems in past disasters (Lindberg, 1990; Garhsnek & Burkle, 1999). They have been misused, overloaded and in some cases even destroyed as a result of the natural disaster. For example, landlines are easily disrupted by earthquakes and may not even exist in some developing nations. A global solution is necessary so that preparations can be made in advance to aid any country in need. Communication satellites with bandwidth dedicated to emergency response paired with portable ground devices could remedy these issues. An exercise recently conducted under the framework of the EU-project Land and Sea Integrated Monitoring for European Security (LIMES) demonstrated the potential for such a communication system to aid in disaster management (Terra Daily, 2008).

The principal features of TREMOR's proposed communications infrastructure are geographic redundancy, bandwidth availability, and multiple user terminals. Deployment of new, strategically placed satellite communications hubs (portable or fixed) could reinforce current ground and space telecommunications systems. Consideration would have to be given to the bandwidth requirements for satellites involved in the response phase. Also, technologies such as hand-held devices, laptop computers and web cams could be employed to ensure that responders can adequately communicate regardless of their location or requirements (*e.g.*, text, voice or image data). These aspects combined would give the overall system mobility and flexibility. Garshnek and Burkle (1999) have proposed that a constellation of satellites in low Earth orbit (LEO) could provide reliable and immediate communications in the event of a disaster, even to remote areas. Hand-held terminals could communicate with the constellation regardless of any damage to the surroundings. Such a constellation would provide an advantage over possible integration of already existing satellite telecommunication networks in that the dedicated constellation's entire bandwidth would be allocated to emergency communications and not just a portion. However, if sufficient bandwidth can be assured by commercial providers in the event of emergency, a dedicated constellation would not be necessary.

Telemedicine

Medical interventions are vital in the response phase. The number of casualties usually overwhelms the physicians on-site. One of the most promising aspects of an integrated communications system is the possibility for telemedicine, which would allow medical doctors and specialists from around the world to assist on-site personnel without having to travel to the affected area. Telemedicine would allow a doctor to perform real-time evaluations by using diagnostic tools, such as ultrasound, or by receiving data from medical examinations done by on-site personnel. Moreover, with store-and-forward telemedicine, a specialist could look at the data and give a diagnosis from home. It may even be possible to perform some minor surgical procedures from a distance, such as laparoscopy (Ballantyne, 2002). The promise of telemedicine was demonstrated in a disaster response exercise by the East Carolina University Telemedicine Center in 2002. Satellite communications were used in conjunction with landlines to enable networking, on-scene video, clinical and environmental data acquisition and telemetry. (Simmons *et al.*, 2003). Cameras, satellite phones for voice communications as well as data transmission capabilities and back up power contingency plans are all examples of requirements for the implementation of such a telemedicine system for disaster response.

Telemedicine is, however, still in its infancy in terms of being used in response to natural disasters since the communications required are rarely in place (Merrell *et al.,* 2008; Teich *et al.,* 2002). A dedicated network that is capable of transmitting image, sound and medical data would be required. Where sufficient bandwidth is available, transmission of video can greatly enhance telemedicine capabilities by giving medical personnel the ability to interact more fully with patients and caregivers at remote locations. Thus, a robust strategy for location, equipment and transport requirements must be in place, as well as a thorough consideration of bandwidth requirements. Implementation of telemedicine would require the installation of specific communications hubs that would allow for medical consultation. On-site responders would support this operation by setting up temporary surgical units that would facilitate patient care according to doctors' requirements (*e.g.*, availability of diagnostic devices). Future requirements that will allow the widespread inclusion of telemedicine in the response process include advanced medical devices (such as diagnostic devices with decision making capabilities), handheld devices (*e.g.*, tablet computing devices) for holding and sharing data and information (Chan *et al.,* 2006), and rapid communications systems for ordering materials, sharing comments and databases (Arisoylu *et al.,* 2005). The TREMOR Foundation could play the role of gathering all the medical resources before an event and ensuring that systems are ready for rapid deployment. Experienced TREMOR personnel would assist with the on-site setup of clinics and the overall organization of the telemedicine system. For regions that already have a telemedicine network in place, TREMOR could enhance the system by integrating additional mobile devices and equipment, and by securing more bandwidth for the duration of response activities.

Remote Sensing

The process of locating and providing assistance to victims of an earthquake is difficult to manage since earthquakes may significantly alter the geographic features of an area as well as damage local infrastructure. Hence, the information provided by remote sensing satellites can be extremely useful to response coordination teams. For example, optical imagery is used to identify high-priority regions and the best transportation routes for reaching them. High-resolution satellites are used to detect damaged bridges and blocked roads, thereby reducing time delays in response. Lower-resolution satellites are used to discriminate between buildings in good condition and those completely collapsed. Optical sensors with high spatial resolution offer accurate images of the affected areas, assuming minimal cloud cover and preferential lighting conditions, while radar sensors provide larger maps in all weather conditions and at any time of day. At present, however, obtaining satellite images showing the extent of destruction of an

area in near-real time is not possible; downlinks and processing time result in most images being available days after being taken. Thus, they are currently of little use to time-critical response operations (Eguchi *et al.*, 2003; ESRI, 2006). To best serve earthquake response efforts, remote sensing satellites require the capability of real-time analysis of images taken of damaged areas in order to provide accurate information to the rescue and response teams. In order to guarantee global coverage, the integration of various satellites is required. Electro-optical and SAR systems such as TerraSAR-X (Germany), SPOT (France), Radarsat-1 and Radarsat-2 (Canada), and Quickbird (United States) could be used to meet this objective. A future requirement is the development of software that could more rapidly interpret remote sensing data and deliver high-quality images with an extremely reduced processing time.

Global Navigation Satellite Systems (GNSS)

To further facilitate SAR activities, it is important to coordinate and track emergency vehicles in order to ensure optimal temporal and spatial coverage of the entire affected area. GNSS constellations such as GPS (USA), GLONASS (Russia) and GALILEO (EU) allow continuous data transmission for tracking and mapping and can be integrated for coordination of SAR teams. However, affected regions must have agreements with these countries to have access to this potentially life-saving data. China, India and Japan are currently developing their own GNSS constellations that will increase space navigation system options (GPS World, 2008; Kulkarni, 2007; JAXA, 2008). In order to provide vehicle tracking and routing information, the deployable communications unit must have direct access to one of these constellations. Response teams can then be directed on how to best distribute rescue vehicles to severely affected areas. ESA's Real-time Emergency Management via Satellite (REMSAT I and II) demonstrated the feasibility of vehicle tracking during a series of forest fires in British Columbia, Canada throughout 2004 (ESA, 2004). Satellite terminals were installed on fire trucks to allow data transmission to a telecommunications satellite. This information

was then passed on to a control centre that coordinated and managed the rescue efforts. Firefighters wore wireless terminals with voice and geo-location capabilities as backpacks. This setup allowed reliable communications in remote areas without the need for terrestrial infrastructure.

Geographic Information System (GIS)

GIS enables the integration, management, analysis and presentation of spatially referenced geographic data. It utilizes information on population, topography, transportation, infrastructure, utilities, housing and communications, to name but a few, and combines it with optical imagery gained from optical and radar sensors. This data is processed to produce highly interactive maps. GIS has applications in all phases of the disaster management cycle. In the response phase it can be combined with GNSS to optimise time-critical operations such as vehicle tracking. It provides emergency personnel with vital information including locations of hazardous materials, electric panels and fire hydrants, and building floor plans.

Despite the recognition of the importance of GIS in disaster management, very few nations and aid organisations are able to implement it. Even when it is possible, there may be gaps in databases on population, utilities, building plans etc., especially in developing countries and remote regions. For this reason, the incorporation of GIS into earthquake response will require the cooperation of all participating nations. However, many states might consider such information classified for reasons of national security, thus preventing a more effective response. The need for real-time RS has already been discussed, and this will also require that GIS packages are made user-friendlier with standard formats to allow rapid data sharing amongst responders.

EARTHQUAKE SIMULATION SYSTEM

To successfully address an emergency incident, such as an earthquake, studies of multiple,

interdependent factors pertaining to the situation are required so that planners, trainers and responders are able to envision the overarching goals of the response (Jain & McLean, 2003). The use of computerised simulation and modelling techniques could allow improvements to earthquake response in both the planning stage and in real-time after an event occurs. By estimating the damage of an impending earthquake while accounting for the local conditions, a comprehensive response strategy can be formulated so that recommendations can be made to emergency responders and the general public (Christensen *et al.*, 2008). Similar simulation tools are employed by governments to prepare for the event of terrorist attacks because such events are inherently unpredictable (Alvares & Shaw, 2006).

A key part of successful disaster management is preparing and planning well in advance of an earthquake event. In the overall TREMOR framework, the simulation system would be used in conjunction with the Response Prototype, and would be enhanced by any information from the Early-Warning System. Initially, the TREMOR simulation tool will be used to: (1) identify earthquake-prone regions in a given country, (2) predict the severity of the damage to the emergency response infrastructure, and (3) propose the optimal allocation of emergency response personnel and equipment. The results of these simulations can form the basis for training of local emergency personnel within the context of the Response Prototype. Additionally, if earthquake precursor data predicting the location and magnitude of an upcoming earthquake becomes available from the Early-Warning System, the TREMOR simulation system will provide updated estimates of the damage prediction and required response resources.

To achieve these objectives, requirements for the simulation system include the following:

- **Integrated solution**: Earthquakes can create many secondary hazards, such as fires and floods. These must also be considered during simulations, both individually and in combination, as decisions will be based on the overall effects of a disaster.

- **Effective data presentation**: The amount of information processed by an integrated system will be enormous. An efficient data-mining system will present only data relevant to the decision making process.

- **Human behaviour simulation**: To better understand the secondary effects produced by earthquakes, models of human behaviour will be considered to identify problems such as bottlenecks in evacuation routes.

- **Continuous connection to local government services**: Simulation tools will assist in planning over the longer-term recovery phase by providing recommendations related to logistics, relief delivery, shelter management, waste disposal, urgent repair, and post-earthquake reconstruction.

The TREMOR simulation system functions by integrating historical records, infrastructure and resources information, Earth observation imagery and geophysical data in a GIS-based architecture to assist disaster management personnel in planning for earthquake response efforts. After identifying earthquake-prone regions in a given country, the system will then use two internal models to predict the impact of the earthquake and to predict the optimum allocation of personnel, equipment and materials during the response activity. The internal models will be as generic as possible, with the ability to customise the parameters to take into account regional variations. The models will be improved over time as data is gathered over multiple earthquake events.

First, the Infrastructure Damage Assessment (IDA) model will be used to predict damage to buildings, roads, hospitals, and other infrastructure that are key during the response phase. It will account for local geology (*e.g.*, soil type and other factors that affect earthquake wave transmission) and any other special geological features that would increase the impact of the earthquake. In addition, the model will incorporate infrastructure information, such

as detailed street maps, building usages, population densities, and building construction techniques, as well as the earthquake-resistance of buildings, bridges, roads, and power generation facilities. Furthermore, the IDA model will estimate the impact of landslides, fires, flooding, and other secondary effects from the earthquake. In particular, it will evaluate the impact on important local facilities such as nuclear power plants or nearby large-scale dams that could require significant attention during response.

Next, the Resource Allocation (RA) model will be used to predict the optimal allocation of emergency personnel, equipment and materials in order to best respond to the earthquake. In order to be effective, the model will require substantial information about the local region's existing response resources. In particular, information pertaining to the locations of hospitals, fire stations, and police stations, as well as the available equipment and personnel at each of the facilities will be needed. An important aspect is to include a model of human behaviour to accurately develop evacuation plans with the limited resources that will be available after the earthquake. The RA model will help identify the required external resources to adequately respond to the earthquake and help plan their optimal allocation once they arrive.

For first-responders, the TREMOR simulation system can be used to provide training scenarios to help prepare for an earthquake. As a long-term planning tool, the TREMOR simulation system can be used to identify gaps in the earthquake preparedness of a given region. The TREMOR Foundation can then provide guidelines to local governments to use as a basis for improving their response systems. In the mean time, in conjunction with the Early-Warning System, the TREMOR foundation can work with the local governments to request the needed resources to respond to an imminent earthquake.

The results of the simulations would have a closed distribution loop because of the requirement for relatively detailed data about a nation's infrastructure that might be deemed sensitive for reasons of national security. Consequently, the simulation system is limited by the willingness of nations to cooperate with the Foundation and provide data. The TREMOR foundation would work in partnership with the host country to help identify gaps and plan appropriately for earthquake response activity. If needed, the simulation information would only be shared with third parties with explicit permission from the relevant national government authority. In this respect, it makes more sense that the TREMOR Foundation be structured as a non-profit, non-governmental agency, as opposed to an intergovernmental organization.

PUBLIC OUTREACH AND EDUCATION

A common theme in disaster management is a reactive rather than proactive approach, where existing deficiencies in available resources and knowledge are only discovered and reduced after a significant event. While the people of China's Sichuan province will no doubt be better prepared for future earthquakes, it is unlikely that the same type of disaster will affect the same region in the same way. In too many other cases some degree of basic preparation and organisation could have done more to reduce loss of life and human suffering than any amount of advanced technology. In this section, we aim to identify and prioritise education-related considerations for the implementation of the TREMOR proposal, with a particular interest in those for developing regions, which typically have the greatest loss of life when disaster strikes.

Educational priorities can be guided by the ways in which earthquakes affect lives:

- Death or injury of family members, friends, neighbours, co-workers, acquaintances
- Secondary immediate threats such as fire, lack of clean water supply, structural damage to buildings
- Loss of property that affects immediate survival (food, shelter), family financial

status or ability to provide for own needs

- Damage to businesses and local infrastructure that affects work and living routines
- Reduced visual appearance of environment as a constant reminder of loss, trauma, and degraded conditions
- Loss of sense of security and safety causing long term stress/anxiety

Education is necessary at many levels for an efficient earthquake response. At the individual and family/work group level, there must be a basic knowledge about how to prepare for and act during an earthquake to minimise injury and loss of life. The education of individuals can be accomplished in many ways, including compulsory training in schools and places of work, lectures by volunteer organizations, and through television and radio broadcasts. An appropriate education program could draw from some of the many online resources developed by wealthy, well-prepared earthquake-prone countries such as Japan, but would need to be tailored to the local environment and made available on locally available media in the local language(s). TREMOR could play a role in this endeavour by collecting and disseminating best practices from successful earthquake education programs worldwide to local authorities and educational institutions.

At the community level, education can help local people to implement practical solutions for local problems. TREMOR can help to catalyse the formation of volunteer groups with basic skills that could augment professional emergency resources by providing useful and timely information as inputs to decision making processes, assisting with specific tasks such as search and rescue or organization of safe areas, providing emotional support to other citizens, and the distribution of information about local secondary dangers such as contaminated water supply or structurally unsound buildings. During the recovery phase, local community working groups can actively participate, thereby regaining a sense of control over their lives and restoring feelings of security. For example, prepared volunteer groups could help organise

neighbours into work teams to rebuild damaged homes and businesses. Visual reminders of progress against the earthquake's destruction are powerful tools in the psychological recovery of a community. These can be as simple as removing debris and damaged buildings, to organizing comfortable, repaired gathering places for people to relax and practice recreational activities. Special attention must also be given to the elderly, those who have lost family and to the long-term care of children and those who had frightening experiences during the earthquake. This could include the creation of special care groups or schools for survivors, and could be helped by attention from public figures. The visit of Chinese Premier Wen Jiabao to schools in the Sichuan area following the May 2008 earthquake is one recent example of this (China View, 2008).

At the governmental level, TREMOR's main educational goals would focus on local emergency response teams, including medical, fire, and police, as well as designated earthquake response personnel who will be direct users of equipment for communications and telemedicine equipment, remote sensing data, and navigation systems to be used in response efforts. In particular, these users must learn how to coordinate with one another to avoid duplication of effort and confusion, and to maximize the impact of resources. One can imagine that providing excellent remote sensing data or telemedicine capability to an unprepared response force in the hours and days following an earthquake would only introduce confusion and delay aid. TREMOR should therefore facilitate the creation of an organisational structure amongst existing local response teams for use during the event of an earthquake. This would include the training of key personnel in each unit to allocate responsibilities, use equipment, and to communicate with one another. If appropriate, this could involve sending TREMOR training personnel and equipment on-site to key areas in the preparation phase to provide hands-on training. TREMOR could also outline a generic organisation and training plan as a starting point that could be adapted by local authorities with minimal resources for an effective organization.

TREMOR could also assist local governments in setting up and coordinating system-wide training scenarios where all elements of the emergency response system would practice together in a simulated earthquake exercise. Such a large-scale coordinated training session would simulate the loss of key infrastructure such as roads, bridges and hospitals, and could also draw on volunteers to participate as injured patients. By involving the entire community, the training exercise will also help prepare individuals to know what to expect following an earthquake and will empower them to respond in cooperation with emergency response personnel who are likely to be overwhelmed. These types of scenarios must be practiced in advance. TREMOR can provide guidance in planning and structuring of training sessions, which can be modelled after the "TOPOFF" 5-day anti-terrorism exercise involving 15,000 people and four countries performed simultaneously in multiple cities across the United States in October 2007 (TOPOFF, 2008). TREMOR can also provide expertise in critical post-evaluation, and work with the government to identify and address gaps in the response. Furthermore, in its role as a focal point for gathering and disseminating best practices learned from around the world, TREMOR can work with national governments to suggest legislative changes on topics such as building standards and emergency preparedness planning. With a big-picture view, the TREMOR organisation could also play a role in proactively identifying those regions that are most in need of reform and suggesting courses of action to relevant authorities.

The TREMOR proposals represent far-reaching objectives ranging from earthquake early warning to long-term recovery after an earthquake disaster. The proposed prototypes provide frameworks for establishing the necessary systems, and the exact implementation will take many forms tailored to specific regional needs. Throughout this development, education and training will represent the backbone upon which all efforts will be built for an effective system.

CONCLUSIONS

The 2008 Sichuan earthquake was a grisly reminder of the devastating power of earthquakes. The potential for massive loss of life and property is still very much a real threat around the world. An international team gathered in the summer of 2007 as part of the International Space University Summer Session Program to propose a global solution to address earthquake disaster response. The resulting TREMOR report outlined a multi-part proposal to establish an international non-governmental agency to provide an earthquake response prototype and earthquake simulation prototype. These prototypes would assist governments in preparing for and responding to earthquakes through integration of a variety of space-based assets pooled from around the world with local terrestrial resources. Combined with a heavy emphasis on education, planning, and coordination of national and international emergency response personnel, regions affected by earthquakes, regardless of economic or political status, will be better empowered to reduce the loss of life resulting from such natural disasters.

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