# The Use of Space Technologies to Monitor and Respond to Earthquakes Economic Perspective

A.M.Eren[1], W. Peeters[2], J. Farrow[3]

[1]International Space University, ahmet.m.eren@gmail.com
Parc d'Innovation, 1 rue Jean-Dominique Cassini, 67400, Illkirch-Graffenstaden, France
[2]International Space University, peeters@isunet.edu
Parc d'Innovation, 1 rue Jean-Dominique Cassini, 67400, Illkirch-Graffenstaden, France
[3]International Space University, farrow@isunet.edu
Parc d'Innovation, 1 rue Jean-Dominique Cassini, 67400, Illkirch-Graffenstaden, France

**Abstract- This paper presents the role of space based technologies like remote sensing (RS) and Global Navigation and Satellite Systems (GNSS) for earthquake disaster management. The space based technologies like GNSS and RS applications can help in prediction, preparation, response and recovery phases of the disaster management cycle. After an earthquake mapping the extents of damages, locating the urgency of the areas and reconstruction of these areas can be provided as valuable information by space based solutions to disaster management. Financial and economic aspects of space systems are also presented through a Cost Benefit Analysis (CBA), and illustrated by a quantitative case study.**

## I. INTRODUCTION

Humankind has been subjected to natural disasters throughout history and each year enormous numbers of deaths occur and millions of dollars are lost due to earthquakes. There are a lot of scientific studies going on all over the world to predict earthquakes before they occur but unfortunately there is not a clear model developed to predict earthquakes. The space techniques which can be very helpful in prediction, assessment, mitigation and recovery periods of the earthquake management cycle will be presented. Economic impacts of earthquakes are also discussed throughout the paper and ways to reduce these impacts especially focusing on space techniques will be presented. A simple cost benefit analysis (CBA) will be carried out to show the framework of how to apply CBA to earthquake management to assess the economic viability of space based systems.

TABLE I shows the economical impacts and effected population relating them with the countries subjected to earthquakes. Experience has also shown that the difference in the level of vulnerability to hazards in the developed and developing countries is not really in the number and magnitude of occurrence of hazards, but in the level of disaster management - disaster preparedness (risk reduction), mitigation, and emergency responses [1].

Most of the world's population is located in areas prone to earthquakes. No matter whether it is a developed or underdeveloped country all nations suffer from these earthquake related losses.

Earthquake losses or costs can be categorized as:

**a) Primary Effects:** Direct physical damage (to buildings and infrastructures), induced physical damage (including fires, floods, hazardous material release, etc), human impacts (deaths and injuries)

**b) Secondary effects:** costs of recovery and response (inspection costs after the earthquake, relocation of people, first response), business interruption and social and environmental costs. Secondary effects involve business continuity losses and failures. The overview of earthquake disasters shows that these secondary effects seriously complicate the rescue and relief operations, and have great economic and human consequences, which sometimes surpass the direct effects of the earthquakes.

TABLE I

Earthquake Loss between 1976-2005 in dollar adopted from [2]

| Country | Number of Earthquakes | Deaths | Public Affected(M) | Economic Loss (B$) |
|---|---|---|---|---|
| Japan | 28 | 5.794 | 3,2 | 132 |
| Italy | 20 | 5.714 | 0,7 | 30 |
| US | 21 | 145 | 0,06 | 25 |
| Turkey | 38 | 24.371 | 6,1 | 16 |
| Iran | 67 | 100.851 | 2 | 10,9 |
| China | 82 | 244.344 | 20,7 | 8 |
| Greece | 21 | 340 | 0,9 | 7,2 |
| Mexico | 20 | 9.738 | 2,5 | 4,7 |
| Afghanistan | 24 | 9.202 | 0,6 | 1,7 |
| Indonesia | 66 | 6.496 | 1,8 | 0,8 |

Earthquakes also have great impact on tourism assets which can be very important for some countries. Social development of the public and their anxiety and stress should also be addressed.

## II. EARTHQUAKE DISASTER MANAGEMENT CYCLE

In all these stages data and information can make a difference between people living and dying [1]. While it is not possible to prevent some natural hazards, if required data is gathered and used effectively during the phases of disasters, it is possible to save lives and assets. This can be achieved by using possible new technologies but especially space systems. GIS (Geographic Information System) has great importance to see the big picture in disaster management together with space based systems.

***Prediction:*** Scientists use satellite data to search for the mechanisms behind the earthquake and try to understand if it is possible to predict them. The recent studies aimed at proving the relationship between earthquakes and the atmosphere can be summarized as:
1. The interaction between the ionosphere and earth's crust, which recently has become the most popular method of seeking precursors for the onset of earthquakes.
2. Looking for water vapor occurrence in earthquake prone areas due to heat.
3. Low ionized earthquake clouds and their relations to earthquake

In addition Global Navigation Space Systems (GNSS) are being used extensively to monitor fault lines

***Preparation:*** Geological mapping of an area, a region or a whole country is of great importance for early detection purposes or post earthquake control and reduction measures. Seismic monitoring networks and geological mapping will provide very valuable information for emergency responses when used with GIS. GIS can be used effectively for prediction and action plans taken for emergency response and recovery.
A European-wide study has shown that the costs of earthquake strengthening range from 5 to 50 percent of the total rebuilding costs. The return period of major earthquakes (100 years and more) is too long to make the investment worthwhile from the owner's point of view, and is also longer than public policy planning periods [3].

***Response****:* Emergency response is the most important issue since it needs to be as fast as it can be in terms of helping people who are subjected to the disasters. To monitor and decide the priority of a local region one has to have an idea what the general view is. If the satellite imagery taken after the disaster is compared to the pre-disaster images, the effected areas are easy to see. In order to satisfy this, pre–disaster imagery should be available and immediately accessible to the managers. This needs an archiving strategy and GIS experts that can easily implement the situation and make comments on the new imagery. Satellite based telecommunication systems have to be adopted for the cases of long time interruptions between the managers and the local regions. This has great importance in an earthquake emergency response phase.

***Recovery:*** During this period mapping of the regions shall be done immediately and all data should be archived as satellite images and in GIS databases and shall be readily available. During the recovery period especially when deciding the urbanization planning, satellite imagery can be very useful in terms of large coverage of areas to be concerned. GNSS systems based on GPS are also widely used in reconstruction works.

Disasters do not care about borders and it is absolutely necessary to take initiatives for international cooperation in all phases from the scientific research to forecast earthquakes right up to the recovery phase cooperation. The UN Charter which aids in the delivery of satellite imagery in case of disasters to the nations subjected to the catastrophes and the Disaster Monitoring Constellation (DMC) are recent examples of space based cooperation between different nations taking part in monitoring disasters all over the globe. A satellite constellation while enabling the nations to operate their own satellites individually also allows data sharing and exchange among them.

### *A. Benefits of Space Systems to Earthquake Management*

Benefits of space based systems to earthquake disaster management can be categorized as GNSS benefits, RS benefits and telecommunication benefits.

***GNSS Benefits****:* GNSS is the unique technology providing knowledge of time and the precise location of landmarks, streets, buildings, emergency services (for fire fighters, ambulances, rescue teams, etc). This information is very important and valuable to reduce the time for rescue teams to get to the desired location to save lives or to reduce losses resulting from earthquakes and their secondary effects (ie fires).

*Detection of ground movements*: Developing seismic instrument networks over large areas requires that these instruments work together precisely timed. GPS based timing works extremely well in such cases in terms of accuracy. Integration of such systems to ground based seismic networks enables scientists to locate the epicenters of earthquakes very quickly. Moreover this helps scientists to understand how strain builds up slowly over time by transferring landscape movements to the seismic networks which can even lead to early warning of earthquakes.

*Aid operation Management and Tracking*: After the earthquake one of the most important actions to be taken is supplying human aid and necessary resources to the regions subjected to maximum hazards. This needs complex logistics solutions especially if the local region is outside the basic infrastructures. Even the infrastructure that is there will most probably be affected by the earthquake. Providing navigation and knowledge of the traffic situation can significantly improve the time to get to the place of emergency. Ambulances, polices and rescue teams can be tracked and managed accordingly in real time without time loss which becomes critical in the case of earthquake emergency response to reduce losses and save lives. Mobile phones with integrated GNSS receivers can be tracked precisely in terms of location. After an earthquake this can lead to enormous help to locate people, and thus save lives.

*Detection of Power Anomaly*: In cases of earthquakes lot of power blackouts occur throughout the network and GNSS can help in increased time synchronization throughout the power grid to locate the power line break by analyzing the precise timing of an anomaly. Quick detection of these power anomalies can offer enormous cost saving in terms of business interruptions of long hours or days which is the case in most disasters[4].

*Detection of Precise Location:* GNSS is widely used to locate the spatial coordinates within mm accuracies. It is used in surveying and mapping of the regions in civil engineering applications which makes it faster and reliable compared to ground based human based surveying engineering. That will help enormously in the recovery phase after an earthquake.

***Remote Sensing (RS) Benefits****:* There is a wide range of sensors used for RS such as optical, microwave and radar. All of them can be used in emergency cases with the great advantage of gaining valuable information during response or recovery phases as well as during the mitigation and preparation phases perhaps even resulting in early warning capabilities in the near future. In response and recovery phases of the earthquake management cycle managers can use RS data to rank the relief efforts within the limited resources if they have the latest information from the disaster region. Optical and radar payloads are also both used to detect and manage the earthquake. However, these techniques are limited by the repeat period of the satellite track (up to 35 days in the case of ERS1/2), which also influences the coherence of radar images.

***Communication Benefits****:* Satellite communication systems like Inmarsat, Comsat, Globalstar and Iridium are essential to communicate and to react as quickly as possible since during a disaster the most important thing is reliable and fast information taken from the local teams. During the first three days after the Marmara earthquake (1999) no communication was established between decision makers and field teams. Moreover for the first six hours no communication was established between local decision makers and central government. The only means of communication was based on amateur short-wave radio frequency. Another application of telecommunication satellites is in the telemedicine. NASA first used telecommunication technology to furnish disaster aid following the devastating 1985 Mexico City earthquake [5].when the Advanced Technology-3 (ATS-III) satellite was used for voice telecommunication among rescue teams and decision makers. The U.S.-U.S.S.R. Space Bridge project, developed for telemedicine support for astronauts in U.S.-Russian space missions, was used to link regional hospitals in Yerevan to US centers through satellites (Intelsat and Comsat) after the Armenian earthquake in 1988[6],[7]. The program utilized two-way interactive audio and unidirectional full-motion video transmissions from Armenia to the United States. Separate data and fax transmission lines provided additional bandwidth [8]. Recently Japan launched the Engineering Test Satellite-VIII (ETS-VIII) to provide S-band mobile satellite communications with hand-held terminals. JAXA will launch the Wideband Inter Networking engineering test and Demonstration Satellite (WINDS) in 2008. WINDS will demonstrate technology necessary for the future satellite-based communications architectures to provide users with high speed internet access and data uplink/downlink capability with small antennas in disaster cases.

## III. COST BENEFIT ANALYSIS TO EVALUATE USAGE OF SPACE FOR EARTHQUAKES

Cost Benefit Analysis (CBA) is a systematical way of evaluating alternative decision options that have an impact on society. It requires bringing together scientists and engineers with social scientists to analyze a problem. Performing a CBA of usage of space techniques to reduce earthquake losses involves a lot of challenges within the nature of the problem from the first step right up to the final steps of the CBA cycle. Ground based systems are taken as one end of the spectrum and space based systems on the other end of the spectrum for the sake of simplicity. Once CBA is performed it is presented to decision makers as a tool to make economic sense to them while satisfying their political concerns with accomplishing the important task to convince decision makers.

*Step 1 Specify the Nature of the Problem:* The question asked is “Should the governments invest in space based techniques to save lives, is it feasible from an economic point of view?” The first step is to identify the options that are available and carried out throughout the rest of the analyses. In our analyses there are basically two options: 1) Ground based systems (status quo) 2) Space based systems.

If the mitigation costs are not less than the expected benefits then the status quo will be maintained that is to say no investment will be made to the alternative options. The question can easily be answered as governments should invest no matter what the cost of a system if it is capable of preventing deaths in earthquakes. For example, a few meteorological satellites built for about $300 to $500 M each, that were already in orbit were used to help predict few days in advance that Hurricane Katrina in the US would be terribly devastating for the southern USA. When one realizes that the total damage from Katrina is estimated today to be close to $100 Billion what could be the savings from the meteorological satellites in this case and would it encourage more systems to be built? The same logic works for earthquakes.

*Step2 Costs of Mitigation Alternatives:* In our case the cost of mitigation alternatives is that involved in building and launching a space based system to mitigate losses of the earthquakes. This mitigation includes satellite costs, network costs, ground based system (database, communication systems, etc) costs and administrative (staff, salaries, etc) costs. The alternative options include telecommunication, GNSS and RS monitoring. GNSS like GPS is already there and only subscription and user costs exist which are not so high. Direct cost of the satellite based systems together with ground stations and all necessary infrastructure including telecommunication, GNSS, RS etc is taken as 100 M$. This is not based on a detailed study number but it is only to show the systematic procedure to be performed for such a kind of cost benefit analysis including the probability of having an earthquake. The numbers are illustrative at this level and are used to illustrate the approach. Cost estimation software like HAZUS can give reasonable numbers though this is out of scope for this paper.

*Step 3 Benefits of Mitigation Alternatives and Attractiveness:* There are only two possibilities. These are that the earthquake will occur with a probability of p over T years, and so no earthquakes with a probability 1-p. The benefits of space based systems taken here is to reduce the lives lost during the earthquake by forecasting its occurrence. There have been surveys in [10],[11],[12] about the economic value of lives by asking people how much they must be paid to accept different risks and these surveys resulted in a value between US $ 2,5 M and 4 M in 1999 dollars in the US. Of course this can be related to the GDP of the country where the survey is carried out but rather than arguing this value, a reasonable amount that can be changed depending on the region is taken as $ 1M which is the same value as in [9].

In this analysis, the probability of an earthquake occurring is taken as 1 in 100 year event (p=0,01) in a 50 year time period and a discount rate of 4% is chosen. Usually the discount rate for social return projects is taken between 3 and 7 %. The expected discounted benefits with the assumptions stated over the time period of 50 years are given in TABLE II.

TABLE II

Expected Discounted Benefit/Cost ratio over time with different number of lives saved

| | Expected Discounted Benefit/Cost Ratios | | |
|---|---|---|---|
| Year | Case 1 (1000) | Case2 (2000) | Case3 (3000) |
| 5 | 0,34 | 0,69 | 1,03 |
| 10 | 0,52 | 1,05 | 1,57 |
| 15 | 0,55 | 1,10 | 1,66 |
| 25 | 0,56 | 1,11 | 1,67 |
| 50 | 0,56 | 1,11 | 1,67 |

*Step 4 Choose the Best Alternatives:* In CBA the main goal is to have the highest NPV or lowest costs. With the calculations shown in TABLE II and Fig. 2, the benefit to cost ratio for 50 yrs time for saving about 2000 lives concludes in investing in space based techniques. Of course changing the T or discount rates or the probability of having an earthquake in the region (ie 1 in 30 yrs) will affect the results significantly. The benefit to cost ratio gets higher with the number of saved lives as shown in the graph below. This CBA analysis is only to show the simple methodology to be carried out to evaluate the return from investments in space based techniques in general. But several more detailed CBA can be carried out separately for special cases of space techniques.

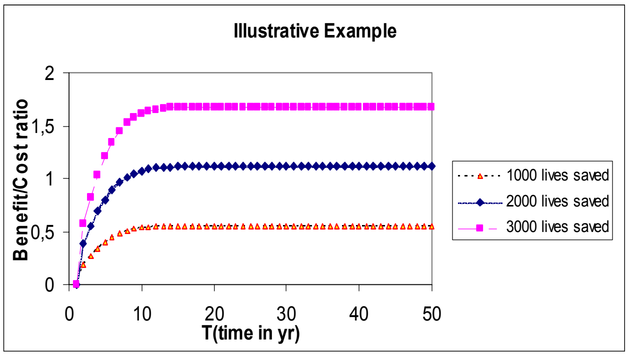


Fig. 1. Benefit/ Cost ratio comparison

As showed Fig. 1, 10 year time period is enough to decide whether to invest in space based techniques within these assumptions. If one increases the discount rate then the benefit to cost ratio will drop accordingly. The assumed value of a life can change from one region to another but it can be correlated with the GDP of the countries for those countries where reference surveys have been carried out.

Now considers not lives saved (direct costs) but business interruption losses (indirect costs) of earthquakes. The direct economic loss methodology in Ref [14] can be used for the estimation of business loss in an area. The initial loss to a business sector j in the region directly after the earthquake is:

$$L_j=(1-a).g_j.F_j \tag{1}$$

where a is the percentage of customers receiving a service after earthquake, j is the separate sector (manufacturing, construction, services, agriculture, etc), g is the gross regional product (GRP) and F is the importance factor of the business sector expressed as a percentage.
For a scenario with an earthquake restoration time T is in days and the loss of production within time T is;

$$L_T = \sum_{t=0}^{T} L_j \times \frac{(T-t)}{T} \tag{2}$$

Assume j=1 (single sector), a= 20%,GRP= $ 0,3 B, d=8 %,T=50 yr, we calculate the benefit to cost ratio for the investment for space systems which can make the restoration time less and thus reduces the losses resulted from business interruptions.

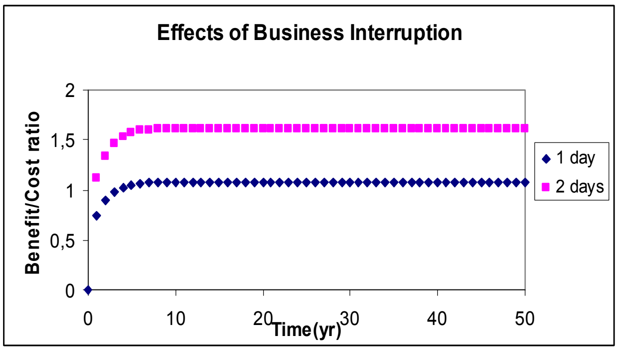


Fig. 2. Business Interruption Benefits

In Fig. 2 saving 1 day or 2 days of indirect losses from earthquakes (business interruption losses) are shown and it can be concluded that space based systems can reduce the business interruption losses with the capabilities in telecommunication, GNSS, RS that are all discussed throughout the paper. Rapid detection of a power anomaly, enabling a reduction of the interruption from 2 days to 1 day will result in millions of dollars of benefit.

## IV. CONCLUSION

To sum up it can be concluded that space systems can enhance the capabilities during disaster management cycles. Especially in the case of earthquakes they can help a lot in saving lives and reducing economic losses. Building a framework that will include the ground based systems together with space based systems is still in an emerging phase. Space based system costs and their benefits should be quantified to show that regardless of the disaster, the benefits have always been greater than the average cost of systems though it is very hard to quantify the benefits. Governments in general are not interested in spending millions for systems that may (this is the key word) help better predict, mitigate, respond or help populations to recover from disasters. CBA is a systematical tool to convince policy makers and managers due to its ability to assess the investments economical feasibility. Further research is needed to refine the figures.

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