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uide to Cost-Effectiveness Study of Instituting Disaster Mitigation Measures for Hospitals in Latin America and the Caribbean

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First Draft

September 14, 1995

I. Introduction

This report details the framework used in developing a cost-effective study of instituting disaster mitigation measures in Latin America and the Caribbean. This does not provide conclusions as to whether or not it is cost-effective to adopt disaster mitigation measures in most of Latin America or the Caribbean islands. The aim of the study is to relate hazard conditions to disaster mitigation measures. Specific site studies will be needed to determine whether or not it is cost effective to adopt these measures in regions facing seismic risk. For hurricanes conclusions are easier to make, since the risk of hurricanes is faced uniformly by a region.

The vital sets of data needed for this study are risk assessment, an estimate of damage of the building at different intensity of natural calamities, assessment of effectiveness of a hospital under different functional capacity during the time of a disaster in terms of epidemiological factors, the social cost of non-functionality at different levels, cost of retrofitting and the cost of repair to the physical building. Below we detail what form this data should be made available and how they should be used. This along with the instruction manual should serve as a guide to the Lotus123 worksheet (to be provided soon).

II. Disaster Risk

In conducting a cost effective analysis of disaster mitigation measures risk assessment must be the first step. While to some extent hurricanes can be predicted, earthquakes are not easily predicted. Risk assessment of meteorological disasters are more readily available than the seismic risk since this sort of risk can be more site specific. Below we detail what is needed and what we have at the present moment.

The data for maximum Modified Mercalli intensity (MMI) is available for many zones in South America. As a first step toward approximating the seismic risk we use this data to calculate the risk. The data is stated in terms of maximum expected intensity with a 90 percent chance of not being exceeded or being exceeded with a 10% chance or in ten 50 years or in a smaller time interval. Note that this is not to say that the probability of the occurrence of an earthquake of the stated intensity is 90%.

The zones are identified either by fault lines or other geotectonic characteristics. The epicentral distance of a site and its soil type determines the actual seismic risk. One method used in devising policy is to reduce the soil specificity to broad categories of average soil types for a region. The first step in assessing risk is to incorporate the maximum MMI and the distance from the epicenter which then later takes into account the average soil conditions. Algermissen et.al. (1995) normalize the intensity level as the difference between the observed intensity at a particular sight, I, and the maximum intensity in the macroseismal region, I_0 is a function of the epicentral distance r. That is $I-I_0 = f(r) = D$. For Chile the calculated $\hat{D} = 4.6492 - 2.960 \log(r)$. $\hat{D}$ is taken as the predicted or average intensity and $D - \hat{D}$ is the residual. These residuals were averaged if they fell within 1 mile of each other and were within the same soil types to obtain site specific response factor. The response factor ranged from -2 to 1.5. A negative site response of, say -2.0 indicates that a site typically will experience two degrees of intensity less than an average site. One can go back to the general zones and assign more site specific MMI by increasing or decreasing the macroseismic numbers according the above calculations.

In Santiago alone differences in average seismic risk can vary up to 1.5 degrees in MM intensity scale. Seismic codes very often do not consider microzonation but incorporates local site effects by recognizing four different categories i) rock, ii) dense gravel or equivalent, iii) medium density sands and stiff clays and iv) soft to medium clays. A more precise definition, including thickness of the strata, soil properties, and the probable shearwave propagation velocity can be used.

What is needed, for a cost effective analysis, is different MMI levels a region might face in a given year. The ideal approach would be to obtain a probability distribution for intensity level between VII-X for each year of the duration of the project. Here we will use the risk assessment for maximum MMI developed by CERESIS and Algermissen et.al. to develop an account of seismic risk. Perhaps finer data detailing the risk at different MMI level could be used in the final draft.

For the present study we would like to propose preparedness for 10% exceedance of the maximum MMI within a 20 year time interval. We will use the conditional probability estimates for the occurrences of these events given over 1989-2009 which we assume would be the lifetime of a hospital structure.[1] Zones facing a maximum MMI of less than VI will not be considered for evaluating structural retrofitting plans. An MMI of V is equivalent to 4 in the Richter scale or 10^{17} level of energy. The highest MMI for Chile provided by CERESIS is X over 20 years starting from 1989. Algermissen et. al. provide the highest level of XI as the maximum MMI for a region in Chile with 90% chance of not to be exceeded in 50 years. Algermissen et. al. estimate is more site specific.

[1] Some data is available for 50 years 10% exceedance level.

The seismic data that we use is of the following type:

Table 1.

Maximum likely seismic intensity	Location	Conditional Probability 1989-1994	89-1999	89-2009
X	Guatemala City	10-29	23-51	50-79
IX	Lima, Peru	3	8	24
VIII	San Salvador, El Salvador	29	51	79
VIII	Antofagasta, Chile	4	11	29
VII	Jalapa, Guatemala	29	51	79

From the data above a reasonable approach would be to carry out the cost effective study for 10% exceedance maximum MMI level by generating a hazard function for each year given the average probability for each of the three periods. It provides the probability of having an earthquake at time t given that one has not occurred between 0 to t years. A hazard function assumes that a earthquake will occur only once in 20 years. This is not an unrealistic assumption since our analysis only takes into account the maximum level of seismic disturbances and magnitude of these seismic disturbances are large.

In our calculation we assumed that the probability distribution of occurrence of earthquake in each year is independent and identical every year within a time interval. The hazard function or the rate can be expressed as

$$\lambda(t) = \frac{f(t)}{1 - F(t)}$$

where f(t) here is the average value for each year from Table 1 and F(t) is the cumulative probability of having had an earthquake. The function $\lambda(t)$ is the instantaneous probability that an earthquake of magnitude or intensity x occurs at time t. The use of λ derived from the data in Table 1 implies that we offer a worst case scenario. Hazard rates increase over time as probability of not having had an earthquake up to a point in time decrease overtime. Below in Table 2, this probability is given for the above raw data. The density used is a weighted average of the number above for a given region over the 20 year time period.

Table 2:

Hazard rate: the probability of earthquake of magnitude x occurring in a given year when no earthquake has occurred in the previous years.

region. An inaccessible hospital makes very little difference at the time of disaster. In this case the impact of a damaged hospital on health status is small.[2] A region may be able to withstand temporary shut down of a single hospital for the duration of repair. If the damage to a hospital has very little impact on the health status of the affected region then the entire cost of retrofitting should be weighted against only the *cost of repair.*

IV. Measurement of the impact on health

Health impact involving hospitals can be divided into internal and external elements. Hospitals are occupied nearly at capacity for the entire 24 hours; its habitants are especially vulnerable to disasters. The casualty rates are usually higher in hospitals than elsewhere in the affected region. A careful analysis of data from past disasters will be completed for this study to indicate expected loss in terms of DALYs (disability adjusted loss of life years) due to damages to the hospital structure and equipment.

The external measurement of health status that is relevant for this study is more complicated. The morbidity rate is most relevant here: It is made up of those that need hospital care immediately and perhaps later when the hospital will remain inoperative. Assuming that the hospitals remain accessible during the time of disaster, certain part of the hospital are vital. Comprehensive epidemiological studies of past disasters provide us with information as to which functions of a hospital should receive priority in order to remain operative at the time of disaster. The effect on long term health status due to damages to hospital is more complicated. It may be heroic to assume that every existing hospital is cost effective. On the other hand it may be that there is an increase in morbidity and mortality immediately after a natural disaster. We are currently trying to obtain this information for the 1985 Mexican earthquake. The cost to society due to a hospital remaining inoperative is not easy to determine. But this is precisely what is needed to see whether or not retrofitting cost should be incurred if retrofitting cost is higher than the repair cost.

The indicators of health status will be stated in units of DALYs, using the current indexes developed here at the Harvard Center for Population and Development Studies.

V. Cost of retrofitting

The cost of retrofitting building for disaster mitigation will be taken from the studies compiled by Tony Gibbs and the FEMA (Federal Emergency Management Administration of the US) document on typical costs for seismic rehabilitation of

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[2] In the case of disaster of large magnitude hospitals may be inaccessible. Risk of loss of lives is also greater within the hospital for such disasters. The cost undertaken to prevent the loss of these lives may be cost effective even if the hospital is inaccessible. Functionality alone does not guide us well in conducting the cost-effective analysis. In the case of disasters of small magnitude, functionality may be the only thing affected; no loss of lives would be expected from, say, normally built US hospitals.

buildings. The study by Gibbs covers the Caribbean where as the FEMA study pertains to the US. Some extrapolation will have to be made. Partial mitigation efforts are important. It would be ideal to relate each dollar spent on mitigation effort to benefit acquired in terms of prevention of damages to building and gains DALYs. But the data available for any cost-effective analysis is not that fine. One way to take into account of the effectiveness of partial mitigation is to prioritize hospital services and determine the cost of preventing disruption of those services. Polard's guide will serve us to find a relation between different levels of retrofitting measures and benefits. It is likely that some basic retrofitting measures is cost effective while more advanced methods are not.

One would like to know the repair cost by square feet. If structural damage is the only concern, this would suffice. The problem of functionality imposes a more difficult problem. Hospital equipment are heterogeneous goods. It would be difficult to come up with unit cost. A simple percentage of the total equipment cost may be all that can be provided. Hence, if there is a 20% in functionality loss then 20% of the equipment will be replaced at a cost 20% of the replacement value of the total equipment. This along with structural repair cost would serve as the monetary cost to which the cost of retrofitting should be compared.

VI. Calculation of the cost and benefit

All of the above cost will be added and discounted according to when the disaster occurs. Suppose the disaster occurs 10 years into the planning period then all the above cost will be discounted by 10 years at a constant rate. We recommend that this be discounted by the growth rate in the economy. Lives lost and health effects will be discounted differently than monetary units, perhaps at 2%.

We will assume that the society is risk neutral. One advantage of this is that it will value the incremental lives saved the same way. That is the society will be willing to pay 1 million $ to save the 10^{th} life saved and the same amount for the 100^{th} life saved. In a 30 year span we may claim that earthquakes occurs once; but hurricanes may occur more frequently. The expected value of loss would be the probability of disaster multiplied by the cost incurred in the year of the disaster under either of the policy actions.

Calculation of benefits due to the prevention measures for each year is the loss of damage without the measures minus the costs that would accrue with the measures. Hence the total benefit for earthquake retrofitting would be:

$$B = \sum_{t=0}^{T} p_t(MMI)(c_t(MMI) - c_t^*(MMI)).$$

where T is the life of the project, the subscript t indicates time away from the present time, $p_t(MMI)$ is a probability distribution over the mercali index or PGA and c and c* is the discounted monetary cost of without the measures and with the measures respectively. At present MMIs are for the maximum MMI levels. Note that B is expressed in the present value terms.

Calculation of B for hurricanes is very similar. We would replace the MMI with intensity of the hurricane. The study is done for one investment period. So only investment at the beginning of the period is considered. That is we do not take into account of the fact future repairs undertaken every time there is a hurricane actually reduces the damage from future hurricanes. We merely look at the effect of one single investment, made at the beginning of the time period.

We need to compare the initial investment cost I with B. Then if B>I, the project should be undertaken even without accounting for any health benefits. The replacement cost alone is so overwhelming that the initial investment is warranted.

If B<I, then we should note the health benefits arising out of the project. Let B-I = W, the true monetary cost of the project. The DALYs gained due to the project is simply DALYs lost without the project minus the DALYs lost with the project; denote this number as Q. Then W/Q is the cost of a unit of DALYs averted, the amount of money that acquires one extra disability free life year. The next question to ask is should the cost W/Q be borne by the society.

VII. Conclusion

We conclude by putting this cost-effective study in a broader perspective. If the health status of a society is not affected strongly by the damage to hospitals then retrofitting cost should be compared to the repair cost. If the retrofitting cost is higher than the expected cost of repair then a risk neutral society will not undertake retrofitting. That is while the society may be risk averse toward health status it is willing to bear the risk of losing money. Costs incurred by a government at the time of a disaster is rather large; there may be, in this situation, a premium attached to an extra dollar spent that would be absent at normal times. This could explain why a society spends money for retrofitting at the time of construction for different buildings even if the expected repair cost could be lower than this cost. The society seeks to achieve expenditure smoothing across time. An insurance scheme could allow for even greater expenditure smoothing.

An insurance scheme could be adopted jointly between smaller countries if risk faced by these countries is not uniform. Seismic risk may not be uniform; however, risk faced from hurricanes may be. Risk faced from all disasters is not uniform. That is not all countries will face equal risk of losses from disasters, for example, hazards from earthquakes could be more site specific and some will face hurricanes in a given year and some will remain unscathed from any sort of natural disasters. In that case an adoption of insurance scheme may be cheaper than retrofitting in allowing for greater expenditure smoothing.

When health status is affected significantly by the condition of the hospital, expenditure smoothing should not play a large role. Jamison (1993) indicates that there are many health intervention that cost less than $75 per DALY. Garber and Phelps (1992) argue that under a reasonable range of assumptions it will make economic sense to pay for DALYs up to a cost of about twice the level of national income.

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