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DEVELOPMENT OF STRATEGY EFFECTIVENESS CHARTS TO COMPARE EARTHQUAKE DISASTER MITIGATION STRATEGIES

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ABSTRACT

To evaluate the cost effectiveness of an earthquake disaster mitigation strategy, the proportional distribution of its costs and benefits between the different sectors in a region should be accounted for. This is important since each sector, such as the homeowners, utility companies, commercial establishments etc., all have different resources and priorities for mitigation. This paper introduces a study currently involved in developing a sector specific technique to evaluate strategies based on benefits directly received by the sector paying for and implementing them. For each sector, the technique will result in a strategy effectiveness chart (SEC), that graphically illustrates the variation of the benefits with incremental dollar investments in different strategies. At the time of writing this paper, the analysis is currently underway and numerical results will be presented during the conference. This paper will describe the approach of the study, steps involved in developing the methodology, assumptions made, and potential applications of the results.

KEYWORDS

Preparedness index; earthquake impacts; recovery requirement; sector; strategy effectiveness chart.

INTRODUCTION

Today, one of the major problems in the field of earthquake disaster mitigation is to evaluate the improvement in earthquake preparedness for every incremental dollar invested in mitigation. To address this problem, strategies have been evaluated using a cost benefit analysis based on the reduction in dollar loss and human casualties at the regional level. Research has developed data for structural strategies like retrofitting of buildings and lifelines (FEMA 1991, Augusti *et al.* 1994, Litan *et al.* 1992) and disaster response strategies (Berke *et al.* 1988). Factors affecting the feasibility of implementation of mitigation measures (May and Bolton 1986) have been identified and results of surveys of the local response to mitigation measures has been collected (Berke *et al.* 1988). The above data is based on a uniform distribution of the costs and benefits within the region. In reality, the marginal effectiveness of dollar investments in mitigation would vary for the different sectors; homeowners, utility companies, commercial establishments etc. There are two reasons for this variation; first, each sector has different social and economic characteristics that affect the severity of the impacts it will experience; second, differences in its priorities and resources would influence the effectiveness and feasibility of the strategies. As a result, a cost benefit analysis of strategies at the regional level does not provide enough information or incentive for the sectors to invest in mitigation.

What is needed is a standardized technique to separately compare the costs and benefits of strategies for each sector. The study described in this paper evaluates mitigation strategies, based on the benefits directly received by the sector paying for mitigation. The study will evaluate how the marginal effectiveness of dollar investments would vary with a change in the risk, priorities and likelihood of implementation of the strategies. For each sector, results of the analysis will be illustrated graphically using a strategy effectiveness chart. The chart will allow a direct comparison of the change in preparedness with every incremental dollar invested in the different mitigation strategies. As an application of the methodology, three strategies are evaluated for the homeowner and the commercial-industrial sectors in the San Francisco Bay Area, California; retrofitting, insurance and recovery operations. Since the analysis is currently underway, numerical results will be presented during the conference.

The goal of this study is to present a comparison of the mitigation strategies rather than to identify which one would be optimal for each sector. That decision will be made by the user of the methodology based on the priorities and the resources willing to be committed. The potential benefits from such a study lie not only in it's final results, the strategy effectiveness charts, but also in the insight gained during the process of developing these charts. First, the SEC's could be used to decide where to invest resources in mitigation to maximize the benefits for each sector. Second, identification of factors affecting the feasibility of implementation of the strategies would help to choose what incentives for mitigation could be effective in each sector. Third, once the SEC's have been developed for all sectors in the region, they could be used to compare the effectiveness of this sector specific approach with the traditional regional approach to mitigation. Finally, though the methodology is being developed for earthquake disaster mitigation, the technique could just as easily be applied to the case of mitigation of risk from other natural or man made hazards. The basic goal in each of these situation is similar; to effectively manage the risk within limitations of resources and implementation problems.

The next five sections of the paper will describe in detail the approach adopted in the study, development of the methodology, results expected, and effects of assumptions made.

BASIC APPROACH OF THE STUDY

The first step in the study, is to divide a region into it's component sectors by combining groups (individuals, families or organizations) with common social and economic characteristics, and comparable priorities and resources for mitigation. Based on this combination, five sectors are chosen

- The homeowner sector
- The commercial-industrial sector
- The lifeline sector
- The government sector
- The financial sector

These sectors are not independent of each other, since the impacts of an earthquake and benefits of mitigation in one sector indirectly affect the others. In this study, since strategies are evaluated in terms of benefits to an individual sector, only the indirect impacts and not the indirect benefits will be considered. For example, while evaluating strategies for the commercial -industrial sector, business interruption due to damage in the lifeline sector will be included. The reduction in business interruption due to mitigation efforts by the lifeline sector will not be incorporated as a benefit for either the commercial or lifeline sector.

To evaluate the benefits, a " Preparedness Index (PI)" is developed for each sector, to represent the severity of impacts of the earthquake and the ability to recover from them. The PI is expressed as a score on a scale of 0-100, where a higher score indicates better preparedness. The effectiveness of a strategy is measured as the change in PI from the base case, considered to be the current level of preparedness of the sector, i.e. before implementation of any new strategy. The current state would inherently incorporate the benefits of mitigation strategies implemented in the past. To easily compare the strategies with each other, one SEC is developed for each sector. The chart is a two dimensional graph, that illustrates the change in the performance index for each incremental change in the dollar investments in the strategy. The actual construction of the performance index and the charts is described in the next section. One must note that the base score of the PI and the benefits of the strategies, will vary with the earthquake scenario being used. While some strategies may be cost effective only in a high impact event, which has a low probability of occurrence, others may be cost effective for a moderate event, which is more likely. To deal with this variation, a range of four intensities (MMI's) will be considered for the San Francisco Bay Area, and their annual probabilities used for the analysis. The four individual PI scores will be combined to give the overall preparedness index for the sector (eqn. 1).

$$\text{PI for the sector (PI)} = \sum_i w_i PI_i \tag{1}$$

$$w_i = \left(\frac{p_i}{\sum_i p_i} \right)$$

where, PI_i is the index score and p_i is the annual probability for MMI(i)

EVALUATING THE BASE SCORE FOR THE PREPAREDNESS INDEX

The data available for each scenario typically provides two sets of information for the region. One set includes the impacts, i.e. dollar loss, human impact, loss of service of utilities and facilities and disruption in daily activities. The second set deals with the resulting recovery costs and time, i.e. response, relief, repair and restoration. (RMS 1995, Perkins 1992). Rather than using the data for the whole region, parameters relevant to the sectors under consideration need to be identified (table 1).

TABLE 1. Parameters relevant to the homeowner and commercial sectors

Homeowner sector	Commercial sector
Structural, non structural and fire loss to residential buildings	Structural, non structural and fire loss to commercial-industrial buildings
Life loss and injury due to residential building damage	Life loss and injury due to commercial building damage
Additional living expenses	Business interruption
Number homeless	Loss of service of utilities and other facilities
Loss of service of utilities and other facilities	Disruption in transportation and supplies
Disruption in transportation and supplies	Time for repair of buildings, utilities and facilities
Time for repair of homes, utilities and facilities	Time for rescue and relief
Time for rescue and relief	Time for restoration of business

While developing a technique to transform this data into the PI score, two issues were kept in mind. First, the parameters involved have different units of measurement. Second, since the sectors will have a different priority for each parameter, the change in the PI score due to a strategy should reflect which parameter the strategy will influence. The technique for developing the PI before and after implementation of a strategy involves the three stage process shown in fig. 1. Each of the three stages is described in detail below.

Stage 1: Evaluating the Severity Scores for the Parameters

One of the underlying concepts of the methodology is to evaluate the parameters(table 1) in terms of the severity of their effect on the sector. This effect includes the inconvenience associated with each parameter, its importance and its influence on the ability of the sector to recover. The absolute values of the parameters are first normalized using values for related physical characteristics of the sector (table 2).

TABLE 2. Characteristics used to normalize the parameters

Parameters	Normalizing factor
Dollar loss and recovery costs	Dollar value at risk
Human impact and disruption	Population
Recovery and response times	Normal response and maintenance time

For each parameter, an upper and lower normalized value is chosen to correspond to severity scores of 100 and 0 respectively. These values are based on expert opinion of what would constitute a severe or low effect on the sector, and on data of past earthquakes in the region. An exponential relationship between the normalized value and the score is used since the severity of the effect due to every marginal increment in the value of each parameter increases for higher absolute values of the parameter(eqn. 2).

$$\text{Severity score for the parameter } (E_i) = A + Be^x \qquad (2)$$

where x is the normalized value of the parameter, and the constants A, B are determined by the values that correspond to the scores of 100 and 0.

As an example, consider the damage to buildings. A dollar loss equivalent to 10% of the total property value in the region is considered to be a disaster situation, while a loss of about 0.01% is a low impact. Using these values in equation 2, (A = -951.83, B = 951.74). Thus, for a damage equivalent to 5% of the property value, the severity score

$$E \text{ (dollar loss due to structural damage)} = 48.7$$

Since dealing with each parameter(table 1) separately is cumbersome, the task is simplified by combining related parameters into a few representative components as described in stage 2.

Stage 2: Evaluating the Component Scores

In developing the components, the assumption is made that parameters with common normalizing factors will have similar effects on the sector, differing only in their relative magnitudes. As a result, the individual scores (E_i) can be combined to give an overall severity score for the sector. The five components used in the analysis are listed in table 3 below.

TABLE 3. The five representative components and contributing parameters

Component	Contributing parameters
Dollar Impact (D)	Structural and non structural damage, fire loss, additional living expenses, business interruption
Human impact (H)	Number dead, injured and homeless
Disruption (Dis)	Loss of utilities like gas, water, electricity and telephones; Loss of other services like hospitals, schools, disruption in transportation, supplies
Recovery Time (RT)	Time for rescue, relief, restoration of services and operations, repair of buildings and other structures
Recovery costs(RC)	Cost of emergency operations, relief and aid, repair of other facilities

For simplicity, a linear relationship is used to combine the parameters (eqn. 3). Relative weights are based on the correlation between parameters, and the importance associated with each. The values used are developed using data from past earthquakes in the region and the author's judgment of the importance that each sector would associate with the parameter.

$$\text{Component score}(S_j) = \sum_j y_j E_j \tag{3}$$

where, y_j is the weight assigned to parameter j.

Each score (S_j) represents the average severity score of a component 'j' for the sector. However, within the sector, for some groups, this score may be lower than the average, and for others much higher. To account for this variation, the average scores (S_j) need to be modified for teach of the component groups.

Modifying the Component Scores by Sector Characteristics. Most of the social and economic factors that influence the severity of the impact that a group will experience are difficult to quantify, either due to lack of data, or because the factor itself is a complex combination of a number of other factors. Rather than ignoring these effects, representative characteristics are chosen (table 4), that would reflect the influence of the critical factors, and for which statistical data is available (Carpenter and Provorse1993).

TABLE 4. Sector characteristics to modify the component scores

Sector	Representative characteristics
Homeowner	Median age, loan to value ratio of the house
Commercial	Revenue, stock price, dependency on other groups within the sector

The greater the age, loan to value ratio and dependency, or the lower the revenue and stock price, the greater the severity of the effects. Since the characteristics are quantified in different units, a standardization technique is used to make the influence of each (C_c) insensitive to the scale of measurement (eqn. 5). The score for each component (S_i), is modified for the different groups in the sector. The modified score of each component (MS_i) is a function of all the characteristics that influence its severity score(eqn 6). The positive sign is used if a characteristic increases the score for a particular group. The base score of a component for the whole sector (B_i) is obtained by averaging out scores over all its component groups (eqn 7). The groups are chosen so as to incorporate the range of values for the characteristics in the sector.

$$\text{Influence of each characteristic on the severity score} = C_c = \left| \frac{(V_c - Mean_c)}{(Max_c - Min_c)} \right| \tag{5}$$

V_C = Numerical value of the characteristic 'c ' for the sector
$Mean_c$, Min_c, Max_c = Mean, minimum and maximum value of 'c' for any group in the region

$$\text{Modified score for each group}(MS_j) = S_j \prod_c (1 \pm C_c) \tag{6}$$

$$\text{Base score for the component}(B_j) = \left(\frac{1}{n}\right)\sum_j MS_j \quad (7)$$

As an example consider a group with median age 32 yrs. in the San Francisco Bay Area, for which $Mean_c = 31.5$ yrs.; $Max_c = 36$ yrs. ; $Min_c = 30$ yrs. Using equations 5 and 6, the modified score for that group, due to the parameter median age is

$$MS_j(\text{for the group being analyzed}) = S_j(1+0.08)$$

Stage 3: Developing the PI Score

In combining the five components into the PI score for each MMI, the main task is to ensure that a change in the PI score due to mitigation reflects which component was influenced by the strategy. This in turn depends on the importance of each component for the sector. Since these values are very subjective, for completeness a range of PI values using different values for the relative importance will be generated.

$$PI_i = 100 - N\prod_j\left(z_j E^{B_j}\right) \quad (8)$$

where, $z_j$is a factor that reflects the importance of the component, and N is a normalizing factor to scale the PI_i to a score between 0 and 100.
The PI scores for each MMI are combined(eqn. 1) to give the base score for the sector.

EVALUATING THE CHANGE IN PI DUE TO EACH MITIGATION STRATEGY

For each of the three strategies, discrete levels of investment chosen to incorporate a wide range of possible benefits are evaluated. Since annual probabilities of the MMI's are being considered, all costs will also be in values per annum. For retrofitting, investments in three different levels of structural and non structural strengthening are compared. The overall cost to the sector is based on the average costs for retrofitting different types of structures(Sabol *et al.* 1988) and the percentages of each type of structure in the region (NIBS 1994). For earthquake insurance, three levels of deductibles and corresponding limits are chosen. The cost to the sector is the average annual premium (DOI 1995). For recovery operations, investments are generally provided by either the government or lifeline sectors. This option is being considered for the homeowner and commercial sector to evaluate the feasibility of investing in a pool which will be used to ensure speedy repair of utilities and facilities after the earthquake. Such an option would involve a number of legal and logistic issues, but these will not be considered to avoid complicating the study.

Due to implementation of a strategy, the original impact and recovery requirement data associated with the earthquake scenario will change. New values for the parameters(table1) are developed using results from past studies (Shah 1989, BAREPP 1985, ATC 13) and expert opinion. These values are used to evaluate new scores for the PI, using stages 1- 3 above. The change in the PI score represents the benefit from that strategy assuming a 100% level of implementation. This value is modified by the actual likelihood of implementation in the sector, which depends on potential weak links in the implementation of the strategy and prospective tradeoffs involved(May and Bolton 1986). The assumed value of 100% is reduced based on the inconvenience associated with implementation, costs, benefits, and perceived risk. Any incentives provided to implement the strategy would increase the likelihood. The actual change in the likelihood is based on data for the past success and implementation problems experienced in the region (Berke and Wilhite 1988, BAREPP 1988, Palm and Hodgson 1992, Palm 1995). The PI score for different levels of investment will be compared to account for the subjectivity in evaluating the implementation levels(eqn 9).

$$PI_i' = PI_i(IL) \quad (9)$$

where, PI_i and PI'_i are the PI scores before and after accounting for the actual level of implementation (IL) respectively. This process will be repeated for each MMI considered.

Once the results for individual strategies have been developed, combinations of strategies will also be evaluated to compare the effectiveness of investing the resources in a single strategy vs. spreading them over a combination of strategies. The costs for a combination will be the sum of the costs of the individual strategies, but the total benefits may be different from the value obtained by simply summing up the individual benefits. This is due to the fact that different strategies may affect the same components and as a result, their benefits may overlap.

Creating the Strategy Effectiveness Charts(SEC)

The results of the analysis will be illustrated in the strategy effectiveness chart. The base case for the sector is a point corresponding to zero cost and the base score for the performance index. For each combination of strategies, points representing the increase in cost for the new level of investment and the resulting modified PI score(PI') will be plotted. The final chart will be a two dimensional representation of the variation in the performance index for every incremental dollar invested by the sector. The SEC's for the two sectors will be presented during the conference.

APPLICATION OF THE RESULTS FOR THE TWO SECTORS

The emphasis of the study is not on the actual numbers themselves but on the development of the SEC's and the insight that could be gained from such an analysis. From the SEC, the effectiveness of investing in retrofitting, insurance or recovery operations, could be directly compared for each of the two sectors. The marginal effectiveness of the dollar investments could be computed as the slope of the curve at any point. An analysis of the components contributing to the PI score will identify which parameters are affected by each strategy. Using these values, a homeowner or commercial property owner could choose whether to invest the resources in a single strategy, or spread them over a combination of strategies, based on the priorities for mitigation. In developing the methodology, the sector specific characteristics influencing the effectiveness of strategies would be useful to choose incentives for implementation of the strategies.

EFFECTS OF ASSUMPTIONS MADE IN THE STUDY

In developing the methodology, assumptions were made to simplify the problem from two perspectives. First, to reduce the number of variables involved to a few critical ones. Second, to represent these variables by parameters that were easier to quantify, but which would accurately reflect the influence of the original variables. The effects of these assumptions on the results of the study are discussed in this section. First, the indirect benefits, resulting from mitigation efforts in other sectors are being ignored. Since strategies are evaluated from the perspective of individual sectors, this interaction should not influence the choice of feasible strategies for that sector. Second, a linear technique is used to combine parameters into the five components(D, H, Dis, RC, RT), and the scaling is based on expert opinion. This scaling will have an influence on the final numbers, but the focus of the methodology is to develop one possible range of values, not the most accurate ones. Third, though only a few of the sector specific factors are incorporated, the asumption is not made that the other factors are not important. The factors are not incorporated either because data is not available, or because a single representative characteristic cannot adequately account for the all the variables that influence them. Finally, due to lack of data, a very subjective technique is used to evaluate the likelihood of implementation. To circumvent this subjectivity, different implementation levels will be considered in the analysis. Though a simplified approach, the methodology provides a standardized technique for comparing mitigation strategies at the sector specific level. With an improvement in the available data, the numbers will be more accurate, but the methodology itself will still be applicable.

CONCLUSIONS

Since the effectiveness of mitigation depends on how likely a strategy is to be implemented, it is important to evaluate how well a strategy addresses the concerns of the sector paying for mitigation and to identify what incentives could be given to implement the strategies. This paper introduces a study currently involved in developing a standardized sector specific technique to compare the options for mitigation and identify factors that influence the effectiveness of these options. During the course of the study, as more data becomes available, the parameters and relationships developed in this paper may change, but the framework of the methodology will stay the same. The focus of the study is to develop one possible range of values for the preparedness of a sector and the benefits of the strategies. The strategy effectiveness charts are developed as a tool to easily compare investments made in strategies, so that the user could decide how to invest the available resources based on the priorities.

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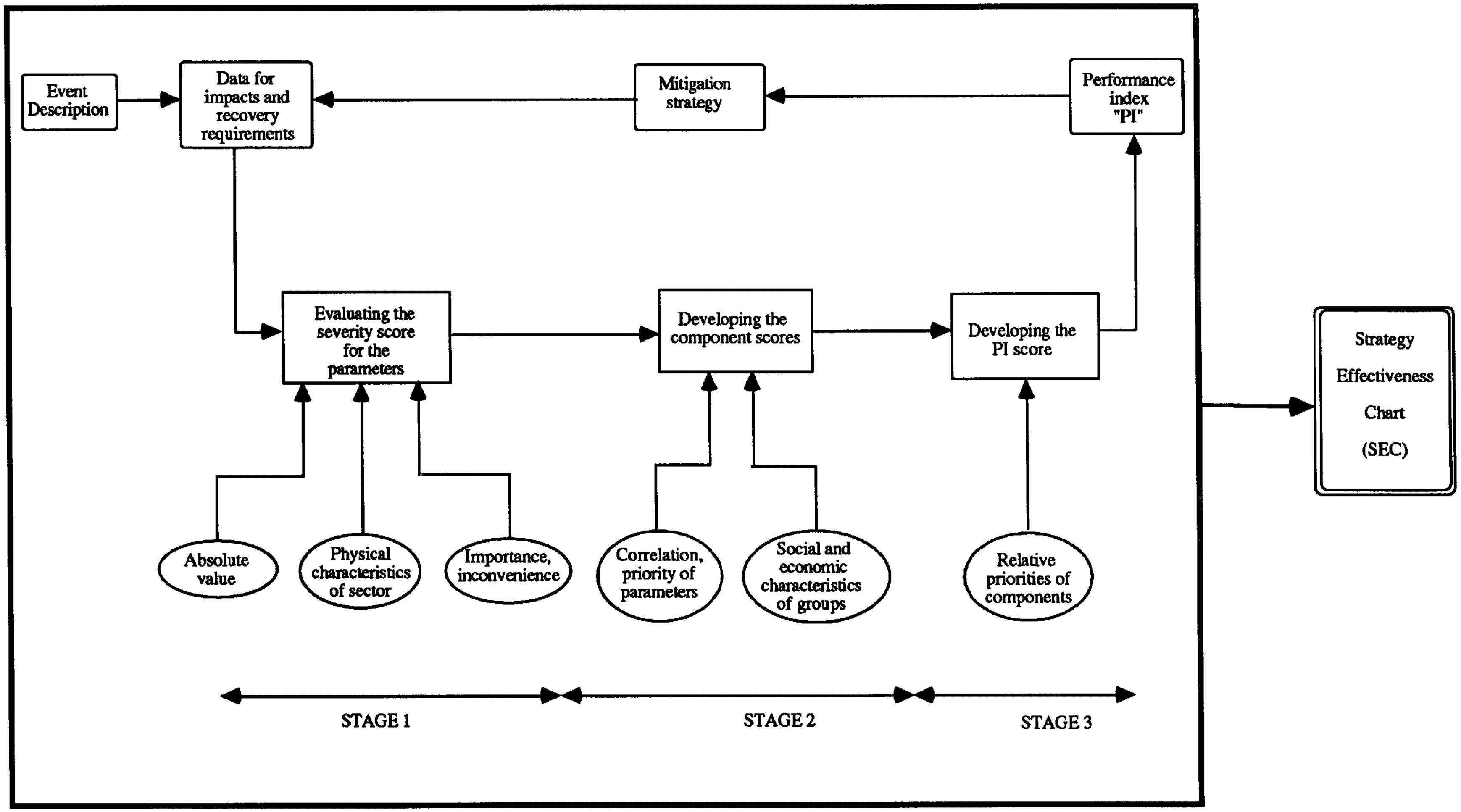

Fig 1. Methodology to evaluate the mitigation strategies