How to Identify Effective and Feasible Integrated Strategies for Seismic Risk Mitigation

by

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Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degrees of

Master of Science in Engineering

Master of Public Affairs

The University of Texas at Austin

December 2004

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Dedication

To my family, friends, and co-workers, for their patience, tolerance, and support.

Acknowledgements

The challenges associated with implementing meaningful seismic risk reduction strategies are well known to the earthquake engineering community. Less well known are the challenges facing a novice in this field who attempts to identify an approach that balances the many conflicting technical, political, and social issues associated with seismic risk reduction.

That it would require the strong support of my family and friends is a given. Through cycles of enthusiasm and despondency, they encouraged me to push forward, emphasizing the work's importance to the greater good or simply the utility of taking advantage of completed coursework. All chose the approach most appropriate for the situation. I appreciate the support they offered.

Perhaps most important, however, was the support of my supervising committee.

Richard Klingner possesses an encyclopedic knowledge in the field of seismic design, but his true usefulness to this thesis was his broad experience in the field. In many countries and over many years he has witnessed the devastating effects of earthquakes first-hand and, with increasing experience, known that more could have been done to reduce these effects. His is the role of Cassandra – fortunately balanced by the knowledge that at least a few people are listening. His understanding of the needs and the issues kept him interested, involved, and motivated. For his ideas, criticisms, and encouragement, I thank him.

David Eaton has many years of experience converting complex technical solutions into practical policy, and he understood the challenges I faced. Well-versed in the potential usefulness of analytic techniques, he recognizes that the true usefulness of any technique is in its application. As such, he was justifiably skeptical of certain aspects of the approach taken. Nevertheless, he remained open-minded, responsive, and patient. Moreover, this thesis is better for his critical comments. Time will tell whether it is useful, as well.

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Floods, fires, and earthquakes continue to impose significant economic and social costs on society. Many technically effective strategies for reducing seismic risk have not been implemented, and so have been of little benefit to the people living on our planet. The major impediment to such implementation is political feasibility, a vague term that encompasses public awareness of the risks, the competing interests of various interest groups, and the availability of resources to meet competing societal needs.

In this thesis, we propose a methodology for comparative evaluation of proposed seismic risk-reduction strategies. The key aspects of the proposed methodology are: (1) explicitly partitioning program effects among interest groups; (2) accounting for differing risk perceptions by the different interest groups; and (3) recognition that interest groups have non-uniform influence on the policy-making process.

The methodology is applied to a hypothetical case study of the Mexican State of Colima, the site of a strong earthquake in January 2003. Although it involves only a few programs, the case study demonstrates the practical applicability of the proposed methodology, and shows how it could be applied to cases that are intractable by casual means.

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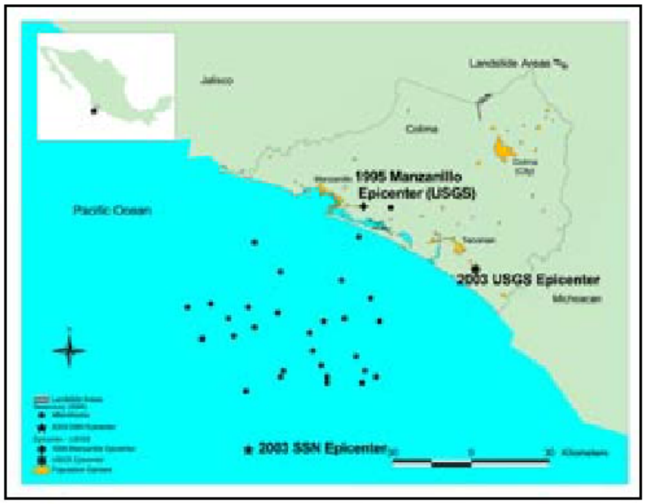
CHAPTER 1

Introduction

On January 21, 2003, shortly after 8 p.m. local time, an earthquake with a probable magnitude of 7.4 (7.6 by some reports) struck the southwestern coast of Mexico near the port city of Manzanillo. The epicenter was 60 km south-southwest of the city of Colima (see Figure 1.1). In the surrounding region more than 500 people were injured and 21 individuals were confirmed dead. More than thirteen thousand structures were damaged, of which more than 2700 were completely destroyed. Governmental authorities responded rapidly, setting up 56 disaster-assistance centers to provide food, clothing, and shelter to affected individuals.[1]

Although the earthquake struck without warning, the region's populace should not have been surprised. In 1995, an earthquake of comparable magnitude struck Manzanillo, approximately 30 kilometers from the epicenter of this more recent event.[2] Moreover, a 1990 report by the Organization of American States had listed Colima as a region with a 66 percent chance of being struck by a major earthquake between 1989 and 2009.[3] Since that estimate was made the area has experienced two such events.



Source: Earthquake Engineering Research Institute, "Preliminary Observations on the Tecoman, Colima, Mexico, Earthquake of January 21, 2003," EERI Special Earthquake Report – March 2003, Figure 1, p.1

Figure 1.1. Location of 2003 Colima Earthquake

1.1 SEISMIC RISK MANAGEMENT

The general consensus of outside observers is that Colima was well prepared to deal with the effects of the 2003 earthquake. Response teams were mobilized rapidly, and relief funds were disbursed soon after the disaster. Nevertheless, the types of failures observed in buildings and other infrastructure were common to those caused by other earthquakes in developing countries. Moreover, the failures were similar to those observed as a result of previous earthquakes in the region. The engineering community was aware of the vulnerability of the affected structures. Technical options existed to reduce this vulnerability, but had not been implemented.

Given the historical seismicity of the western coast of Mexico, the assessment of the OAS, and the warning of the 1995 earthquake, one may be inclined to ask, "Could more have been done in the intervening years to reduce the seismic risk of the region?" What types of technical solutions could have been adopted? If they were not, why not?

Such questions should be posed before a disaster rather than after it. Managing seismic risk involves balancing engineering, finance, economics, and political realities. The low probability of an earthquake striking a particular region in the near term seems to approach zero when there are other pressing needs. As a result, adoption of seismic risk-mitigation strategies is rare.

Nevertheless, the need for solutions is real, particularly in developing countries. The product of low probability (the chance of an earthquake occurring) and high consequence (devastating damage if an earthquake does occur) results in real societal risks. The greatest challenge to addressing this risk is implementation, because technically effective solutions are not always politically feasible. The challenge is therefore to identify risk-management strategies that are both technically effective and politically feasible.

1.2 Relevant Issues

If the goal is to reduce societal risk from natural hazards such as earthquakes, any potential risk-management strategy must satisfy two requirements: technical effectiveness and political feasibility.

Technical effectiveness implies that the approach, if implemented, will reduce the risk to society. Assessment of technical effectiveness requires a combination of engineering and economics. It involves probabilities of occurrence, vulnerabilities of affected structures, and economic losses in the event of collapse of these structures. In evaluating technical effectiveness, individuals exist only in the abstract, as potential casualties and potentially lost contributors to the economy of the affected area. The attitudes of these individuals are generally not considered.

Political feasibility implies that the approach has some hope of implementation. Even an approach that could entirely eliminate seismic risk would be beneficial to society only if it were implemented. Political feasibility, while difficult to define, includes public perceptions of risk and benefits, support levels offered by the relevant interest groups, and the influence of special interests.

Finally, any single approach to risk management rarely addresses the many facets of risk. In fact, approaches may be beneficial to one group and at the same time detrimental to another. The end result is that combinations of programs must balance benefits and costs among interest groups. We refer to such combinations of programs as strategies.

1.3 Overview

This thesis explores how to evaluate integrated risk-management strategies for technical effectiveness and political feasibility. The discussion is directed towards persons who coordinate or review such strategies, and is focused on the specific area of seismic risk management.

After providing background information on the subject matter (Chapter 2), we explore how programs and strategies are evaluated for effectiveness (Chapter 3) and implemented (Chapter 4). These two chapters address the general effects (both positive and negative) of risk-management programs, the analytical tools used to compare programs and strategies, and the political realities associated with the implementation of those strategies.

Based on this review of the state of the practice, we propose a methodology for evaluating risk-management strategies, with the specific goal of identifying those that combine technical effectiveness and political feasibility. An underlying assumption of the approach is that feasible strategies will evoke broad-based support among the various interest groups. As such, Chapter 5 characterizes the interest groups (stakeholder groups) relevant to seismic risk management. Chapter 6 then describes several representative risk-management programs with a special emphasis on how these programs disproportionately affect different interest groups.

Chapter 7 outlines the proposed methodology, which consists of two phases: (1) program evaluation; and (2) strategy evaluation. Program evaluation assesses the impact of any particular risk-management program. Specific characteristics of program evaluation that are unique to this thesis include the following:

- explicit partitioning of program effects among interest groups;
- recognition that risk perceptions affect program valuations; and
- recognition of differing group influence levels in the policy-making process.

The second phase of the methodology is strategy evaluation, in which possible combinations of programs (strategies) are evaluated, with the goal of identifying strategies that are both technically effective and politically feasible. To avoid having to select a single objective to optimize, a multi-objective analysis (MOA) framework is used. Strategies are identified by first defining relevant constraint criteria, and then sequentially eliminating strategies that do not meet these criteria. The focus here is to eliminate inferior strategies rather than to identify a single optimum strategy. The remaining strategies are considered potentially feasible and warrant further discussion with the relevant interest groups. The total effects of the strategies on society, taking into account the influence levels of interest group, are also calculated to allow ranking the potentially feasible strategies by each of the types of effects considered.

In summary, the proposed methodology is intended to provide a rational basis for identifying overall mitigation strategies (combinations of programs) that balance the social, political, and economic effects of those programs within existing economic and political constraints. The methodology is an attempt at a rational basis for identifying risk-management strategies that are both effective and feasible.

The methodology described in Chapter 7 is theoretical, focusing on definitions, assumptions, and the mechanical steps of producing a solution. In Chapter 8, the methodology is applied in a hypothetical case study of Colima, Mexico. Based on that application, in Chapter 9 comments are advanced regarding the significance of the solution and on its possible application.

CHAPTER 2
Background

2.1 INTRODUCTION

Five topics, addressed in this chapter, describe the environment in which seismic risk-management strategies are developed:

- historical review of seismic disasters;
- the difference between hazard and risk;
- approaches to risk management;
- perceptions of risk; and
- special issues associated with developing countries.

The first topic sets the stage for discussion of seismic risk and methods of reducing this risk. The second and third topics clarify definitions related to risk management, and further refine the scope of the present work. The fourth topic addresses an important factor in the implementation of risk-management strategies: perceptions of risk. The fifth topic addresses the reality that risk management in developing countries must be implemented under a much different environment from that of the developed world.

2.2 HISTORICAL REVIEW OF SEISMIC DISASTERS

If one were to review a set of newspapers collected at random over any given year, one might conclude that earthquakes pose a minuscule or even non-existent threat to the general public. The odds are that this set of newspapers would include not a single reference to an earthquake. If an earthquake did make the news that day, it might be on the front page on the day immediately following the event, but after that most likely it could be relegated to the second or third page.

Risks associated with earthquakes are real, however. Table 2.1 lists the ten deadliest earthquakes in recorded history. While they date back to the first millennium, two of them occurred in the 20th century, with one of the most deadly occurring less than 30 years ago. In terms of deaths, the risk of earthquakes has been ever-present, and clearly remains with us today.

Table 2.1. The Ten Deadliest Earthquakes in World History

Rank	*Year*	*Region*	*Estimated Deaths*
1	1201	Upper Egypt, Syria	1,100,000
2	1556	Huaxian, China	830,000
3	1976	Tangshan, China	655,237
4	1737	Calcutta, India	300,000
5	1662	Anhwei, China	300,000
6	1850	Sichuan, China	300,000
7	1138	Aleppo, Syria	230,000
8	856	Qumis, Iran	200,000
9	1703	Jeddo, Japan	200,000
10	1920	Gansu, China	200,000

Source: GeoHazards International website, available on-line http://www.geohaz.org/member/news/signif.htm, accessed June 29, 2004.

Overall, the number of individuals affected by disasters is increasing. Approximately 10 million people were affected in Latin America and the Caribbean by some type of disaster (earthquakes, floods, etc.) in the 1960s. During the 1970s and 1980s the numbers were six and three times greater, respectively.[4] Non-seismic disasters affect a greater number of individuals, but earthquakes cause the greatest number of deaths. Between 1960 and 1989, earthquakes in Latin America and the Caribbean killed approximately 11 million people, greater than those killed by all other types of disasters combined.[5]

2.3 HAZARD VERSUS RISK

In non-technical publications, the terms "hazard" and "risk" are often used interchangeably; in fact, the two terms are even defined reciprocally in the Oxford English Dictionary[6]:

hazard (n) - risk of loss or harm; peril, jeopardy
risk (n) - hazard, danger; exposure to mischance or peril

While both terms express a possibility as opposed to a certainty, in this thesis and in this area of research in general, they are clearly distinct. Hazard refers to the probability of an event. For natural disasters such as earthquakes, hazard could refer to the probability of an earthquake of a given magnitude occurring in a given time frame; to an expectation of the consequent level of ground shaking; or to the likelihood of liquefaction. Risk, on the other hand, is the probability of loss, and is a function of both the hazard and the probability that the hazard will cause loss to structures or individuals. An example of risk is the probability of collapse of a structure in an earthquake.

When considering seismic events, hazard is taken for granted, because there is no known method of reducing the probability or severity of a seismic event. What we can control, however, is seismic risk – the probability of loss in a region where seismic hazard exists.

2.4 Seismic Risk Management

Methods of managing risk are commonly categorized as (1) risk avoidance, (2) risk transfer, and (3) risk mitigation. All three methods reduce risk and are discussed further below.

2.4.1 Risk Avoidance

Risk avoidance means deciding to avoid a recognized hazard. The risk posed by nuclear waste can be avoided by avoiding nuclear technology. Seismic risk can be avoided by choosing not to build in areas prone to seismic events, or by limiting the types of structures built in those areas. If development is prohibited in seismically hazardous areas, for example, risk is avoided completely. As this example makes clear, however, risk avoidance has limitations. It is seldom possible to prohibit development even in areas of high seismic risk. A more modest approach is to reduce risk by land-use or zoning restrictions for such areas. For example, high-density apartments can be prohibited in areas prone to liquefaction or landslides and used instead for parks or warehouses.

2.4.2 Risk Transfer

Risk transfer means transferring the risk of one group to another group. In risk transfer, one group accepts the risk of another, offering a certainty in return. The transfer generally involves payment to the group accepting the risk.

Insurance is the most common example of risk transfer. An at-risk individual pays a fee in exchange for the promise that a particular category of loss, if it occurs, will be compensated. The risk of loss is not reduced – it is the same as it was before the transfer – but the ownership of that risk has changed. In addition, by spreading the risk over a much larger geographic area or pool of insured individuals, the uncertainty in the outcome is reduced. The owner of a single house has a low probability of being struck by an earthquake, but this house is at risk of complete destruction. Conversely, the insurance carrier has a much higher probability of an earthquake affecting the region of coverage but can expect that only a small fraction of the houses in this region will be damaged.

2.4.3 Risk Mitigation

Risk mitigation means reducing (mitigating) the effects of a hazard (for example, an earthquake) by societal decisions. Two categories of seismic risk mitigation are structural mitigation and response planning.

Structural mitigation is intended to reduce the probable damage to physical infrastructure under a given level of seismic loading. Physical damage includes damage to buildings and to lifelines. Ideally, structural mitigation would make infrastructure invulnerable to seismic events. More realistically, it reduces the level of damage in order to save the lives of the occupants and prevent damage to other structures. For example, after a severe earthquake, a building designed and constructed to modern seismic design standards may be a total economic loss, but it should remain standing. This significantly reduces the loss of life and prevents its collapse from damaging other nearby structures. When the damage of one piece of infrastructure causes the damage of another it is termed a "cascading failure." Lifeline engineering is a broader type of structural engineering and focuses on limiting cascading failures through the systems supplying water, electricity, and other necessities. For example, the simultaneous failure of supply lines for gas and water can lead to fires that cannot be extinguished.

Response planning is intended to mitigate risk in the immediate aftermath of a seismic event. It accepts a given level of initial damage due to the seismic event and then seeks to mitigate the secondary damage. For example, rapid medical response can mitigate human suffering by reducing the cascading of injuries into fatalities. Because this thesis is focused on reducing the risk to buildings and other types of infrastructure, response planning as an approach is not discussed further here.

2.5 PERCEPTIONS OF RISK

The political feasibility of risk-management programs is often determined by perceptions of risk, loosely defined as the valuation that each individual places on the outcome of an uncertain event. This valuation, often very different from that assigned by a statistician, is affected by three primary characteristics of the individual: knowledge of the risk; perceived time horizon for the risk; and aversion to or acceptance of risk. Each characteristic is discussed further below.

2.5.1 Knowledge of Risk

Knowledge of risk, determines whether the individual is capable of making an informed decision. Suppose that, in a game of chance, you are told that the first three outcomes have been 2, 1, and 3. You are asked to place a bet on what the next number will be. Given no other knowledge, you might suppose that these are the only possible outcomes, with there being a one-in-three chance of guessing the correct number. If you were then informed that the game involves a six-sided die, your perception of the uncertainty of the outcome would change.

When considering seismic risk, knowledge of the level of hazard is important. If you lived in an area your entire life and had never experienced an earthquake there, you might assume there to be little chance of one ever occurring. A seismologist who knew that a major earthquake occurred there every 50 years, on average, would have a different perception.

2.5.2 Perceived Time Horizon

The second factor is the individual's perceived time horizon – the duration of time over which the individual considers the risk to be relevant. For most individuals, the probability of receiving a phone call some time in the next week is very high, almost a certainty, but the probability of receiving a call in the next hour is much lower. If the time horizon is reduced to ten seconds, the probability approaches zero.

While the time horizon for earthquakes is measured in years, the effect is identical. A longer time horizon increases the probability that an earthquake will occur. A company planning to build a large factory in a seismic area will have a much longer time horizon, and hence be exposed to greater risk, than a student attending a university in that same area.

2.5.3 Aversion to or Acceptance of Risk

The third factor, and perhaps the most difficult to rationalize, is the individual's inherent aversion to or acceptance of risk. Unlike the factors of knowledge and time horizon, both of which influence perceptions of risk, aversion to or acceptance of risk is an emotional decision that is best explained by analogy.

If you were offered an even-money bet on the results of a coin toss, would you accept? From a completely rational viewpoint, the expected value of the outcome is identical to the value of the bet. Your response, however, depends on how you value certainties compared to uncertainties and the amount at stake. Would you bet one dollar? Would you bet a thousand?

Each individual, asked these questions, will decide based on his or her individual feelings towards risk. In the same way, collective decisions regarding seismic risk are affected by the emotions and beliefs of the individuals making those decisions. For example, aversion to risk encourages participation in insurance schemes. Conversely, acceptance of risk discourages such participation, with the feeling that "whatever happens, happens." This feeling may be intensified by other reactions, such as an acceptance of "God's will."

2.6 Special Issues Related to Developing Countries

The World Bank defines developing countries as "low- and middle-income countries in which most people have a lower standard of living with access to fewer goods and services than do most people in high-income countries." [7] This vague definition is augmented by guidelines that low-income countries have annual per capita incomes of less than US$765, while the upper limit for middle-income countries is US$9,385.[8] By comparison, the per-capita income for the United States was US$37,610, or about fifty times greater than the low-income criterion.[9]

2.6.1 Economic Environment in Developing Countries

Developing countries have fewer economic resources and, in general, greater social problems. These two factors severely constrain the resources available for seismic risk reduction. It is difficult to argue for greater spending on seismic risk reduction in the face of pressing immediate problems such as crime, unemployment, and sanitation.

2.6.2 Governmental Instabilities in Developing Countries

Government often plays a strong role in seismic risk mitigation because they have legal control and can coordinate efforts. Many seismic risk-mitigation programs (such as zoning restrictions or building codes) require legal status and hence governmental approval. Government is often the best coordinator and arbiter among public, private, residential, and commercial interests.

Because risk-management programs require long-term commitments to be effective, they are particularly susceptible to the effects of drastic changes in governmental structure. Coups, civil wars, and foreign invasions are more common in developing countries and severely hinder the ability of the governments of those countries to maintain a consistent, long-term commitment to seismic risk management.

2.6.3 Corruption in Developing Countries

Developing countries have a greater problem with corruption, whose adverse effects are widespread and include the following, according to the World Bank[10]:

- hindered investment and growth;
- eroded macroeconomic and fiscal stability;
- reduced effectiveness of public administration;
- distorted public expenditure decisions;
- undermined rule of law; and
- diminished reputation of and trust in the state.

All these adverse effects reduce a country's resources, motivation, and commitment to seismic risk management. Corruption, in addition, has a very direct impact on seismic risk mitigation. For example, properly enforced building codes are generally the most effective method of reducing the vulnerability of the built environment. When building inspectors can be bribed to overlook the use of substandard materials or inadequate reinforcement in concrete structures, the building is much more vulnerable to seismic loading. Given the long period of time between earthquakes, the effect of such corruption may go unnoticed for many years, long after both the inspector and the construction foreman have moved on to other jobs.

2.7 Concluding Remarks: Background

In this chapter we have reviewed a variety of topics relevant to seismic risk management. This review has included a historical review of seismic disasters, the semantic difference between risk and hazard, and the three approaches to risk management (avoidance, transfer, and mitigation). Of particular relevance to the methodology proposed in Chapter 6 is the reality that perceptions of risk often differ significantly from the objective, probabilistic assessment of risk. This difference affects how individuals value the benefits associated with risk-mitigation programs. The final section of the chapter focused on special issues associated with developing countries.

CHAPTER 3

Evaluating Risk-Management Programs

3.1 INTRODUCTION

This chapter reviews how risk-management programs are evaluated for technical effectiveness and consists of sections on risk-management programs, benefit-cost analysis, and multi-objective analysis.

The first section provides an overview of the effects of risk-management programs. This topic is not as straightforward as one might think. Cascading effects can significantly increase both the costs of risk-management programs and the benefits that accrue from them in the event of a disaster.

The second and third sections address how values are assigned to those costs and benefits. The first of these focuses on the traditional method of evaluating programs: benefit-cost analysis (BCA). BCA provides a framework for objective evaluation of program effects, thereby permitting a neutral comparison of the relative strengths and weaknesses of various programs. BCA has the inherent disadvantage, however, of requiring valuations to be expressed in consistent units (typically monetary units), so that net benefits or benefit/cost ratios can be quantified. When different individuals assign different valuations to non-monetary effects, though, the limitations of BCA become evident.

The third section of this chapter addresses multi-objective analysis (MOA), a collection of techniques designed to avoid the restriction that effects be valued in consistent units. Fatalities are counted as fatalities, and increased costs are counted in monetary units. While this generality of application avoids the need for denomination of everything in dollars, it has the disadvantage that, in general, there is no single response variable to optimize. Consequently, MOA can be used to eliminate the least effective approaches, as well as identify an approach that dominates the other options in terms of the various effects.

3.2 Program Effects

The evaluation of any risk-management program begins with an assessment of program effects. The purpose of this section is to describe, in a general sense, different types of program effects relevant to analysis of risk-management programs. Three distinctions are drawn here: (1) direct versus indirect effects, (2) known versus anticipated effects, and (3) costs versus benefits.

Direct and indirect effects are differentiated as follows: Direct effects are those directly attributable to the risk-management program, while indirect effects are indirectly attributable. For example, the cost of mandated retrofitting of unreinforced masonry is borne directly by the owners of these buildings. Indirect effects are also attributable to the program, but in a less direct way. Continuing the above example, a subsequent increase in rental rates, as building owners attempt to recoup their retrofit costs, could be considered an indirect effect. As another example, damage to buildings and office equipment is a direct effect of an earthquake; decreased economic activity by affected businesses is an indirect effect of the earthquake. Estimation of direct effects is reasonably straightforward, even when considering a hypothetical earthquake, whereas indirect effects are more difficult to determine. Will building owners increase rental rates to recover costs of retrofit or will such increases be tempered by supply and demand? Will increased rental rates lead to a subsequent decrease in the consumption of other goods? These questions have no clear answers. The analyst must recognize that the effects of disasters may cascade through the system, and may be more far-reaching than is obvious at first glance. Some judgment must then be applied to decide when to stop counting.

Known effects and anticipated effects are differentiated as follows: Known effects are those associated with the program independent of whether an earthquake occurs – for example, the cost of retrofitting or the premiums paid to an insurance scheme. Anticipated effects are those realized only in the event of a disaster. The number of buildings saved by a retrofit program is an anticipated effect. In analyzing risk-management programs, known effects are most often considered as costs, and anticipated effects (for example, buildings saved), as benefits. Risk-management programs are inherently uncertain with respect to anticipated benefits.

Costs and benefits are differentiated as follows: Costs describe the negative consequences of a program, for example the program cost borne by the government or the increased costs of production after implementation of pollution controls. Benefits describe positive consequences of a program, for example, the lives saved by requiring the use of seat belts. Generally, non-monetary effects are transformed into monetary effects by assigning them a valuation, such as the value of a human life or lives, or an hourly wage figure for time. By transforming all effects into common units, the benefits can be compared with the costs and objective assessment of the effectiveness of different programs is possible.

3.3 Benefit-Cost Analysis (BCA)

Benefit-cost analysis is a traditional method of comparing proposed programs. The expected benefits and costs of each program are estimated, and metrics such as net benefits (the difference between benefits and costs) or benefit/cost ratios are calculated. In theory, programs with the highest B/C ratios are preferred because they offer the greatest return on the investment. Numerous texts exist on the subject of BCA. The information presented here is taken from Gramlich.[11]

Estimating benefits and costs requires various assumptions, including an assumption regarding the time value of money. Benefits and costs that are not yet realized (that is, that do not take effect until some time in the future) are discounted by an assumed rate of return. Natural disasters and other events with associated probabilities further complicate this analysis approach. The most common way of handling this is to further discount the possible future effects of each event by the probability of the event.

A second assumption is the valuation of non-monetary benefits and costs. Metrics such as net benefits require that benefits and costs be expressed in common units, typically monetary units. Valuation of casualties and fatalities on this basis is difficult and contentious. Different individuals justifiably value these effects differently, sometimes refusing to assign any valuation at all.

Benefit-cost analysis, while providing essential information, is not objective because subjective assessments must be made regarding assumed effects. Different interest groups often lumped together under a broad category of taxpayers, value benefits differently.

Another weakness of conventional BCA is that it may ignore political realities, such as public perception of various mitigation programs, or the reality that some interest groups have a greater voice than others in policy-making. A supposedly "optimum" strategy, derived without consideration of these realities, is at best only a noble statement of what could be done, and at worst a prescription for failure.

BCA, nevertheless, is an important tool for policymakers. Any mitigation program requires some level of funding, for which it must compete with other mitigation programs and other societal demands. BCA allows analysts to compare possible programs.

3.4 Multi-objective Analysis (MOA)

Natural disasters cause a wide range of consequences, ranging from economic loss to human suffering to fatalities. While BCA is a useful for making objective comparisons among programs, it has the weakness of requiring that all valuations be made in common units, typically monetary units. This requirement implies that all non-monetary effects, from fatalities to days of service lost, must be assigned monetary equivalents. Multi-objective analysis avoids this requirement.

MOA is the name given to a broad class of techniques designed to address problems with more than one response variable.[12] A response variable is some metric that the analyst is attempting to control by adjusting one or more decision variables. In the case of seismic risk management, response variables could include reductions in the number of fatalities or reductions in economic loss. Decision variables could include the various parameters of a risk-management program.

MOA techniques are an outgrowth of constrained-optimization analysis. Given a single response variable (for example, net benefits) and the assumption of linear relationships between decision variables and response variables, linear programming techniques make it possible to determine values for the decision variables so that the response variable is maximized, given constraints applied to the decision variables. Linear programming techniques permit rapid solutions to problems with hundreds or thousands of decision variables and related constraints. If decision variables and response variables are not linearly related, non-linear programming techniques can provide iteratively determined solutions.

With more than one response variable, the problem becomes significantly more complex. While some of this added complexity results from the additional equations that must be handled, most of it stems from the conceptual difficulty of attempting to optimize multiple objective functions simultaneously. The question, “What is optimal?” becomes real rather than rhetorical. Some MOA techniques consider alternative methods of aggregating multiple response variables into a single objective function (in a sense converting the problem back into a conventional constrained-optimization problem); others focus on exploring the relationships among the multiple response variables. In the latter case the focus shifts from identifying the optimum options to eliminating relatively inferior ones. The resulting options are “non-inferior,” or better in all ways than the inferior ones.

The field of MOA is extensive and comprises a wide range of approaches and assumptions. In the methodology developed in Chapter 7, two particular MOA techniques are used: (1) simple additive weighting and (2) sequential elimination.

Simple additive weighting transforms multiple objective functions into single objective space. Weights are assigned to each of the objectives (that is, response variables), and a single objective function is defined as the weighted summation of the original objectives. This approach allows aggregation of values with either similar or dissimilar units. Aggregating values with similar units (for example, monetary units) is useful when direct summation does not represent the net value in the eyes of the decision makers. Aggregating values with dissimilar units (for example, monetary units and human lives) is identical to the approach of BCA and will not be used here.

Sequential elimination provides a method of ranking alternatives in the absence of a single objective function to optimize. The focus is on elimination of inferior options rather than identifying the single best option. The method begins by defining a set of criteria that must be met. While at least one criterion is typically defined for each objective, the set of criteria can be more complex and can include, for example, multiple criteria for each objective or restrictions on the relative magnitudes of two or more objectives. Options that do not collectively satisfy these criteria are eliminated as inferior; those that remain are non-inferior. The strictness of the criteria can be subjective and can be chosen to reduce an unmanageable set of options to a more manageable set.

3.5 Concluding Remarks: Program Evaluation

The implementation of any program is constrained by availability of resources. Risk-management programs are no exception to this rule – decisions must be made between various options. Objective evaluation of these various options allows decision-makers to make informed decisions.

The first step in evaluating a risk-management program is to identify its various effects. Program effects can cascade through a system. Indirect effects may be quite complex. The reality must be simplified to a manageable level by limiting the number of indirect effects to only those most important.

After the most important program effects have been identified, the "goodness" of the program must be assessed. The traditional approach for this assessment is benefit-cost analysis (BCA). BCA transforms all effects into common units (typically monetary), which requires assigning unit costs to effects such as lost days of service or the number of fatalities. While valuating a human life by a certain dollar figure is certainly contentious, doing so allows the computation of objective figures of merit such as benefit/cost ratios and net benefits.

Multi-objective analysis (MOA) is a set of decision-making tools designed to avoid the need of assigning valuations to non-monetary effects. In MOA, objectives are kept in their original units. This offers an approach for identifying and eliminating inferior options. Some of these techniques are used in the methodology proposed in Chapter 7.

CHAPTER 4
Implementing Risk-Management Programs

4.1 Introduction

This chapter provides an overview of the program implementation by program advocacy, by mandate, and by community-based involvement. At one end of the implementation spectrum is program advocacy, in which programs are proposed and advocated by individuals and groups. Program advocacy is a "bottom-up" approach that occurs independent of central coordination of risk-management policy. Section 4.2 describes this approach, and Section 4.3 extends it by reviewing an empirical study of how program advocacy works in practice.

At the other end of the implementation spectrum is implementation by mandate, in which a central coordinating body, typically governmental or quasi-governmental, directs the implementation of risk-management policy. Mandated risk management, described in Section 4.4, is a "top-down" approach that requires a strong central government or an external organization with exclusive control over development funds.

Somewhere in the middle of the implementation spectrum is community-based involvement. This hybrid approach, combining the first two approaches, is described in Section 4.5. In community-based involvement, a central coordinating authority (similar to the mandated approach) pulls the community into the planning process much earlier than in the mandated approach, and uses the community to help formulate the policy from the bottom up. Prescriptive decisions are avoided, with the focus instead on communicating information about potential risks to the community at large. A seminal event in the field of seismic risk management was the UN-sponsored RADIUS project, in which community-based involvement has been used to implement risk-management policy in approximately a dozen case studies throughout the developing world.[13]

4.2 Program Implementation by Program Advocacy

The free-market economic system popular in much of the world is based on the idea that a collective of independent individuals, each acting in his or her own self-interest, results in the most efficient distribution of societal resources. Implementation by program advocacy works in a similar manner, using the assumption that individuals (program advocates) who understand a portion of the risk equation will work together with similarly minded individuals to promote programs that address specific risks. Program advocates often are specialists whose education or experience leads them to recognize inadequacies with current practices. Each program advocate organizes like-minded individuals, often through professional societies or community groups, into a collective whose voice is strong enough to maintain the topic on the policy agenda.

Simultaneously, similar efforts are undertaken by other groups to address other risks. Those groups with the most compelling arguments will be the most successful, leading to an integrated strategy that makes the best use of the available resources. For example, a structural engineer might recognize that local building codes do not include seismic design provisions and might lobby for implementation of such provisions. Simultaneously, a geotechnical engineer might observe the development of housing in an area prone to landslides or liquefaction and might push for restrictions on such development. While both individuals would presumably be motivated by a certain level of altruism, in terms of reducing societal risks, they would also stand to reap the potential rewards of increased demand for their respective areas of expertise. Proponents of program advocacy argue that such individually motivated actions best serve the interests of the overall society.

Program advocacy is perhaps the most common implementation approach throughout the world, and is quite consistent with European and US political systems. It can be termed a "bottom-up" approach because of the key role played by the advocates, who are familiar with the details of their respective areas.

One advantage of this approach is that advocates usually know their own aspect of risk management and can back arguments with data. Another advantage is that the advocates work to keep their program options on the policy agenda, an important factor in the mitigation of risk from events with low probabilities of occurrence but potentially severe consequences.

Program advocacy also has disadvantages, however. First, program advocates, being specialists in one area, may lose sight of the broader picture and fail to comprehend fully the effects of the program they advocate because they tend to focus on that area with which they are most familiar. Adverse unintended consequences, which program advocates may ignore or minimize, may limit the effectiveness of the program they are promoting.

Second, a risk-mitigation strategy based individual program advocate actions is likely to be neither coherent, nor optimum in any sense. While decision-makers should, in theory, balance the arguments of different program advocates, those programs having the most articulate, insistent, and politically-connected advocates typically advance at the expense of other programs, regardless of relative technical effectiveness.

4.3 PROGRAM ADVOCACY CASE STUDY

One seminal work on the implementation of seismic risk-management programs is the monograph by Alesch and Petak.[14] These authors review the development of ordinances related to unreinforced masonry (URM), a construction technique particularly vulnerable to seismic loading, in the Southern California cities of Long Beach and Los Angeles. Their study focuses on the period between the 1933 earthquake in Long Beach and the adoption of URM retrofitting ordinances in that city in 1971 and in Los Angeles in 1989. A central question addressed by this study is why such ordinances took so long to be implemented. Although this was not its original intent, the study provides insight into the workings of program advocacy as discussed in the previous section.

From their review of the history of these ordinances, the authors conclude that the "Garbage Can" model of policy development, originally proposed by Cohen, March, and Olsen,[15] best describes the implementation process. This model is essentially a hypothesis for how program advocacy works. Nevertheless, by providing useful insight for policy advocates, it can be considered an extension of the program-advocate model.

The Garbage Can model draws its name from Cohen, March, and Olsen's analogy that decision-makers face a "garbage can" filled with a wide range of problems. While some of these have simple and attractive solutions that decision-makers pursue independently, most have complicated and messy solutions and are not addressed unless certain conditions are met.

According to the Garbage Can model, adoption of a risk-mitigation program requires the confluence of four "streams:" a problem stream; a solution stream; a participant stream; and an opportunity stream. Unlike a conventional view that solutions are developed in response to problems, these four streams are assumed to be independent. Bringing together the problem and solution streams requires a participant stream, which includes the advocates actively promoting the problem/solution pairs that they have identified, and also includes those required to implement the program. Without including all relevant groups and giving them a sense of ownership of both the problem and the solution, the participant stream can be reduced to a trickle of policy advocates preaching to an empty church. Even if a program is adopted, other potential participants may view it as an imposition and do little to implement it. More likely, the program will never be adopted because the decision-makers will recognize that it is not a pressing issue on their overloaded political agendas.

In any event, the first three streams are inactive until an opportunity stream emerges, finally allowing implementation of the program. The opportunity stream represents a shift in public perception of the problem that brings the issue to the attention of policymakers. In seismic risk mitigation, the opportunity stream is generally the "window of opportunity" that may open following a relevant natural disaster. It may be opened by a nearby event, generating sympathy with citizens of similar background, or by a distant event, in a location with similar infrastructure and demographics. For example, Alesch and Petak argue that the 1985 earthquake in Mexico City was an important factor in catalyzing interest in seismic risk mitigation in the City of Los Angeles.[16]

The general lesson from this analysis is that advocates of a particular seismic risk-management program must remain aware of the locations and relative strengths of these four streams. Because a window of opportunity rarely remains open for long, the first three streams (problem, solution, and participant) must be kept ready in order to capitalize on a possibly short-lived opportunity stream.

Two conclusions can be drawn from the Garbage Can model regarding the goal of this thesis. First, to be technically effective, risk-management strategies must match appropriate problems and solutions (some of which may already exist). Second, to be politically feasible, risk-management strategies must draw support from most relevant participants.

Nevertheless, the Garbage Can model has limitations. First, although pairing of problems and solutions may ensure effectiveness, it does not address how different possible pairings should be evaluated. Second, recognition of the participant stream as a requirement for politically feasible programs does not address how to generate this participant stream from the independent and often conflicting streams of individual participants or interest groups.

4.4 PROGRAM IMPLEMENTATION BY MANDATE

Mandated risk-reduction policy ultimately occurs in only one way – the prevailing governmental authority deems the policy to be necessary and enforces government mandates. There are, however, different ways to reach this point. With the exception of purely dictatorial governments in which the dictator has taken a personal interest in risk reduction, the government must be induced to mandate such programs.

One path is through professional engineering or business organizations. Building codes, for example, are typically developed by civil engineering organizations. The codes are based on research and practitioner advice. Updated versions are issued periodically as new research and experience is incorporated into the code, but adoption of an updated version is the decision of the local governing authorities. If a code is adopted in its entirety, it is possible for the organization that develops the code to institute certain provisions. Typically, these would be small changes because drastic changes could risk non-adoption of the design code, but it is possible to institute mandates incrementally. As another example, the insurance industry could decide that only buildings that had been inspected for seismic vulnerability would be eligible to apply for property insurance.

One effective path for a mandated program is when development funds are held hostage by some external organization. This path occurs most frequently in developing countries. If one of these countries is applying for a $100 million aid package from the World Bank, for example, the grant could be contingent on a certain fraction of these funds being applied to seismic risk reduction. The country could choose to decline the overall fund package. However, if the risk-reduction requirements are a minor portion of a package that is desirable overall, the risk-reduction portion can be considered a mandate. The federal government can act in a similar manner when granting funds to states or local authorities.

Mandated program implementation can be an effective approach to implementing effective risk-reduction strategies. The mandates can, however, be driven by politics as much as by benefits. Nevertheless, in practice, the greatest reductions in seismic risk are achieved when the participants "buy-in" to the efforts and make it a priority for themselves.

4.5 Program Implementation by Community-based Involvement

The political process is the ultimate arbiter in nearly all risk-mitigation efforts. Regardless of the technical and economic arguments in favor of a program, implementation is possible only with the support of most of the relevant political players. Recognition of this reality has led to increased emphasis on inclusion of all relevant interest groups early in the policy development process, a process more formally referred to as community-based involvement (CBI).

CBI, like mandated implementation, is directed by a centralized coordinating organization. In contrast to mandated implementation, however, the purpose of this organization in CBI is not to prescribe actions, but rather to bring community organizations together to discuss potential risks and potential risk-mitigation actions. After these public representatives are educated, they are then called upon to help develop solutions.

In the United States, the Federal Emergency Management Agency (FEMA) currently recommends the use of CBI to develop risk-management policy. To facilitate CBI, FEMA uses Social Impact Assessments (SIAs),[17] which are essentially tabulations of the catastrophic effects of a hypothetical natural disaster with and without different proposed risk-management options. All effects are kept in their original units, be they dollars, deaths, or down-time, to avoid having to assign monetary valuations to non-monetary costs. Participants in the decision-making process apply their own valuations to these effects, either explicitly or (more likely) implicitly. Reiterating, the focus of implementation by CBI is on communicating information to and among the participants. The participants, who are intended to represent the relevant interest groups, are then encouraged to work together to develop solutions.

The RADIUS project, introduced by the United Nations, was a seminal event that sought to implement an integrated strategy for seismic risk mitigation using the CBI framework. Nine cities worldwide were funded to act as case studies for implementing an integrated seismic risk-management strategy. Risk analysis was performed for these cities with contributions from local officials and researchers, and the results were presented to community representatives. Options to address the identified risks also were offered, but the community representatives then were encouraged to work together to develop programs that suited their respective communities. Funding from the United Nations was offered for a portion of the program costs, providing further encouragement for implementation.[18]

The central advantage of CBI is that any implementation strategy developed by consensus inherently has the support of the groups involved, and therefore is by definition politically feasible. Moreover, since the interest groups have developed the strategy, they are more likely to feel a sense of ownership and to work for its implementation. Nevertheless, even this powerful implementation approach has disadvantages.

First, although discussion among the participants provides a wide range of starting points, it does not provide a goal toward which to work. If the coordinators have no plan for leading the discussions, the interest groups with the most skillful negotiators will leave the room with the greatest gains. A related disadvantage is that, although each participant is in theory working for the greater good of society, each participant in reality also tends to try to gain more for the group he or she represents.

Second, although any strategy developed through consensus should be politically feasible, it does not have to be technically effective. To get what they want, groups can overestimate benefits and underestimate costs (a standard negotiating technique). Real results may fall far short of program estimates.

4.6 Concluding Remarks: Program Implementation

The "bottom-up" approach of program advocacy allows the possibility of a wide range of risk-management solutions and ensures that at least one group (that of the program advocate) supports the solution. Interest groups without an advocate can be ignored, however, and coordination among programs can be difficult. Nevertheless, this approach is consistent with the governmental structure of most developed nations and is how many programs are developed and implemented. One study of how program advocacy works in practice led the author to suggest that the Garbage Can model shows how programs succeed or fail.[19]

The “top-down” approach of mandated risk management provides for the development of an integrated strategy, but the coordinating agency may overlook aspects of the potential risk, and the prescribed solution may face resistance from those who implement it at a local level. Top-down mandates are easier with a strong central government (such as a dictatorship) or an active professional organization (such as the Structural Engineers Association of California or the New Zealand Society for Earthquake Engineering), or the incentive of external funding offered with the requirement that a certain fraction be spent on risk management.

Community-based involvement (CBI) is a hybrid approach that combines the benefits of program advocacy with those of mandated risk management. A central authority directs risk-management efforts while involving interest groups early in the process. The focus is on educating participants regarding the risks and potential solutions and then allowing them to develop the most appropriate integrated strategy. This process has been formalized by FEMA through its use of Social Impact Assessments (SIA’s) and has also been used successfully by the United Nations’ RADIUS project in nine case studies throughout the world.

Despite its strengths, CBI by itself provides no method for simultaneously assessing the effectiveness and feasibility of potential risk-management strategies. With even a modest number of possible risk-management programs, the number of possible strategies (combinations of programs) can be overwhelming. The remainder of this thesis is directed to providing guidance to those responsible for the development of integrated risk-management strategies.

CHAPTER 5
Interest Groups

5.1 INTRODUCTION TO INTEREST GROUPS

A central theme of this thesis is that the effects of seismic risk-management are not uniformly allocated over a population, and that this non-uniformity must be recognized and addressed in the development and implementation of such programs. When discussing this non-uniformity it is useful to divide the population into a number of groups with common characteristics and motivations. We refer to such collections of individuals as "interest groups" sometimes also referred to as "stakeholders." The purpose of this chapter is to review the key characteristics relevant to seismic risk management (Section 5.2) and then to use these characteristics to define representative interest groups (Section 5.3). While the focus of this discussion is seismic risk management in particular, the characteristics and classifications of interest groups are applicable in general to many natural and man-made hazards.

5.2 KEY CHARACTERISTICS OF INTEREST GROUPS

Before considering the typical interest groups relevant to seismic risk-mitigation programs, it is useful to consider the key characteristics that can be used to define these groups:

- the geographic location of the interest group;
- the class of structure that the interest group uses or owns;
- the level and source of the interest group's income; and
- the discount rate and time horizon for future costs to the interest group.

5.2.1 Geographic Location

Because the geographic location of an interest group affects the hazard level to which the group is exposed, it also affects that group's attitude towards risk management. While earthquakes may occur randomly in time, they are more likely to occur in some areas than others. Seismic hazard is defined as the probability of experiencing an earthquake of at least a given severity over a specified period of time. Perceptions of relative seismic hazard have existed for centuries, but over the last half-century statistical analysis of previous seismic events has led to the creation of seismic hazard maps that quantify the annual probability of exceedance for various acceleration thresholds. Similar maps have been developed for probabilities of liquefaction, a dangerous condition in which the earthquake causes the ground to lose strength and stiffness, and in effect to become fluid. Propensity to earthquake-induced landslides, a condition only possible on or below slopes, is another localized phenomenon that causes seismic hazard to depend on geographic location.

While hazard maps allow individuals and governments to quantify seismic risk, they also highlight the geographic distribution of seismic hazard and may lead to conflict over risk-management programs that include these areas. For example, it is difficult to convince residents of Texas, a seismically inactive region, to enroll in an earthquake insurance program that also includes residents of California, an area with much greater seismic hazard. The Texas residents will feel that they are subsidizing individuals who chose to place themselves at risk.

As another example, individuals living in low-lying areas may be more concerned with flooding than with earthquakes.

Geographic location affects collective as well as individual attitudes toward risk management. Individuals typically have greater empathy with their geographic community than with those who live farther away. For this reason, risk-management programs focusing on smaller geographic areas can sometimes be more successful than those focusing on larger areas. Unfortunately, some programs require a large geographic area to be feasible. Earthquake insurance, for example, requires a minimum number of participants, distributed over a wide geographic area, before the pooled resources are sufficient to cover the catastrophic localized damage that often results from earthquakes.

5.2.2 Class of Structure

While structures themselves are ignorant of risk management, a structure's class can influence the attitudes of its occupants and owners. In this sense, each structure's class is a defining characteristic of the interest groups that use or own that structure. A structure's class often correlates with other factors, such as its geographic location or the income level of its occupants or owners.

First, the vulnerability of a structure (the relationship between hazard and risk) is strongly tied to its class. For example, non-engineered buildings, especially those constructed of adobe or unreinforced masonry, are much more vulnerable to seismic damage than are engineered buildings constructed of steel, reinforced concrete, or reinforced or confined masonry.[20] The geometric characteristics of a structure are also important. In the soft lake-bed area of Mexico City, for example, the 1985 Mexico City earthquake was much more damaging to taller buildings than to shorter ones, due to the site-specific amplification of long-period acceleration.[21]

Each structure's class also affects the types of risk-management programs that are attractive to the users or owners of that structure. Programs that address seismic risks to multi-story engineered structures of reinforced concrete, for example, are of limited interest to the owners of low-rise, non-engineered structures of unreinforced masonry. A structure's class may determine whether that structure's occupants or owners are eligible for programs such as insurance, or may determine whether they are affected by changes to building codes.

5.2.3 Level and Source of Income

Nearly all such programs require initial costs that must be borne by society long before any benefits are realized. The level and source of an individual's income can affect that individual's attitude towards risk management.

Income level affects attitudes towards risk management. Those with lower income levels generally have less money available to address initial costs. When a family is living week-to-week or day-to-day, obtaining food and other basic necessities may be more important than strengthening the family dwelling against a potential earthquake. Income level is often correlated with education, so that even with some disposable income, groups with lower income levels may make less-informed choices in using their resources for risk mitigation.

The source of a group's income can be as important as the level of that income. For example, because earthquakes often cause significant damage to agriculture and commerce, those who gain their livelihood in those sectors are likely to support risk-management programs focusing on those areas. Similarly, programs that increase current operating costs may be opposed by the groups most directly affected. More stringent building codes, for example, typically increase construction costs and may be opposed by developers as well as construction companies concerned about losing business.

5.2.4 Discount Rate and Time Horizon

While some risk-management costs are immediate and incurred only once, others, such as insurance premiums, continue into the foreseeable future. Less clearly defined future costs include, for example, increased rents due to more stringent design codes or land-use restrictions. When the costs of a risk-management program are calculated, these future costs must be discounted to present values. This calculation requires two parameters: a discount rate and a time horizon.

The discount rate is the interest rate used to calculate the time value of money, or a surrogate to reflect the cost of borrowing money. Higher discount rates cause future values to be worth less today. For example, at a discount rate of 5 percent, a payment of $100 to be received ten years from now is worth $61 today; at a discount rate of 10 percent, that payment is worth only $38 today. The discount rate affects individuals most directly when they must borrow funds to pay for mitigation measures. At higher discount rates, monthly payments on those loans are greater.

The time horizon is the period of time, measured from the present into the future, over which effects are considered. While insurance payments will in theory exist indefinitely, it is unreasonable for human beings to think in such terms. A more reasonable period might be the expected ownership period of the item being insured. Each individual's time horizon is highly personal.

An individual's time horizon is particularly important when considering the potential benefits of seismic risk management, because those potential benefits are realized only if a damaging earthquake occurs. Hazard and risk levels are defined probabilistically over intervals of time – the longer the interval, the greater the hazard and the risk, and hence the greater the probability that the benefits of risk management will be realized. Individuals with long time horizons may have higher potential net discounted benefits than those with short time horizons.

5.3 INTEREST GROUPS

Now that the key defining characteristics of interest groups have been addressed, it is time to classify those groups in the context of seismic risk management. As with any categorization of people, such classification requires a certain level of abstraction. Lines of demarcation between interest groups are not clearly drawn; individuals may consider themselves to be part of more than one interest group; and a diversity of attitudes exists within each interest group. Moreover, the classifications differ from region to region, so different researchers might propose different classifications even for the same population.

In the following discussion, four major classifications of interest groups are considered: residential, commercial, development, and governmental. A distinction is drawn between residential and commercial interest groups because these two groups generally occupy different types of structures, and also because programs that address residents can be very different from those directed toward businesses. Moreover, business interest groups can extend into different geographical regions based on a business's size, suppliers, and customers. Development interest groups are listed separately because they are directly affected by restrictions on land use and construction techniques. Finally, governmental interest groups are listed separately because they have the unique power to enforce risk-management ordinances. The specific groups chosen for analysis will typically vary with the region under consideration.

5.3.1 Residential Interest Groups

Residential interest groups comprise essentially all of society and share many common goals. They want safe and clean homes and streets. They need an employment source that provides them with sufficient income for necessities and perhaps a few luxuries. They need a transportation system that allows them to reach their place of employment and the stores where they buy goods and services. If they have children, they are particularly concerned with the safety and quality of schools. At a more conceptual level, they typically share some sense of national or regional identity.

Despite these common goals, it is not practical to aggregate residents into a single interest group. Because significant differences exist within the broad classification of residents, significant differences exist in how residents are affected by risk-management programs.

Residential interest groups can be subdivided by geographic location, discussed above in Section 5.2.1. In a national risk-management program, residents in a given region can be expected to show greater concern for their region than for others. In regional programs, residents can be grouped by localities. The geographic relationship between these localities and available hazard maps can be considered.

Residential interest groups can also be subdivided into urban residents and rural residents, two sub-groups who often live very different lives. Urban residents are concerned with safe and clean streets, affordable housing, safe and reliable public transportation, and jobs. The latter are particularly important in developing countries, because many urban residents are former rural residents drawn to urban areas in search of jobs. Rural residents also have sanitation and educational needs but tend to be more self-sufficient. They often produce much of their own food. While potable water is important and often lacking, rural residents at least have access to streams or rivers, which are generally not available to urban residents.

Another important distinction is between residents who own their dwellings and those who do not. While both sub-groups are concerned for their safety and personal property, owners are concerned for the dwelling itself. Owners may be more interested in do-it-yourself mitigation programs; non-owners may be more interested in building codes for apartments.

Finally, residential interest groups can be distinguished by income level. In developing countries, many people live at or near a subsistence level. Although these individuals often live in substandard housing and may be at significant risk from earthquakes, their marginal standard of living precludes investment in risk management; they probably have relatively short time horizons. These individuals benefit most from direct assistance programs.

5.3.2 Commercial Interest Groups

Commercial interest groups represent the business activity of a society apart from real-estate development, which is discussed separately below with respect to the development interest groups. Commercial interest groups focus on their own economic success. At the broadest level, their goal is general economic development; at the level of individual sectors, their goal is the economic success of their own sector.

Like residential interest groups, commercial interest groups share some common goals. If the common goal of the former is quality of life, the common goal of the latter is generation of profit. In addition to business acumen and technical skill, the generation of profit also requires a general economic environment with reasonably priced inputs, reliable supplies of equipment and labor, consumers willing to purchase finished goods at a sufficiently high price, and enough economic stability to allow continuity of operation and planning for the future. How these conditions are best achieved depends on the characteristics of each business, and these differences divide commercial interest groups into sub-groups.

Commercial interest groups, like residential interest groups, are associated with a geographic location which determines the type and level of hazard and ties the business to the local community. Risks to residential interest groups become risks to commercial interest groups because residential interest groups provide employees and customers and support the governmental infrastructure that provides necessary utilities and services. Unlike residential interest groups, however, commercial interest groups may have multiple geographic locations, which mitigates their risk of catastrophic losses from geographically concentrated hazards.

Another distinguishing feature among commercial interest groups is the size of the business in which they are involved. In addition to possibly having multiple locations, larger businesses can devote more capital to risk management. These businesses are also more likely to own their facilities and therefore have greater decision-making authority over risk-mitigation efforts. Smaller businesses, on the other hand, are more likely to rent and are therefore subject to the decisions of the owner of their place of business. Whatever their size, though, all businesses should be interested in reducing the risk to their structures in order to reduce down-time.

Another distinguishing feature among commercial interest groups is the type of business in which they are involved, which determines what types of infrastructure each commercial interest group most requires. Distributive businesses such as wholesalers and suppliers depend strongly on transportation infrastructure. Manufacturing businesses have similar needs (in order to obtain raw materials and deliver finished products to market) but may also depend strongly on local utilities such as power and water. Manufacturing businesses also tend to be located on the outskirts of urban areas and potentially have less interest in urban risk reduction provided that their sources of labor are protected.

Another distinguishing feature among commercial interest groups is the market served by each interest group's businesses. Agricultural or manufacturing interests that export most of their product, for example, depend strongly on ports and highways and are likely to support risk-management programs focused on those elements. Retail shops, in contrast, whose primary market is local, depend strongly on local transportation infrastructure, and are likely to support risk-management programs with a local focus.

5.3.3 Development Interest Groups

Development interest groups are commercial interest groups focused on the construction, renting, and selling of building space. While these interest groups have some of the same attributes and concerns as commercial interest groups, they warrant a separate classification because of their particular focus on the creation of structures, whose collapse causes almost all earthquake-related fatalities and much of the related economic losses.

Development interest groups can be further subdivided into landowners, developers, and the construction industry. Landowners own undeveloped areas, holding them for future sale or development. Developers provide the money to subdivide and prepare the land for construction, they design and construct the buildings, and they either sell them or rent them. Within development interest groups, the construction industry is responsible for actual construction. Neither the landowners nor the construction industry have much incentive to promote risk-management programs.

Landowners have little incentive because an earthquake causes little or no damage to undeveloped property. Landowners have a stake in the maintenance of an orderly legal infrastructure since, without legal title, their land is worthless. Aside from a complete breakdown of society, however, their risks are minimal. Also, once a developed land parcel is sold, there is little or no liability associated with it.

The construction industry may have limited incentive to protect buildings even though a builder is potentially liable for building-code violations if these violations result in the collapse of the structure. The probability of this risk in any particular year is minimal, however, because of the long return periods customarily associated with seismic events. In other words, significant risk of collapse may fall beyond the time horizon of the builder. In this context of perceived risk, market forces and building standards determine the required level of quality.

Developers, on the other hand, should have a much stronger interest in risk management, particularly if they own buildings and intend to rent them after completion. While this is true to up a point, developers are often the strongest opponents to risk-mitigation efforts. Developers, being businesses, are motivated primarily by profit. Since rental and building prices are driven by supply and demand, they argue that they will not be able to recover any increase in construction costs.

5.3.4 Governmental Interest Groups

The government mediates and balances competing local and national interests to provide an overall policy direction that it then enforces through legislation. In theory, then, government serves society as an unbiased moderator.

In practice, governmental agencies have self-interests. For this reason, it is important to consider the government as an independent interest group.

Governmental interest groups occupy a unique position in seismic risk management because only a government can enact or enforce laws supporting risk-management programs. While professional engineering associations may write design provisions that address seismic risk, it is the government that turns these provisions into codes by adopting them legally and then enforcing them. Nevertheless, risk management is not the only issue on a government's agenda. These competing issues are often placed ahead of risk management because the government is often handicapped by the relatively short time horizon of elected officials. Such officials maintain their position only by delivering to their constituents. Given the normally long return period between catastrophic earthquakes, failure to address seismic risk shows itself years or decades after the responsible officials have left public service. As such, politicians are inclined to support programs that demonstrate results in the short term, such as providing clean water or stimulating the economy. Officials in dictatorial governments can potentially take a longer view, but even these individuals must demonstrate results to their superiors, and have little incentive to do so without a commitment from above.

Despite popular reference to "The Government" as a single entity, in practice there are many organizational divisions within the overall structure. Aside from the functional divisions (economic development, law enforcement, etc.), structural divisions exist from the national down to the local level, each with its own areas of jurisdiction. With regard to seismic risk management, a local government is typically the most important governmental interest group. It adopts and enforces building codes and land-use restrictions. Even if disaster preparedness is organized nationally, local responders are the first to arrive on the scene, and play a crucial role in the effectiveness of that response.

Non-governmental organizations (NGOs) may share a government's goal of societal improvement. These organizations include professional engineering societies and international development organizations. While NGOs may not have the legal authority to implement risk-management policy, and have distinct individual motivations, they often assist in the development of such policy. Even if an NGO's members might benefit from such policies, the NGO itself is not profit-motivated. As such, they are considered here as a subset of governmental interest groups.

Professional societies exist to facilitate collaboration and knowledge transfer within the profession they represent, and with the greater public outside that profession. These societies are particularly important for seismic risk mitigation because they typically serve as the technical experts for infrastructure. They are primarily responsible for the development of design codes that establish safe and consistent construction practices. Professional societies are hampered, however, by lack of knowledge of risk management outside their own areas of expertise; they have little incentive to advocate mitigation solutions that lie outside that expertise. Multidisciplinary professional societies, such as the Earthquake Engineering Research Institute in the United States, can address these limitations by facilitating interaction among more specialized professional societies.

While international development organizations are organized like professional societies, their goals are usually more specific than the general enhancement of a body of technical knowledge. They may be as broad as general economic development or as narrow as reducing seismic risk in urban areas. Unlike professional societies, which are composed primarily of volunteers, international development organizations use paid staff to accomplish their goals, obtaining funding from member states or through international groups such as the United Nations. These organizations provide an important vehicle for sharing experiences and expertise across national borders. They can also have substantial influence on a developing country's risk-management policies, depending on their level of financial contribution relative to that of the national or local government.

5.4 CONCLUDING REMARKS: INTEREST GROUPS

Society is composed of individuals, each exposed to different seismic risk levels and each with his or her own attitudes towards this risk. While seismic risk-mitigation policies cannot be tailored to individual characteristics, broad-based support is likely to be engendered by integrated risk-management strategies that balance effects among different interest groups. In this chapter, we have attempted to classify individuals into interest groups with respect to their attitudes toward seismic risk. To do so, we first defined specific characteristics relevant to seismic risk management, including (1) geographic location, (2) class of structure, (3) source and level of income, and (4) discount rate and time horizon of the group. These characteristics were then applied to define four interest groups: (1) residential interest groups, (2) business interest groups, (3) development interest groups, and (4) governmental interest groups.

These are not the only classifications, or even the most appropriate classifications, relevant to seismic risk management. Moreover, in reality, society cannot be neatly partitioned into these groups. Nevertheless, some compromise must be made between considering each member of a society as an individual and considering society as a homogenous entity. The process of identification and characterization of interests helps to identify potential commonalities and conflicts with respect to seismic risk management. The next chapter considers different types of risk-management programs and how these programs can have non-uniform effects on the interest groups described above.

CHAPTER 6

Seismic Risk-Management Programs

6.1 Introduction

A risk-management program is a proactive attempt to implement risk reduction using a specific underlying rationale. In general, these programs are organized or implemented by the government, which possesses unique legal and funding authority. This government role exists even for programs conceived and developed by community organizations or professional societies.

In this chapter, representative seismic risk-management programs are considered, with emphasis on programs to address risk to buildings and other structures. An important aspect of this chapter is how these different types of programs, including at least one from each of the methods of risk-management described in Chapter 2 (avoidance, transfer, and mitigation), affect the different interest groups described in the preceding chapter. Explicit recognition of these non-uniform effects is utilized in the methodology proposed in Chapter 7.

It is useful to preface this discussion by noting the difference between a program's known effects and its anticipated effects, as these terms are used in this thesis. Known effects are those that exist whether or not an earthquake occurs and represent the cost of implementing the program. Anticipated effects, on the other hand, are recognized only in the event of an earthquake. Typically, these effects are the benefits of risk-reduction efforts, most often accounted for as reduced losses. It is, however, important to recognize that known effects are not always costs and anticipated effects are not always benefits. This is particularly true when effects are partitioned among different interest groups.

The four risk-management programs considered in this chapter are: land-use restrictions; earthquake insurance; building-code improvement or enforcement; and building retrofit. The first two programs are examples of risk avoidance and risk transfer, respectively; the third and fourth are examples of risk mitigation. This list of programs is not intended to be all-inclusive. Rather, it is intended to represent common programs and to illustrate how these programs can affect interest groups.

6.2 LAND-USE RESTRICTIONS

Land-use restrictions, when applied to seismic risk management, are examples of risk avoidance. Conceptually, construction is restricted in areas of greatest seismic hazard, such as those prone to liquefaction or landslides. In its most extreme form, construction is completely prohibited in these areas. This does not necessarily imply that these areas no longer have value – they can be used for parks or other forms of open space – but it does devalue the land, since it can no longer be used for more lucrative investments such as housing developments. In a more benign form, restrictions can apply, for example, only to multistory residential structures.

The known effects of land-use restrictions are directed primarily toward developers. By restricting development in some areas, developers lose at least some of the income potential of those areas. Those who own land that was purchased with the intent of development in the near term are affected most directly and adversely. The effect of these restrictions on the region as a whole, due to a reduction in the supply of available land, is an increase in property values and rental costs. This increase is a benefit to developers and other property owners who own land not affected by the restrictions, but there may be resistance even from these individuals if they are concerned that the restrictions will eventually be extended to include their properties. If the restrictions apply only to areas intended for development in the long term, the effect on most interest groups is minimal.

The anticipated effects of land-use restrictions are reduced losses to the residents and businesses that would have been located in the affected areas. The greatest direct economic benefit is directed towards the developers and other property owners who would have owned these buildings and to the businesses that would have been disrupted by damage to these buildings. The greatest social benefit is to the residents who would have lived in these areas. These residents also avoid economic losses in terms of personal property, especially if they own their residence, and wages lost by family members who would have been injured or killed.

The strongest opponents of land-use restrictions are usually the developers who argue that they are already aware of the risks and have incorporated them into their business plans. Such an argument may hold true for a large, multifamily dwelling in which the developer anticipates an income stream from the renters. For smaller, single-family homes seismic risk is immediately transferred to the homeowner and the mortgage lender. While large lending institutions may realistically account for this risk, individual homeowners are less likely to be aware of its magnitude.

One important limitation on the usefulness of land-use restrictions in developing countries is the presence of significant populations of squatters – individuals who move, most often from the countryside, and populate inherently less desirable urban areas without title to the land on which they live. Most often, these areas are of limited economic use, partly due to the risk of flooding or landslides. These individuals act outside of existing land-ownership regulations and it is therefore unrealistic to expect them to follow land-use restrictions or building-code requirements. As a result, natural disasters such as floods and earthquakes can lead to high casualties and fatalities in this group.

6.3 PROPERTY INSURANCE FOR SEISMIC EVENTS

Insurance transfers risk from one individual to another, with the second typically being a group of individuals. The group accepts the low and highly uncertain risks of its single constituent individuals, and converts those risks into a collective averaged risk with much less uncertainty. Insurance also provides a vehicle by which the transferred cost is invested until the event occurs, thereby providing a mechanism through which funds can be set aside for the future. In summary, insurance averages risk across both individuals and time.

Earthquake insurance is generally designed to cover loss to property only. The individual pays a fee (that is, a premium) to a fund at regular intervals. The fee is proportional to his or her potential loss and the probability that that loss will occur at regular intervals – in other words, proportional to the risk of the individual. In the event of an earthquake, the fund is intended to cover the losses. These fees constitute a cost to the individual and the interest groups to which that individual belongs.

The known effect of earthquake insurance is the financial cost of the premiums, borne by the insured. The insured potentially include residents, businesses, and building owners. Residential interest groups, commercial interest groups, and development interest groups represent these individuals. The administrator of the insurance program can either be a business (typically large) or the government, represented by either commercial or governmental interest groups.

If a damaging earthquake occurs, the potential effects of an insurance program are realized. The insurance administrator covers the losses of those submitting claims resulting in a transfer of funds from either commercial or governmental interests (depending on which group is administrating the program) to those interest groups that participated in the program. There is no net change in the economic losses due to insurance, only a shift in who bears these losses.

A broad-based and well-administered insurance program can actually reduce potential losses in two ways, however. First, before an earthquake occurs, insurance programs can provide incentives to encourage risk mitigation. If sufficient analysis has been performed to quantify the risk reduction achieved by various mitigation techniques, the insurance scheme can reduce premiums accordingly. This cost reduction, from the perspective of the insured, encourages risk reduction by providing direct and tangible benefits. Second, after the earthquake, rapid disbursement of funds can ameliorate indirect economic losses by accelerating the recovery effort.

The greatest challenge associated with implementing earthquake insurance is encouraging sufficient participation to make the program financially sound. Without a large, geographically distributed base of participants, the program runs the risk of not having sufficient funds to cover claims if a damaging earthquake occurs in the near term. In some cases, government has mandated participation in an insurance program to overcome this challenge.

6.4 BUILDING-CODE IMPROVEMENT OR ENFORCEMENT

Building-code improvement or enforcement, alone or in combination, falls under the classification of risk mitigation. While seismic hazard is not reduced, structures designed and constructed in compliance with a rational building code generally behave better than other structures in earthquakes. Most building codes are intended to prevent loss of life by building collapse. For this reason, they do not necessarily reduce losses to the property owner. They do generally provide significant reductions in social costs (casualties and fatalities) and indirect losses (internal property and business disruption).

For a building code to reduce seismic risk, three elements are necessary: the building code must be legally enforceable; an adequate number of competent inspectors must exist; and the social and legal framework must limit corruption.

The first requirement, stated most directly, is for legal standing. Building codes are typically developed at the national level through discussions between the national government and relevant professionals, including engineers. Building codes are almost always enforced locally, thus the local jurisdictions must adopt the national code for any potential effect to be realized.

The second requirement is that the local jurisdiction employ a sufficient number of competent inspectors to ensure that the adopted code provisions are enforced. The required number of inspectors is related to the size of the locality and the level of construction activity.

The third requirement, most relevant to the developing world, is for a culture that eliminates or greatly reduces the possibility of simply bribing a building inspector rather than complying with the building code. Enforcement failure was an important factor in the damage from recent earthquakes in Turkey. In that country, which has building codes comparable to those of the highly seismic state of California, many of the thousands of deaths in the earthquakes of 1999 and 2000 were attributable to buildings constructed without adherence to existing codes.[22] The pay of building inspectors can be an important factor in this regard. In the 2001 earthquake in Bhuj, India, much of the observed damage was attributable to failure to use that country's seismic design codes, which were well developed but not mandatory.[23]

The known effects of building codes – increased engineering and construction costs – are borne primarily by developers and the construction industry (development interest groups). Such costs may ultimately be passed on to residents and businesses through increased rents. Prices for residential and business space are set by the supply and demand of the real estate market, however, at least in the short term.

Another known effect is the cost of building-code enforcement. Without adequate enforcement, disreputable firms will ignore the more costly aspects of even the most straightforward design code. Over time the potential benefits of an effective seismic design code will be lost. The government must provide enough building inspectors, and pay them well enough to minimize the chance that they will be bribed to overlook violations, so that the adopted design codes are adhered to. If enforcement has been a problem in the past, the cost to the government could be significant. If enforcement has not been a problem, then the cost of adopting a seismic design code should be minimal, limited only to the training of the existing inspectors.

The anticipated effects of effective building codes are reduced economic and social losses in the event of an earthquake to those residents and businesses occupying structures built under such codes. It is important to note, however, that most design codes do not attempt to prevent catastrophic damage to buildings in the event of an earthquake. Rather, the goal is to prevent complete collapse of the building and hence minimize injuries and fatalities. Preventing collapse also minimizes losses of personal effects within the structure. Nevertheless, a properly designed and constructed building subject to an earthquake could result in reduced injuries and fatalities, even if the building itself is a complete economic loss. As such, the primary beneficiaries of seismic design codes are the occupants of the structures – the residents and businesses. The owners of the structures (developers, homeowners, or lenders) derive little benefit from seismic design codes under severe seismic loading.

6.5 Retrofitting of Existing Structures

Although building codes evolve over time, a building, once constructed, is tied to the building code under which it was designed. This is particularly problematic with respect to seismic design codes. Seismic design has evolved significantly in the past 50 years based on better understanding of strong ground motion, improved analysis and testing techniques for dynamic loading, and study of failure mechanisms in buildings that have collapsed during major earthquakes. This last point often causes seismic design codes to evolve in a series of "growth spurts" following major earthquakes.

Many older buildings were designed and constructed with essentially no formal consideration of seismic loading. Retrofitting is the process of modifying these structures to bring them into compliance, or closer to compliance, with current design standards, and thereby to reduce their seismic vulnerability. As such, it falls under the classification of risk mitigation and the effects are similar to those from building-code improvement or enforcement.

Retrofitting programs range from the most basic, requiring no formal design or engineering analysis, to massive construction projects whose cost approaches that of complete demolition and reconstruction. An example of a basic retrofitting program is encouraging residents to strap water heaters to the wall to prevent them from tipping over during an earthquake and starting a fire. Encouraging residents to bolt shear walls to the foundation is a slightly more advanced approach but does not require engineering analysis. Simple, do-it-yourself retrofitting programs can be encouraged through educational mailings and rebates offered on material costs. For example, low-interest loans for seismic retrofit are available through the City of Los Angeles and the state government of California. The City of Berkeley waives permit fees for such work. Santa Cruz County offered grants of up to $10,000 to pay for half the cost of professional retrofitting.[24]

At the other extreme are mandated retrofit programs. In these programs, building owners are given a deadline by which their structures must comply at some level with current design standards. If the deadline is not met, the building is condemned and ultimately demolished. As extreme as this program sounds, it has been applied successfully in the Southern California cities of Long Beach and Los Angeles. These programs were instituted after much study and debate for seismic retrofitting of unreinforced masonry buildings, which had been shown to be particularly vulnerable to seismic loading.[25]

The known effects of retrofit programs are limited to the process of retrofitting the structures. For grant and loan programs, the government may subsidize the costs of these subsidies as well as bear the administrative costs of the program (public education, processing of applications, etc.). Residents and businesses that participate in the program may also contribute. The construction costs of retrofit, however, can be considered a benefit to the construction industry.

The potential effects of retrofit are essentially the same as building code enforcement or upgrade. The residents and businesses that occupy the retrofit structures can expect reduced economic and social costs following the earthquake. Once again, the avoided losses benefit primarily the occupants and their personal effects. Retrofitting, like building codes, is not designed to prevent severe structural damage to a building, only to prevent it from collapsing.

6.6 Concluding Remarks: Seismic Risk-Management Programs

Seismic risk-management programs are organized attempts to reduce the risk to society. This chapter reviewed four representative risk-management programs that address risk to buildings and other structures. The purpose of this discussion was emphasizing two aspects of the difference between the programs.

One emphasized difference was between "known" versus "anticipated" effects. As used in this thesis, known effects are the effects of implementation and exist whether or not an earthquake occurs. Anticipated effects are those realized only after a damaging earthquake. This distinction was drawn because differing perceptions in risk, as discussed in Section 2.5, affect the valuation that individuals assign to the anticipated effects of any risk-management effort. When program effects are partitioned in this manner, risk valuations may be assigned independently to each of the interest groups.

A second emphasized difference was how programs non-uniformly affect different interest groups. In general, the known effects of any program have a net cost to society, while anticipated effects provide a net benefit. (It is difficult to argue for the implementation of a program that detracts from society overall!) Nevertheless, when one considers how these effects are partitioned among different interest groups, even if a particular program provides a net benefit to society it may adversely affect certain interest groups. Any given program can have positive and negative effects, both before and after a damaging earthquake. Explicit recognition of non-uniformities is a step in the process of developing integrated strategies that are both effective and capable of evoking broad-based support.

CHAPTER 7
Proposed Methodology

7.1 Introduction

This chapter proposes a rational methodology for simultaneously evaluating technical effectiveness and political feasibility. It builds on the two approaches for evaluating risk-management programs that are discussed in Chapter 3 and a review of how such programs are implemented as discussed in Chapter 4. The methodology is based on three assumptions: politically feasible strategies balance effects (benefits and costs) among relevant interest groups; political support depends on subjective perceptions of risk and effects rather than purely objective assessments; and interest groups have non-uniform levels of influence on the policy-making process.

After providing an overview of the proposed methodology in Section 7.2, the relevant variables and required assumptions are listed in Sections 7.3 and 7.4. The mechanics of the two phases of the methodology – program evaluation and strategy evaluation – are described in Section 7.5 and Section 7.6. Concluding remarks are offered in Section 7.7.

7.2 Overview of the Methodology

The proposed methodology is intended to provide a bridge between the objective assessment of technical effectiveness and the subjective assessment of political feasibility. It is directed towards those responsible for coordinating risk-management strategies or those attempting to understand why previous risk-mitigation efforts have succeeded or failed. Due to its complexity, it is not intended to provide results for direct presentation to interest groups, but rather to provide guidance to those planning such presentations.

The methodology is an application of multi-objective analysis, a field that has developed significantly in the last several decades in response to the limitations of benefit-cost analysis. The methods used in this application – weighted summation[26] and sequential elimination[27] – are not new. Their application to the challenge of seismic risk reduction, however, has been limited, particularly with regard to the development of integrated strategies. The main contribution offered here is a framework within which these tools can be applied to this area of risk management.

The proposed methodology has two phases: (1) program evaluation; and (2) strategy evaluation. In the first phase, individual programs are evaluated for effectiveness. Programs are defined as discrete units that are part of an overall risk-management strategy. Program evaluation consists of quantifying known and anticipated effects of the program, and partitioning these effects among the various interest groups (that is, stakeholder groups). Known effects (typically costs) are those associated with program implementation. Anticipated effects (typically benefits) are those realized in the event of an earthquake. Anticipated effects for each interest group are then adjusted based on that group's particular perception of risk, resulting in valuations for perceived effects.

In the second phase of the methodology, the effects of possible strategies (combinations of programs) are evaluated. The effects of strategies are assumed to be the linear combinations of the effects of programs. Constraints on the various effects are defined, with the goal of eliminating strategies that are either relatively ineffective or relatively unfeasible. The remaining strategy options are deemed worthy of further exploration. The goal is to reduce the potentially extensive list of all possible strategies to a more manageable list of strategies that are both technically sound and politically feasible. This abridged list can then be used as a starting point for focus-group discussions.

7.3 ASSUMPTIONS OF THE PROPOSED METHODOLOGY

The three assumptions underlying the proposed methodology, listed in the introduction to this chapter, are as follows: politically feasible strategies balance effects among the various interest groups, perceived benefits are more important than actual benefits; and interest groups have non-uniform levels of influence on the policy-making process. In addition to these three conceptual assumptions, six procedural assumptions are required for the computational aspects of the methodology:

- discrete program units;
- known program effects;
- discrete interest groups;
- known risk-perception levels;
- known influence levels; and
- absence of synergistic effects among programs or interest groups.

The assumption of discrete program units is required for strategies to be defined as various combinations of programs. In other words, in any given strategy, a particular program is either included or it is not. This assumption permits considering several levels of implementation of a program as several discrete program units. Doing so, however, requires that if the strategy includes a particular level of program implementation, then it must also include all preceding levels.

The assumption that program effects are known is made to simplify calculations. In practice, all valuations of program effects are associated with some uncertainty. It is possible to carry these uncertainties through the analysis using conventional error-propagation techniques, resulting in bounded estimates for each parameter. While useful, these additional calculations were not deemed worthwhile at this stage of development. Embedded in the assumption of known program effects is that the valuations represent "average" or expected values for the program / interest-group pair under consideration.

The assumption of discrete interest groups allows society to be partitioned into a manageable number of sufficiently distinct interest groups. It is recognized that any given individual may, in fact, belong to more than one interest group. For analysis, however, each interest group is considered as a single, unique entity that represents the interest of the group as a whole. It is further assumed that the interest groups used in the analysis, when aggregated, represent all relevant sectors of society.

The assumption that risk perception levels are known is similarly required only to simplify the quantitative aspect of the analyses. As with program effects, uncertainty in valuations could be carried through the analysis but was deemed to be excessively complex at this stage.

The assumption that political influence levels are known is similar to the assumption of known risk perception levels, but has the added restriction that a single influence level is assigned to each interest group and applies to all programs considered. In reality, the levels of political influence could vary from program to program. Subsequent development of the methodology may include the additional complexity of defining influence levels defined for each program / interest-group pair.

The assumption of no synergistic effects among programs or interest groups is the most tenuous. It is made so that the program effects can be aggregated, either across interest groups or over multiple programs, without the need to correct for interaction effects. Thus, the overall effect of a program is the sum of the effects on each of the interest groups (accounting for the influence level of each of the interest groups) and the overall effect of a strategy is the sum of the effects of the programs that comprise that strategy. In reality, synergistic effects nearly always exist. While no clear approach to considering synergistic effects has been identified, techniques may exist that could be incorporated into the proposed methodology.

7.4 NOMENCLATURE OF PROPOSED METHODOLOGY

The variables and terms used in the proposed methodology are defined in this section. The variables are defined in Table 7.1, which is followed by short descriptions of the key variables. More complete descriptions and the use of these variables are given in the subsequent sections.

Table 7.1. Variable List

Variable	**Range or Dimensions**	**Description**
m	*(arbitrary)*	Number of possible programs
n	*(arbitrary)*	Number of interest groups
p	*(arbitrary)*	Number of known effects
q	*(arbitrary)*	Number of anticipated effects
K	2^m	Number of strategies
i	*1, 2…m*	Program index
j	*1, 2…n*	Interest-group index
a	*1, 2…p*	Known effect index
b	*1, 2…q*	Anticipated effect index
k	*1, 2…K*	Strategy index
PIL	*1 x n*	Political Influence Level
KPE	*m x n x p*	Known Program Effects
APE	*m x n x q*	Anticipated Program Effects
PPE	*m x n x q*	Perceived Program Effects
RPL	*m x n x q*	Risk Perception Level
SM	*k x n*	Strategy Matrix
KSE	*k x n x p*	Known Strategy Effects
PSE	*k x n x q*	Perceived Strategy Effects
TKSE	*k x p*	Total Known Strategy Effects
TPSE	*k x q*	Total Perceived Strategy Effects

Program – A program is a discrete action intended to reduce risk. In the proposed methodology, a program is either implemented completely or not at all. If an overall approach to risk reduction has various stages of implementation, each stage is considered as a discrete program.

Strategy – A strategy is combination of programs. The effects of each program are assumed to be independent, making the overall effect of a given strategy the linear combination of the effects of the programs comprising it.

Interest Group – An interest group is a subset of society with common goals and interests. In the analysis presented here, an interest group is considered as a uniform entity with common goals and values.

Known Effects – Known effects are those associated with implementing a risk-reduction program or strategy, and exist whether or not an earthquake occurs. Known effects are typically costs because implementation of risk reduction usually requires initial financial outlays in anticipation of the potential benefits.

Anticipated Effects – Anticipated effects are those associated with a program in the event of an earthquake. Because the goal of seismic risk reduction is to reduce the negative consequences of an earthquake, anticipated effects represent reduced losses from the reference approach of doing nothing.

Perceived Effects – Perceived effects exist for both programs and strategies and represent the valuations assigned by each interest group to the anticipated effects it receives from the risk-reduction effort. Perceived effects differ from anticipated effects in that they have been adjusted for perceptions of risk by each of the interest groups..

Risk Perception Level – Perception of risk, discussed in Section 2.5, can be loosely defined as the valuation that that individual or interest group places on the outcome of an uncertain event. Factors that influence this perception include the group's knowledge of the risk, its time horizon, and inherent aversion to or acceptance of risk. In the analysis, the risk perception level is a multiplier that transforms anticipated effects into perceived effects. A unique value may be assigned for each program / interest group pair and for each type of anticipated effect.

Political Influence Level – The political influence level represents the fraction of influence that each interest group carries in the overall policy-making process. A single value is defined for each interest group.

7.5 PROGRAM EVALUATION (PHASE 1)

The first phase of the proposed methodology involves evaluating the effects of each proposed program. Program evaluation is divided into five steps:

1. Assess program effects (known and anticipated);
2. Assess risk-perception levels for anticipated effects;
3. Compile program effects and risk perception levels into arrays;
4. Compute perceived effects; and
5. Define influence levels for the interest groups.

The first step is an objective assessment of the technical effectiveness of a program. The second step is a subjective assessment of how each interest group perceives the anticipated effects of the program – the risk-perception level. These two steps are performed independently for all possible programs. The third step compiles these results into a set of matrices. Using these matrices, the fourth step transforms anticipated effects into perceived effects. Finally, in the fifth step, political influence levels are assigned for each of the interest groups. Each step is described in greater detail in the following subsections.

7.5.1 Assess Program Effects

The first step, assessment of program effects, is equivalent to the assessment step in conventional benefit-cost analysis (BCA) or multi-objective analysis (MOA). Program effects include the known effects of implementing the program and the anticipated effects in the event of an earthquake. The proposed methodology does not assume that all effects are monetary – social costs such as fatalities or lost jobs may also be included in their original units.

Known effects exist whether or not an earthquake occurs, and are typically positive costs. These costs must be apportioned among the various interest groups with the idea that the total cost of the program is the summation of its costs to each interest group. Negative costs, if they exist, represent a gain by the interest group as a consequence of the risk-management program. For example, mandated seismic retrofitting would represent a negative cost for the construction industry.

Anticipated effects are realized only in the event of an earthquake. No discounting is applied for the seismic hazard; thus, the methodology requires selecting a representative earthquake. This could either be an earthquake of a given magnitude at a specified location or some average level of ground shaking. Anticipated effects are generally considered as reduced losses due to implementing the program. In other words, these effects are typically viewed as benefits compared to the zero-case approach of doing nothing. Anticipated effects are similarly apportioned among the various interest groups. Negative benefits are also possible, and represent a loss by an interest group. For example, after an earthquake the insurance industry would incur negative effects in the form of claims paid out to insured individuals.

The result of the program-assessment step is a set of tables, each summarizing the effects of one program. Table 7.2 shows the layout of such a table in which two interest groups (A and B) are considered, with one type of known effect ($) and two types of anticipated effects ($ and lives). If this program is implemented it will cost Interest Group A $5 and Interest Group B $10. In the event of an earthquake, the program results in reduced losses of $20 and 5 lives to Interest Group A. Interest Group B avoids losses of $30 and 10 lives.

Table 7.2. Sample Program Effect Assessment

	A	*B*
Known Effect	$5	$10
Anticipated Effect – 1	$20	$30
Anticipated Effect – 2	5 lives	10 lives

7.5.2 Assess Risk-Perception Levels

The second step is assessment of risk-perception levels – the relative valuation that each interest group places on the anticipated effects of the program. It is much more subjective than assessment of program effects.

The risk-perception level is used to transform the anticipated effects of a program into perceived effects. For each program, valuations are required for each interest group and for each type of effect. Each value is a multiplier representing that interest group's valuation of an anticipated effect of a program. Factors in assessing this subjective value include each interest group's time horizon and financial discount rate; awareness of the risk level; and acceptance of or aversion to risk.

The goal is to arrive at a value that measures how the interest group values the anticipated effect (in general, the benefit) of the program. Also, even though each interest group's time horizon is included in the assessment, it is not necessary to consider the probability of an earthquake occurring within this time frame. We are not seeking to perform a formal benefit-cost analysis in which the present value of an uncertain outcome (the benefit) is weighed against the cost of implementation. Rather, the goal is to determine a set of values that are internally self-consistent so that comparisons can be made across interest groups and among different programs. For example, a purely objective probabilistic assessment of risk over a specified time horizon could be assigned a reference value of unity. Values for interest groups with shorter time horizons, lower awareness of risk, or greater acceptance of risk would be assigned correspondingly lower risk-perception levels.

For a single program, the risk-perception matrix is a listing of the relative valuation that each interest group places on each type of anticipated effect. Table 7.3 shows an example of the risk-perception level matrix for a single program with two types of anticipated effects. Interest Group A is chosen as the reference, and is assigned a valuation of 1.0 for both types of effects. For the first type of anticipated effect ($), Interest Group B is assigned a valuation of 0.5, representing greater discounting of this anticipated effect. A value of 0.25 is assigned for the other anticipated effect (lives), representing an even greater devaluation by Interest Group B. The extreme case of indifference would be a value of zero, representing no value of anticipated effects.

Table 7.3 Sample Risk Perception Level Assessment

	A	*B*
Anticipated Effect 1 ($)	1.00	0.50
Anticipated Effect 2 (lives)	1.00	0.25

7.5.3 Compile Program Assessment Matrices

The results of program assessment are compiled into three arrays: known program effects (*KPE*); anticipated program effects (*APE*); and risk perception levels (*RPL*). The first two dimensions of these arrays, which can be thought of as rows and columns, correspond to programs and interest groups, respectively. The third dimension of these arrays corresponds to the number of effect types considered (for example, monetary, human, and so forth).

Table 7.4 shows a single layer (that is, only the first two dimensions) of the *KPE* array. The rows represent the different programs and the columns represent the different interest groups. The values in this table represent implementation effects in consistent units, for example, monetary units. Reading across a row shows how effects of a given program are distributed among the different interest groups. Reading down a column shows how the different programs affect a given interest group. Other types of known effects would be compiled on other layers of this array. There are as many layers as there are types of known effects considered in the analysis.

Similarly, Table 7.5 shows a single layer of the *APE* array. Once again, the rows and columns represent different programs and interest groups, respectively. The values in any layer are in consistent units and there as many layers as there are types of anticipated effects considered in the analysis.

Finally, Table 7.6 shows a single layer of the *RPL* array. This array has the exact dimensions of the *APE* array because a risk perception level is assigned for every type of anticipated effect and for every program / interest group pairing.

Table 7.4. Known Program Effects (KPE)

Interest Groups

$KPE =$

KPE_{12}	KPE_{12}	...	KPE_{1n}
KPE_{21}	KPE_{22}	...	KPE_{2n}
...	...	...	...
KPE_{m1}	KPE_{m2}	...	KPE_{mn}

Programs

Table 7.5. Anticipated Program Effect s(APE)

Interest Groups

$APE =$

APE_{12}	APE_{12}	...	APE_{1n}
APE_{21}	APE_{22}	...	APE_{2n}
...	...	...	...
APE_{m1}	APE_{m2}	...	APE_{mn}

Programs

Table 7.6. Risk Perception Level s(RPL)

Interest Groups

$RPL =$

RPL_{12}	RPL_{12}	...	RPL_{1n}
RPL_{21}	RPL_{22}	...	RPL_{2n}
...	...	...	...
RPL_{m1}	RPL_{m2}	...	RPL_{mn}

Programs

Examples of these three arrays are given in Table 7.7 through Table 7.9. The first table is of known program effects (*KPE*). Only a single type of effect (monetary, \$) is considered, so this matrix represents the entire *KPE* array. The first row of this matrix lists the known effects of the first program as partitioned between the two interest groups (see Table 7.7). The second row of this matrix lists the known effects of a second program not discussed above. This row shows that the second group costs \$7 to Interest Group A and \$4 to Interest Group B.

Continuing with the example begun in the previous section, two interest groups (A and B) and two programs (1 and 2) are considered. The first row of this matrix lists the known effects of program 1, in this case monetary, as they are distributed among the two interest groups (A and B). The monetary cost of program 1 is \$5 to interest group A and \$10 to interest group B. These values are taken from Table 7.2. The second row of this matrix lists the known effects of the second program as they are partitioned between the two interest groups. In this case, the cost of implementing Program 2 is \$7 to Interest Group A and \$4 to Interest Group B, values not listed above.

Table 7.7. Sample KPE Array

KPE =

\$5	\$10
\$7	\$4

The second array (Table 7.8) lists the anticipated program effects, those realized by the different interest groups if an earthquake occurs. Only the first layer (monetary effects) is shown here; a similar matrix could be constructed for human effects (lives). In this case, Program 1 provides \$20 of benefit to Interest Group A and \$30 of benefit to Interest Group B (see Table 7.2). Similarly the second program (not listed above) provides benefits of \$36 and \$16 to Interest Groups A and B, respectively.

Table 7.8. Sample APE Array (First Layer)

APE_1 =

\$20	\$30
\$36	\$16

The third array (*RPL*, Table 7.9) compiles the risk perception levels of each of the programs. This array has the same dimensions as that of the *APE* array because a risk perception level is assigned for every program / interest group pairing and for every type of anticipated effect considered. Only the first layer, representing monetary effects, is shown here. The first row represents the relative weighting assigned by Interest Groups A and B to the anticipated effects of the first program. In this case, Interest Group assigns a weight of 1.00 and Interest Group B assigns a weight of 0.50. These values are taken from Table 7.3. The second row represents the weights assigned by these interest groups to the second program, not discussed above. A second layer of this matrix (not shown) also exists. This second layer represents the weights assigned to the human effects (lives) by Interest Groups A and B to the two programs.

Table 7.9. Sample RPL Array (First Layer)

RPL_1 =

1.00	0.50
0.75	0.25

7.5.4 Compute Perceived Program Effects

Perceived program effects are the product of anticipated effects (those realized if an earthquake occurs) and the risk-perception levels assigned for each of the interest groups. This transformation is a scalar multiplication – matrix manipulation is not required – but the required values have been compiled into arrays and these arrays will be used to perform the transformation.

The arrays used to compile anticipated effects and the risk perception levels have equivalent dimensions – the same number of rows and columns (corresponding to programs and interest groups) and equivalent depth (corresponding to number of types of effects considered). The elements of the perceived program effects array (*PPE*) are the product of the corresponding elements in the anticipated program effects (*APE*) and the risk perception levels (*RPL*) arrays. This computation is shown here:

$$PPE_{ijb} = APE_{ijb}\, RPL_{ijb} \qquad i=1..m,\, j=1..n,\, b=1..q \qquad (7.1)$$

The result of this computation is a perceived program effects array with equivalent dimensions, the first layer of which is shown in Table 7.10.

Table 7.10. Perceived Program Effects (APE)

Interest Groups (columns); *Programs* (rows)

$PPE =$

PPE_{12}	PPE_{12}	...	PPE_{1n}
PPE_{21}	PPE_{22}	...	PPE_{2n}
...	...	...	...
PPE_{m1}	PPE_{m2}	...	PPE_{mn}

Returning to the example developed in the previous sections. the monetary layer of this array is shown in Table 7.11. The elements in the first row represent the perceived monetary effects of the first program as apportioned between the two interest groups (A and B). The perceived effect of the first program is \$20 to Interest Group A and \$15 to Interest Group B. These values are computed from the values given in Table 7.8 and Table 7.9. The values in the second row of Table 7.11 are computed in a similar manner.

Table 7.11. Sample PPE Array (First Layer)

$PPE_1 =$

\$20	\$15
\$27	\$4

7.5.5 Assess Political Influence Levels

The political-influence level accounts for differing levels of influence of each interest group on the policy-making process. These differences exist due to differing levels of wealth, political involvement, or organization. In the proposed methodology, the political-influence level serves as a weighting factor when aggregating effects across interest groups to determine an overall effect on society.

A single influence level is defined for each interest group (see Table 7.12). Its value represents the fraction of influence that the interest group carries in the policy-making process. It is therefore bounded between zero and unity, with the requirement that the values sum to unity across all interest groups:

$$0 \le I_j \le 1 \qquad \sum_{j=1..n} I_j = 1 \qquad (7.2)$$

Table 7.12. Political Influence Levels

PIL =

Interest Groups			
PIL_1	PIL_1	...	PIL_n

If each interest group carries equal weight in the decision-making process, then all have the equivalent value of 1/n, where n represents the number of interest groups. The equal-weight assumption provides a good starting point for estimating the influence levels. The values of individual groups can then be subjectively increased or decreased. An example with two interest groups (A and B) is shown in Table 7.13. With equal weights, each interest group has an influence level of 0.50, representing equal representation in the decision-making process. Assuming that Interest Group B has a much stronger voice in this process, the influence value for this group has been adjusted upwards to 0.75. To maintain the requirement that the fractions sum to unity, the value for Interest Group A has been reduced to 0.25.

Table 7.13 Sample PIL Array (PIL)

	A	*B*	*Total*

Equal weighting	0.50	0.50	1.00
Adjusted weighting	0.25	0.75	1.00

7.6 STRATEGY EVALUATION (PHASE 2)

The second phase of the methodology – strategy evaluation – consists of four steps:

1. Evaluate effects of possible strategies;
2. Define relevant constraints;
3. Apply these constraints to identify feasible strategies; and
4. Rank feasible strategies.

The first step is essentially "brute-force." It consists of computing the effects of all possible combinations of programs. The second step is the most important, and also the most subjective. Constraints are defined based on the analyst's assessment of the requirements that must be met for a strategy to be considered feasible. In the third step, these constraints are applied to possible strategies. Those that do not meet these constraints are considered not feasible and eliminated from consideration. In the fourth and final step, the feasible strategies are ranked in terms of the overall impact on society. Each of these steps is outlined in greater detail in the following subsections.

7.6.1 Evaluate Effects of Possible Strategies

A strategy is defined here as a combination of risk-reduction programs. Because programs are defined as discrete units that are either included in a strategy or not, for m possible discrete programs there are 2^m possible strategies. This value represents all possible combinations of programs, from the "zero case" of doing nothing to the unconstrained case of implementing all possible programs.

Although the mathematics of possible combinations is relatively straightforward, the practical consequences are not trivial. Five programs correspond to a manageable 32 possible combinations; with seven programs the number of possible strategies increases to 128; and with 10 programs, it exceeds 1000.

Program effects are transformed to strategy effects using the strategy matrix, a Boolean matrix whose rows correspond to the possible strategies and whose columns correspond to the possible programs. The Boolean elements have a value of 1 (TRUE) if the program is considered in that strategy and 0 (FALSE) if it is not. The rows in this matrix correspond to the different strategies and the columns correspond to the different programs. The dimensions of this matrix are therefore (*K x m*), as shown in Table 7.14.

Table 7.14. Strategy Matrix (SM)

Programs (columns); *Strategies* (rows)

SM =

SM_{12}	SM_{12}	...	SM_{1m}
SM_{21}	SM_{22}	...	SM_{2m}
...	...	...	...
SM_{K1}	SM_{K2}	...	SM_{Km}

The strategy matrix for the simple case of two possible programs (1 and 2), resulting in 2^2=4 possible strategies, is shown in Table 7.15. In this case, Strategy 3 includes Program 1, because this element has a TRUE Boolean value, but not Program 2. Note that the values in any given row, when joined as digits, are the binary form (that is, base 2) of one less than strategy number. For example, Strategy 3 corresponds to (3-1=2) = 10.

Table 7.15. Strategy Matrix for Two Programs

	1	*2*	*Strategy*
SM =	0	0	*1*
	0	1	*2*
	1	0	*3*
	1	1	*4*

The transformation from program effects to strategy effects is a matrix multiplication. This multiplication is shown in Equation 4, in which it is assumed that there is only one type of effect (for example, monetary) for both known effects and perceived effects. If there is more than one type of known effect, this multiplication is performed on each layer. Similarly, if there is more that one type of perceived effect, the multiplication is performed on each layer.

$$KSE = [SM][KPE] \qquad (7.3a)$$

$$PSE = [SM][PPE] \qquad (7.3b)$$

These transformations result in arrays that list the effects of all possible strategies partitioned among the various interest groups. The known strategy effects array (*KSE*) has as many rows as possible strategies, as many columns as interest groups, and as many layers as types of known effects. The first layer of this array is shown in Table 7.16, in which the values for a given row (that is, a given strategy) represent the summation of the effects of all programs included in that strategy. A similar array exists for perceived effects but the number of layers may be different, corresponding to the number of types of anticipated / perceived effects.

Table 7.16. Known Strategy Effect s(KSE), First Layer

Interest Groups (columns); *Strategies* (rows)

KSE =	KSE_{12}	KSE_{12}	...	KSE_{1n}
	KSE_{21}	KSE_{22}	...	KSE_{2n}
	...	...	...	...
	KSE_{K1}	KSE_{K2}	...	KSE_{Kn}

A sample of the *KSE* array is given in Table 7.17. This array is based on the sample *KPE* array (Table 7.8) and the strategy matrix shown in Table 7.17. The first strategy is the degenerate case in which neither of the two programs are implemented. The known effects to both interest groups are zero in this case. Strategies 2 and 3 correspond to implementation of either Program 1 or Program 2, respectively, but not both. The fourth and final strategy represents implementation of both programs, thus the values listed represent the sum of the effects of each of the programs. A similar array could be constructed for perceived strategy effects (*PSE*) but is not included here.

Table 7.17. Sample Known Strategy Effects Array (KSE)

	A	*B*	*Strategy*
KSE =	\$0	\$0	*1*
	\$7	\$4	*2*
	\$5	\$10	*3*
	\$12	\$14	*4*

Partitioning of the effects (both known and perceived) between the various interest groups is an important aspect of the methodology, but the overall effect on society is also a useful metric. In a purely objective sense, the total effect on society is the sum of the effects on each of the interest groups. In practice, some interest groups are more important than others. The political influence level vector is used when aggregating effects over all of the interest groups.

The political influence level (*PIL*) assigned to each of the interest groups (see Section 7.5.5) represents the fraction of influence that each group possesses in the overall policy-making process. These values are used to generate a weighted summation of the overall effects for each strategy. This weighted summation combines the individual effects attributed to each of the interest groups but balances the objective aggregation against the realities of political influence. The calculation is the multiplication of the effect matrix by the transpose of the influence level vector, scaling the result by the number of interest groups:

$$TKSE = n[KSE][I^T] \tag{7.4a}$$

$$TPSE = n[PSE][I^T] \tag{7.4b}$$

These two arrays (*TKSE* and *TPSE*) represent the total effect on society produced by each of the strategies after adjustment for the political influence levels. Both arrays have the same number of rows, each of which represents a possible strategy. The columns correspond to different types of effects, for example monetary or human. These two arrays are shown in Table 7.18 and Table 7.19.

Table 7.18. Total Known Strategy Effects (TKSE)

Known Effect Types (columns); *Strategies* (rows)

$TKSE =$

$TKSE_{12}$	$TKSE_{12}$	...	$TKSE_{1p}$
$TKSE_{21}$	$TKSE_{22}$	...	$TKSE_{2p}$
...	...	...	...
$TKSE_{K1}$	$TKSE_{K2}$	...	$TKSE_{Kp}$

Table 7.19. Total Perceived Strategy Effects (TPSE)

Perceived Effect Types (columns); *Strategies* (rows)

TPSE =	$TPSE_{12}$	$TPSE_{12}$	...	$TPSE_{1q}$
	$TPSE_{21}$	$TPSE_{22}$	...	$TPSE_{2q}$
	...	...	...	...
	$TPSE_{K1}$	$TPSE_{K2}$	...	$TPSE_{Kq}$

Table 7.20 shows a simple *TKSE* array based on the simple example developed above. The influence levels are taken from the second row Table 7.13 (0.25 for Interest Group A and 0.75 for Interest Group B) and the known strategy effects are taken from Table 7.17.

Table 7.20. Sample TKSE Array

	Known Effect	*Strategy*
TKSE =	$0.0	*1*
	$9.5	*2*
	$17.5	*3*
	$27.0	*4*

To see how this calculation is performed, consider the fourth element of this array – Strategy 4, corresponding to implementation of both programs. From Table 7.17, Interest Group A has a known strategy effect of $12 and Interest Group B has a known strategy effect of $14. Direct, unweighted aggregation of these two values would result in a total known effect of $26. With the weighting provided by the political influence level, the calculation is:

$$2\,[(0.25)(\$12) + (0.75)(\$14)] = \$27 \qquad (7.5)$$

7.6.2 Define Relevant Constraints

Relevant constraints are those that must be met for a strategy to warrant further discussion with either decision-makers or relevant interest groups. Any number of possible constraints may be identified. Unlike optimization analysis, which seeks to maximize a single response variable, the goal here is to eliminate strategies that have little hope of implementation and focus on those that have potential. Stated most directly, the goal is elimination of the worst strategies rather than identification of the best ones.

The challenge to those overseeing mitigation efforts is to identify those constraints that are critical – in other words, those constraints that, if not satisfied, would preclude consensus. These are highly subjective assessments and the constraints chosen will depend on the region under analysis and the judgment of the analyst. What the methodology provides is a vehicle by which constraints, once identified, can be carried through the analysis to identify their influence on how various strategies will affect society.

We shall not attempt in this section to enumerate all possible constraints. However, certain general statements can be made. First, individuals as well as groups have limited resources. This suggests the constraint of maximum acceptable costs, values typically associated with the known effects of implementation. Maximum values can be assigned to each interest group, or to the overall cost to society. For example, a maximum amount that the government is willing to spend on risk mitigation is a typical constraint that would limit the number of feasible strategies.

Second, interest groups will want some benefit from the mitigation efforts, especially if their group is also incurring some of the costs. This suggests assigning minimum positive perceived effects (that is, benefits).

Third, strategies that evoke broad-based support, as argued by this thesis, balance both costs and benefits (typically known effects and perceived effects, respectively) among interest groups. This constraint can be applied implicitly by specifying constraints for each interest group. It can also be applied explicitly by specifying that comparable effect levels exist between pairs of interest groups. For example, the number of avoided fatalities, as a percentage of the population, could be constrained to be within a certain number of percentage points when comparing any two interest groups defined by geographic location.

7.6.3 Apply Constraints

Feasible strategies are defined as those that meet all relevant constraints. In this step of the process, unfeasible strategies are eliminated through the application of the constraints defined in the preceding step. Although these two steps are described as sequential, they are actually iterative, requiring adjustments in the number and nature of constraints until a suitable number of non-eliminated strategies remain.

This iterative process has many possible variants. For example, sensitivity analysis could be used to identify the most probable non-eliminated strategies, or strategies could be ranked by effectiveness with respect to costs or avoided fatalities.

As a simple example, consider the known strategy effects listed in Table 7.17. If a constraint had been identified that Interest Group A would not accept any strategy that cost them more than $5, this would eliminate Strategies 2 and 4, which have known effects for this interest group of $7 and $12, respectively. Aside from the base case of Strategy 1 (implementing neither program), only Strategy 3 remains.

In the hypothetical case study of the next chapter, the calculations required for identifying possible strategies and applying possible constraints are accomplished using widely available spreadsheet software. In practice, the methodology could be implemented using brute-force hand calculations or computer programs that automatically perform sensitivity analysis of the estimated valuations and the assumed constraints.

7.6.4 Rank Feasible Strategies

The strategies that remain after application of the relevant constraints are deemed feasible. These strategies are then ranked in order of each type of overall effect. While this does not identify a single optimal strategy, it does allow review of rankings based on various types of effects (for example, known monetary effects or perceived human effects). Strategies that rank highly in several aspects would then be considered more likely to be well-received by the interest groups as a whole.

7.7 Concluding Remarks: Proposed Methodology

In this chapter we have outlined the mechanics of a methodology for identifying integrated risk-management strategies that are both technically effective and politically feasible.

The methodology consists of two phases. In the first phase, the programs are evaluated with regard to their effects. Known effects are those associated with implementing the program; anticipated effects are those realized if an earthquake occurs. Effects are partitioned among various interest groups. The anticipated effects of the programs (typically benefits in terms of reduced loss if the earthquake occurs), are then adjusted for the risk-perception level of each interest group. This approach accounts for differences in such factors as time horizon and acceptance of or aversion to risk.

In the second phase of the methodology, the effects of strategies, defined as combinations of programs, are explored. All possible strategies (combinations of programs) are considered. For m possible programs there are 2^m possible strategies, ranging from doing nothing to implementing all possible programs. This extensive list of possible strategies is then reduced to a more manageable size by applying constraints that attempt to balance both positive and negative effects among the various interest groups while keeping the overall effort within the limit of available resources. The remaining strategies are then deemed to warrant further discussion within the relevant interest groups. To assist in these discussions, rankings are developed based on the various types of total effects. Total effects are obtained by aggregating across all interest groups, using the political influence levels assigned to the different groups to adjust for the fact that some interest groups have a stronger voice in the policy-making process.

CHAPTER 8

Hypothetical Case Study: Colima (Mexico)

8.1 INTRODUCTION

The proposed methodology can be applied to a case study of developing appropriate seismic risk reduction strategies for the Mexican State of Colima (see Figure 8.1). The case study can demonstrate the methodology and the user choices that the methodology affords.

Centro Nacional de Prevencion de Desastres (CENAPRED) y la Comision Economica para America Latina de las Naciones Unidas (CEPAL), "Impacto Socio-Economico del Sismo Ocurrido el 21 de Enero de 2003 Sobre el Estado de Colima," Marzo de 2003. [in Spanish], Figure 3.6, p.12.

Figure 8.1. State of Colima, Mexico

The State of Colima was selected as the site of the case study for several reasons. First, the city experienced two nearby seismic events within five years (1999 and 2003), permitting a review of mitigation efforts taken between those two events. Second, although the city is located in a developing country, it has a good Civil Protection system and good records of responses to the 1999 and 2003 events. Finally, one of the academic advisors of this thesis served on a reconnaissance team following the 2003 earthquake. He provided improved access to data as well as a first-hand description of that earthquake's effects. This case study has a limitation in that Colima, like any case, is unique. Lessons learned in Colima may not be applicable directly to other cities.

8.2 Description of the Region

This hypothetical case study is loosely based on the building inventory in the Mexican State of Colima, located on the Pacific coast southwest of Mexico City. Based on estimates for 2003, the year that the last major earthquake struck, Colima had 575 thousand residents with a total housing stock of 140,000 homes. The average annual population growth was 2.1%.[28]

8.3 Interest Groups Considered

The population has been partitioned into six separate interest groups. Residents comprise two of these interest groups – one for urban residents and one for rural residents. Business interests have been divided into three interest groups – small businesses, large businesses, and developers. The sixth interest group is the government. Summarizing, these six interest groups are: Urban residents (UR); Rural residents (RR); Developers (DEV); Small business (biz); Big business (BIZ); and Government (GOV). More complete descriptions of these interest groups are presented in the following subsections.

8.3.1 Urban Residents (UR)

Urban residents are those individuals living in the greater metropolitan areas of Colima, comprising approximately one-fourth of the overall population. They live in single-family dwellings that they own, or in apartments that they rent, with approximately half in each type of dwelling. They are employed by local stores and business, and in the factories on the outskirts of the urban area.

These residents form the largest interest group numerically but do not carry the greatest political influence, because they are in general not as organized as large businesses or developers. The individuals that form this group are interested in the safety and security of their families. They are sensitive to the non-monetary effects of disasters, but are also dependent on the business community as a source of income.

8.3.2 Rural Residents (RR)

Rural residents live in and around the small towns of the region. Nearly all live in small, single-family dwellings that are not governed by building codes and are often self-constructed. They may work in the local community but also produce much of what they need at home. They often live hand-to-mouth, and are focused on the immediate needs of their families.

These residents are also concerned about the safety and security of their family, but are less concerned with natural hazards than daily economic existence. They are not well organized and hence do not have a strong voice in policy discussions, but they do possess a majority of the votes. Programs that can shown to benefit them therefore have the potential to generate support for the politicians that institute these programs.

8.3.3 Developers (DEV)

Developers are a relatively small group of individuals whose business is the planning and funding of projects that provide residential and commercial building space in urban areas. Once built, the real estate is typically sold to others. Apartments, however, remain under the ownership of developers, who rent the space to residents.

Despite the small number of individuals in this interest group, they possess a disproportionately large voice in the policy-making process. They are well informed of the rules and regulations, take an active interest in changes to these policies, and tend to be fairly well-connected politically. In general, they are opposed to policies that restrict their ability to undertake projects or increase the cost of these projects, but are also aware of the risks associated with earthquakes.

8.3.4 Small Business (biz)

A majority of the businesses in the area are small operations owned by a single individual, a family, or a limited number of individuals. They provide goods and services to the local economy and employ local residents. The customer base of these types of businesses is limited to the immediate geographic area surrounding their business location, and hence is particularly concerned with maintaining this customer base following an earthquake. At the same time, they recognize the need to maintain open connections with their suppliers, who are often located in other areas.

8.3.5 Big Business (BIZ)

Big business operations are located primarily in urban areas and often operate multiple locations distributed geographically. Factory owners also fall into this interest group. They are often better organized than small businesses. Often they have a long time horizon, and hence are more amenable to efforts to reduce the vulnerability of their structures to earthquakes. These businesses are also heavily dependent on a reliable supply of labor, which makes the vulnerability of the surrounding community that supplies that labor also one of their concerns.

8.3.6 Government (GOV)

The interest group of government includes local, regional, and federal authorities as well as input from international governmental and non-governmental agencies. It represents the group that both serves as the coordinator of mitigation efforts and as the authority and source of funding to mandate these efforts.

8.4 PROGRAMS CONSIDERED

Four seismic risk-reduction programs are considered. The focus is on programs that reduce risk to the building inventory. Two programs reduce the vulnerability of existing structures; one reduces the vulnerability of structures built in the future; and one reduces the level of hazard for future structures. These programs are:

1. Do-it-yourself home retrofit (DIY);
2. Professional retrofit of commercial buildings (PRO);
3. Building-code improvement / enforcement (BC); and
4. Land-use restrictions (LU).

These four programs are summarized in the following subsections.

8.4.1 Do-it-yourself Home Retrofit (DIY)

Homes fabricated from adobe or unreinforced masonry are vulnerable to seismic loading due to the low strength-to-weight ratio of these materials. Walls made of this material are prone to fail in shear during an earthquake. One simple approach reducing this vulnerability is to attach wire mesh to these walls and then plaster the mesh in place with stucco. In this program, the government provides vouchers to homeowners that are redeemable at local hardware and construction supply stores. In exchange for a voucher, the homeowner obtains materials to perform this simple retrofitting procedure.

8.4.2 Professional Retrofit of Commercial Buildings (PRO)

While vulnerable commercial buildings can also benefit from retrofitting, it is unlikely that a do-it-yourself program would be sufficient to significantly affect the commercial building stock. In part, this is because these are larger buildings that would require more than a simple retrofit; it is also because the owners of these buildings would regard it as cost-effective to pay for this work to be done. To encourage retrofit of these buildings the government can provide matching grants.

8.4.3 Building Code Improvement / Enforcement (BC)

Although seismic design standards have evolved significantly over the last half-century, many regions of the world have not incorporated this knowledge into their building codes, or do not rigorously enforce existing building codes. By choosing to improve building codes or enforce existing ones, the government can reduce the vulnerability of any new buildings.

8.4.4 Land-Use Restrictions (LU)

Even well constructed buildings are significantly vulnerable if they are located on areas of significant seismic hazard. In some areas, earthquake-induced liquefaction can reduce soil strength to near zero, allowing buildings literally to fall over. In hilly areas, particularly deforested ones, earthquakes can initiate landslides. Overall seismic risk can be reduced if development is prohibited in these areas.

8.5 PROGRAM EVALUATION

The five steps of program evaluation – the first phase of the methodology – are repeated here from Chapter 7:

1. Assess program effects (known and anticipated);
2. Assess risk-perception levels for anticipated effects;
3. Compile program effects and risk perception levels into arrays;
4. Compute perceived effects; and
5. Define influence levels for the interest groups.

The five subsections below apply these steps to the hypothetical case study. Only the information essential to the discussion is included here. The details of the process are given in the Appendix.

8.5.1 Assess Program Effects

Program evaluation consists first of estimating the known and anticipated effects of each program. This is a purely technical assessment and is independent of the respective attitudes towards risk reduction of each interest group.

The known effects of a program (the cost of implementation) are based on the building inventory and the monetary costs per building of the programs. For the two retrofit programs, the current building inventory is used and a participation rate is assumed. For the two other programs, the calculation is based on an estimate of new buildings to be built between 2003 and 2020. This potential inventory is projected based on the current growth rate of the region. These effects are apportioned among the various interest groups based on their building ownership, and then adjusted for transfers between groups.

The anticipated effects of a program (those realized if an earthquake occurs) are calculated by estimating the damage avoided by program implementation. Some fraction (50 percent or 75 percent, depending on the program) of the buildings affected by the program is assumed to avoid damage. As a result, there are fewer fatalities and less building damage. The avoided fatalities are attributed to the urban and rural residents; the avoided building damage is attributed to the building owners. An estimate of relief funding that the government will not have to disburse as a result of the risk reduction effort is also included. Note that no adjustment is made for the probability of an earthquake.

The details of evaluating each of the four programs are given in the Appendix. As an example, the summary table for do-it-yourself retrofitting (DIY) is shown in Table 8.1. The rows represent the three types of effects considered in the analysis – known monetary effects, anticipated monetary effects, and anticipated human effects. The columns represent how these effects are partitioned among the various interest groups.

In this example, the cost of the program ($0.3 million) is borne by the government, the funds of which are ultimately received by businesses (half to small businesses and half to large businesses). These businesses accrue a negative known effect (a benefit). Similar tables for the other three programs are given in the Appendix (Table A.10, A.14, and A.18)

Table 8.1. Program Evaluation for Do-it-yourself Retrofitting (DIY)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*GOV*
Known ($M)				(0.15)	(0.15)	0.30
Anticipated ($M)	75.00	22.50				2.81
Anticipated (K lives)	9.0	27.0				

8.5.2 Assess Risk Perception Levels

Risk perception levels are assigned for each interest group, each type of anticipated effect, and for each program. The values assigned represent relative assessments of how each interest group values the anticipated effects of the program. The risk perception levels assigned for the do-it-yourself retrofit program are shown in Table 8.2.

The government, under the assumption that it is operating with full information and understanding of seismic risks, is assigned a relative risk perception level of 1.0. Residents are assigned lesser values (0.25) under the assumption that they have an incomplete understanding of the risks involved or a shorter time horizon. Note that it is not necessary to assign risk perception levels for every program / interest group pairing, only those for which an anticipated effect exists. Risk perception levels assigned for the other three programs are given in the Appendix (Table A.11, A.15, and A.19).

Table 8.2. Risk Perception Levels for Do-it-yourself Retrofitting (DIY)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*GOV*
Monetary ($)	0.25	0.25				1.00
Human (lives)	0.25	0.25				

8.5.3 Compile Program Assessment Arrays

The results of assessing the program effects (known and anticipated) and the risk perception levels are compiled into three arrays: known program effects (*KPE*), anticipated program effects (*APE*), and risk perception levels (*RPL*). Each of these is a three-dimensional array. The first two dimensions (rows and columns) correspond to programs and interest groups. The third dimension, which can be thought of as layers, corresponds to different types of effects.

The known program effects array (*KPE*) is shown in Table 8.3. Because only one type of known program effect is considered in this case study (monetary effects), this table is the entire array. The rows represent the different programs and the columns the different interest groups. Reading across a row shows how known effects of a given program are apportioned among the interest groups. Reading down a column shows how different programs affect a given interest group. For example, implementing land use restrictions (LU) will cost urban residents (UR) $5.56 million.

The other two arrays – anticipated program effects (*APE*) and risk perception levels (*RPL*) – are given in the Appendix (Table A.21 and A.22).

Table 8.3. Known Program Effects (KPE)

	UR	*RR*	*Dev*	*biz*	*BIZ*	*Gov*	
KPE =				-0.15	-0.15	0.30	*DIY*
($M)			1.25	1.50	1.25	4.00	*PRO*
	5.00		5.00	7.50	18.75	5.00	*BC*
	5.56		5.56	8.33	20.83	5.56	*LU*

8.5.4 Compute Perceived Effects

Perceived effects are the valuations that the interest groups assign to the anticipated effects of a program. This valuation is estimated as the product of an anticipated effect and a risk perception level. This calculation is a scalar multiplication carried out for every program / interest group pair and for every type of anticipated effect.

Table 8.4 shows this calculation for the first type of anticipated effect (monetary avoided losses) used in the case study. The table is a compilation of the first layer (monetary effects) of each of three arrays: (1) the anticipated program effect array (*APE*); (2) the risk perception level array (*RPL*); and the perceived program effects array (*PPE*). The first and third of these are monetary values and the second is dimensionless.

As an example, consider the first element, corresponding to the effects of the do-it-yourself retrofit program (DIY) on urban residents (UR). The perceived effect (18.8) is the product of the anticipated effect (75.00) and the risk perception level (0.25).

Table 8.4. Calculation of Perceived Program Effects

	UR	RR	DEV	biz	BIZ	GOV	
APE_I =	75.00	22.50				2.81	DIY
($M)			13.75	16.50	13.75	1.00	PRO
	5.00		5.00	7.50	18.75	5.00	BC
	79.17		79.17	118.75	296.88	99.42	LU
RPL_I =	0.25	0.25				1.00	DIY
			0.50	0.50	0.75	1.00	PRO
	0.15		0.25	0.25	0.50	1.00	BC
	0.25		0.50	0.25	0.50	1.00	LU
PPE_I =	18.8	5.6				2.8	DIY
($M)			6.9	8.3	10.3	1.0	PRO
	7.9		13.1	19.7	98.4	72.8	BC
	19.8		39.6	29.7	148.4	99.4	LU

8.5.5 Define Political Influence Levels

Assigning political influence levels (*PIL*) to each of the interest groups is the fifth and final step of program evaluation. The values assigned represent the fraction of influence that each interest group possesses in the overall policy debate. If each interest group possessed an equal voice in this debate all six interest groups would be assigned an influence level of 1/6 = 0.167. Based on the assumption that residents are less aware or concerned with seismic risk reduction, the influence levels for these groups were assigned a lower value (0.10). Conversely, it was assumed that developers and the government have a greater interest and were assigned slightly greater values (0.20). Large businesses were assigned the highest influence level (0.25). These values are shown in Table 8.5.

Table 8.5. Political Influence Level (PIL)

	UR	RR	DEV	biz	BIZ	Gov	
PIL =	0.10	0.10	0.20	0.15	0.25	0.20	$\Sigma = 1.0$

8.6 Strategy Evaluation

The four steps of strategy evaluation – the second phase of the methodology – are repeated here from Chapter 7:

1. Evaluate effects of possible strategies;
2. Define relevant constraints;
3. Apply these constraints to identify feasible strategies; and
4. Rank feasible strategies.

The four subsections below apply these steps to the hypothetical case study. Only the information essential to the discussion is included here. The details of the process are given in the Appendix.

8.6.1 Evaluate Effects of the Possible Strategies

The effects of each possible strategy are obtained by direct summation of the effects of the programs included in that strategy. Given m possible programs, there are 2^m strategies, or unique combinations of programs. Four possible programs are included in this hypothetical example; hence, there exist 16 possible strategies including the zero-case strategy of doing nothing and the unconstrained strategy of including all possible programs.

The mathematical details of this computation are given in the Appendix but are summarized briefly here. The program effects are compiled in two arrays: known program effects (*KPE*) and perceived program effects (*PPE*). Each of these arrays has as many rows as programs, as many columns as interest groups, and as many layers as types of effects considered in the analysis.

Strategy effects are evaluated by transforming these program arrays into strategy arrays. This transformation is accomplished with a strategy matrix, a

Boolean matrix that formally defines the programs included in each of the possible strategies. This matrix is given in the Appendix, but is also included here with a listing of the programs included in each of the strategies (Table 8.6). Note that the first strategy provides a lower bound on implementation (implementing no programs) and the last strategy provides an upper bound (implementing all programs).

Table 8.6. Strategy Matrix and Included Programs

	DIY	*PRO*	*BC*	*LU*	*Strategy*	*Included Programs*			
SM =	0	0	0	0	*1*				
	0	0	0	1	*2*				LU
	0	0	1	0	*3*			BC	
	0	0	1	1	*4*			BC	LU
	0	1	0	0	*5*		PRO		
	0	1	0	1	*6*		PRO		LU
	0	1	1	0	*7*		PRO	BC	
	0	1	1	1	*8*		PRO	BC	LU
	1	0	0	0	*9*	DIY			
	1	0	0	1	*10*	DIY			LU
	1	0	1	0	*11*	DIY		BC	
	1	0	1	1	*12*	DIY		BC	LU
	1	1	0	0	*13*	DIY	PRO		
	1	1	0	1	*14*	DIY	PRO		LU
	1	1	1	0	*15*	DIY	PRO	BC	
	1	1	1	1	*16*	DIY	PRO	BC	LU

Multiplication of the strategy matrix by each of the layers of the program effects arrays results in layers of the strategy effects arrays. The known strategy effects array (*KSE*), which has only a single layer (monetary effects), is shown in Table 8.7 The rows correspond to the possible strategies and the columns correspond to interest groups. The values in a given row represent the distribution of costs among the different interest groups. In this table the values are in millions of dollars. The array summarizing the perceived strategy effects (*PSE*), which has two layers (one for monetary effects, one for human effects) is given in the Appendix in Table A.27.

Table 8.7. Known Strategy Effects (KSE)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*GOV*	*Strategy*
KSE =							*1*
	5.6		5.6	8.3	20.8	5.6	*2*
	5.0		5.0	7.5	18.8	5.0	*3*
	10.6		10.6	15.8	39.6	10.6	*4*
			1.3	1.5	1.3	4.0	*5*
	5.6		6.8	9.8	22.1	9.6	*6*
	5.0		6.3	9.0	2	9.0	*7*
	10.6		11.8	17.3	40.8	14.6	*8*
				-0.2	-0.2	0.3	*9*
	5.6		5.6	8.2	20.7	5.9	*10*
	5.0		5.0	7.4	18.6	5.3	*11*
	10.6		10.6	15.7	39.4	10.9	*12*
			1.3	1.4	1.1	4.3	*13*
	5.6		6.8	9.7	21.9	9.9	*14*
	5.0		6.3	8.9	19.9	9.3	*15*
	10.6		11.8	17.2	40.7	14.9	*16*

This step also includes calculation of total effects for each of the strategies. A total effect is defined as a weighted summation of the effects assigned to each of the interest groups. The political influence level (*PIL*), listed in Table 8.5 above, provides the weighting factors. The details of these calculations are given in the Appendix, but the result is that a single value is assigned for each of the three types of effects (one known effect and two perceived effects) for each of the possible strategies.

8.6.2 Define Relevant Constraints

After assessing the effects of each of the strategies, the relevant constraints are defined. Some of these constraints represent an assessment of what known effects (typically costs) are acceptable to each of the interest groups. Other constraints are applied to perceived effects (typically benefits) and similarly represent acceptable levels to for the group to "buy in" to the risk reduction effort. While no hard-and-fast rules are offered here, the general goal is to balance costs and benefits among the different interest groups so that strategies with broad-based support are identified. The constraints defined in this hypothetical case study are:

1) *KSE* (GOV) < 10
2) PSE_1 (all interest groups) > 0
3) PSE_2 (UR and RR) > 0

The first constraint represents a budgetary maximum for government spending – the known strategy effect to the government must be less than $10 million dollars. The second constraint (actually a set of constraints) requires feasible strategies to offer some positive perceived monetary effect, that is, some positive benefit in the event of an earthquake. The third constraint requires feasible strategies to also provide some positive perceived human effect to residents.

8.6.3 Apply Constraints

The constraints are applied sequentially to each column (interest group) and layer (effect type) of the known strategy effects (*KSE*) and the perceived strategy effects (*PSE*) arrays. Rows (strategies) that do not meet the constraints are deemed not feasible and sequentially eliminated from both arrays. The remaining rows are the potentially feasible strategies. The details of this process are shown in the Appendix (see Section A.5.3) and the remaining (feasible) strategies are listed in Table 8.8. Of the sixteen possible strategies originally considered, only five remain.

Table 8.8. Identification of Relatively Better Strategies

Strategy	*Included Programs*			
10	DIY			LU
11	DIY		BC	
13	DIY	PRO		
14	DIY	PRO		LU
15	DIY	PRO	BC	

Now consider how the constraints chosen resulted in this listing of feasible programs. First, note that do-it-yourself home retrofitting (DIY) is included in all feasible strategies. The necessity of this program arises from the third constraint – that perceived human effects (avoided fatalities) be positive for both urban and rural residents. Because DIY is the only program that potentially reduces fatalities in rural areas, it must be included in any strategy that seeks the support of these individuals.

Second, note that the feasible strategies include either building code improvement/enforcement (BC) or land use restrictions (LU) but not both. The first constraint is on maximum government expenditures to implement a program. From the perspective of the government, these two programs are the most costly (see *KPE*, Table 8.3) and together they exceed this budgetary constraint. Strategies that contain both are therefore eliminated as infeasible.

The second constraint – that all interest groups accrue some perceived monetary effect from feasible strategies – is also important. With just the first and third constraints applied, Strategy 9 (implementation of DIY only) could be considered feasible. The government's budget is not exceeded and both urban and rural residents perceive some positive human effects. Implementing only DIY, however, provides no perceived monetary benefit to developers, a relatively well-connected interest group. Developers could perceive this strategy as a "hand-out" to residents while they (the developers) receive nothing, despite having comparable levels of seismic risk. Consequently, it could be difficult to garner the support of developers for such a strategy which, when considered alone, seems to be a very effective.

8.6.4 Rank Feasible Strategies

Applying constraints identifies potentially feasible strategies, but provides no information on the relative merits of these strategies. To provide this information, the strategies can be ranked in a variety of ways. Strategies with lower known effects (positive values denote costs) and higher perceived effects (positive values denote benefits).

One approach is to generate rankings based on each type of effect and for every interest group. This information is useful when speaking with specific interest groups but does not address issues such as overall effectiveness or feasibility of the strategies. For this, total effects are a more useful metric.

Total strategy effects provide a measure of the overall impact on society of the different strategies. As discussed above in Sections 7.6.1 and 8.6.1, total effects are computed by aggregating each type of effect across all interest groups. The political influence level of the interest groups is used as a weighting factor in this aggregation to account for the fact that not all interest groups have an equal voice in the policy-making process. The result is a set of values – one for each type of effect considered – that are representative of both technical effectiveness and political feasibility.

The potentially feasible strategies identified in this case study and the three types of total strategy effects (known monetary, perceived monetary, and perceived human) are listed in Table 8.9. Also included is the rank based on these three metrics.

Table 8.9. Ranking of Potentially Feasible Strategies

Strategy	*Included Programs*				*TKSE ($M)*	*Rank*	*$TPSE_1$ ($M)*	*Rank*	*$TPSE_2$ (K lives)*	*Rank*
10	DIY			LU	65	3	520	2	23	1
11	DIY		BC		58	2	340	4	17	3
13	DIY	PRO			11	1	59	5	6	5
14	DIY	PRO		LU	76	5	558	1	23	1
15	DIY	PRO	BC		69	4	377	3	17	3

The information provided at the extreme ends of these rankings, at least in this case, is of limited usefulness. Strategy 14 (DIY, PRO, and LU) has the lowest ranking in terms of known effects (in other words, is the most costly) but provides the greatest benefit to society in terms of perceived effects (the greatest amount of avoided losses). Strategy 13 is the least costly but provides the least benefit.

Strategies with intermediate rankings are perhaps more interesting. Strategy 11 (DIY and LU), for example, ranks third in terms of known effects but is either first or second in terms of perceived effects. Moreover, this strategy ranks higher than Strategy 15 (DIY, PRO, and BC) for all three types of effects, substantially so for perceived monetary effects.

8.7 CONCLUDING REMARKS: HYPOTHETICAL CASE STUDY

The methodology proposed in Chapter 7 has been to a simple hypothetical case study for the Mexican state of Colima. The building inventory and population estimates are based on actual demographic data compiled following the 2003 earthquake that affected the region, but many other parameters were subjective estimates that seemed reasonable. Once again, the goal was to demonstrate concretely how the methodology could be applied, rather than to provide exact policy guidance to the region of study. Further refinement of the input data and corresponding numerical coefficient would produce such guidance.

The results of this hypothetical case study are arguably trivial. With only four potential programs and a clearly defined partitioning of the populace into discrete interest groups, a brief review of the program effects matrices and the relevant constraints indicates the need to include the do-it-yourself home retrofit program (DIY), and the inability of government to afford both of the two most costly programs.

Nevertheless, the proposed approach has several fundamental attributes that are useful. First, by explicitly recognizing that different interest groups have different perceptions of risk, it eliminates the need to assume a single time horizon and attitude towards risk for the entire populace. While this approach complicates the analysis, it allows the analyst to more appropriately account for the current perceived value of future uncertain events. Second, by defining constraints in terms of the interest groups, one avoids the temptation to focus on strategies that provide benefits overall but neglect the potential concerns of key interest groups. Finally, by recognizing the effect of political influence on the success or failure of implementing any integrated strategy that impacts many different aspects of society, some method of ranking the potentially feasible strategies is offered. At the very least, the methodology offers some objective basis when considering strategies that are technically promising but may be politically unattractive.

The ultimate usefulness of the proposed methodology is probably in the analysis of very complex situations. Increasing the number of programs (particularly if there are multiple number of similar programs with common goals but different distributions of effects among interest groups) would raise the number of possible strategies to a level only tractable by such formal methodologies. Similarly, one could envision dividing the population into dozens of interest groups. Using GIS software, for example, the region of study could be sub-divided geographically, associating with each various demographic and socio-economic characteristics. Aggregating the results for different groups of these characteristics could provide guidance when addressing community groups and promoting various strategies.

CHAPTER 9

Summary, Conclusions, and Recommendations

9.1 SUMMARY

Floods, fires, and earthquakes impose significant economic and social costs on society. While much has been learned in the past 50 years about how to manage these risks, the risk posed to society by natural hazards remains significant. Many of these advances in risk management have focused on technical solutions based on engineering, finance, and risk analysis. Many of these solutions have not been implemented, and so have been of little benefit to the people living on our planet.

The major impediment to implementation of risk-management strategies is political feasibility. While this term is vague, it generally encompasses public awareness of the risks, the competing interests of various interest groups, and the availability of resources to meet competing societal needs.

The central question addressed by this thesis is a difficult one: "How does one identify seismic risk-reduction strategies that are both effective and feasible?" As an example of the level of challenge entailed, one reference cited in this work focused on why two cities in California spent half a century implementing mitigation measures for a particularly vulnerable class of buildings. The issue was not technical understanding; it was political acceptance.

In this thesis, we propose a methodology for comparative evaluation of proposed seismic risk-reduction strategies. The proposed methodology involves conventional assessments of known and anticipated program effects, and then adjusts those anticipated effects based on the perceptions of risk and the political influence levels of the various interest groups involved. The premise underlying the proposed methodology is that given a group of technical effective strategies, those that are also politically feasible evoke broad-based support among all affected interest groups, and therefore balance their concerns. The key aspects of the proposed methodology are: explicit partitioning of program effects among interest groups; recognition that risk perceptions affect program valuations; and, recognition of differing influence levels in the policy-making process.

The groundwork for this approach is laid in Chapters 1 through 6, and focuses in particularly on the developing world. The methodology is described in detail in Chapter 7. The key parameters are listed and the necessary calculations are described mathematically. Finally, in Chapter 8, the methodology is applied to a hypothetical case study, the details of which are included in the Appendix.

9.2 Conclusions

The hypothetical case study involves the region surrounding the Mexican city of Colima, the site of a strong earthquake in January 2003. The hypothetical case study, laid out in detail in the Appendix to this thesis, is used to show that a particular class of program (do-it-yourself home retrofitting) is an essential element of all successful seismic risk-reduction strategies. This case study is hypothetical because the interest groups, possible programs and numerical coefficients, while reasonable, have not been refined as much as they might be. Because it involves only a few programs, the results could have been arrived at by less formal means. Nevertheless, the case study demonstrates the practical applicability of the proposed methodology, and shows how the methodology could be applied to cases in which the number of possible programs, or the complexity of competition among interest groups, would render the problem intractable by casual means.

9.3 RECOMMENDATIONS

The proposed methodology for evaluating integrated seismic risk-mitigation strategies addresses both technical effectiveness and political feasibility. Implementation of this framework is needed to validate its usefulness, however. This could be done through further work with the hypothetical case study, or it could be applied to other cases in general. The following attributes are necessary:

- A suitable region must be identified, amenable to mitigation efforts, with reasonably well-organized and active interest groups and sufficient resources to implement a strategy of at least several programs.
- Technical assessments of programs should be available or achievable, including known effects, anticipated effects, and perceived effects.
- Relevant constraints must be identified, either through surveys or interest-group leaders.
- The necessary matrix generation and manipulation would be facilitated by further development of a special-purpose computer program or graphical user interface. For the hypothetical case study of this thesis, with a limited number of programs and interest groups, the mechanics of the process still led to a reasonably complex set of spreadsheets.

The true usefulness of the proposed framework is probably best realized when implemented in a GIS-based (geographic information systems) software environment. Such an implementation would allow graphical display of the geographical distribution of the effects of various strategies for each key interest group.

Finally, and perhaps most importantly, the proposed methodology should be discussed with all those involved in seismic risk management, to get their ideas on the best way to use and refine it in our ongoing efforts to mitigate the potential devastation that earthquakes cause.

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A. Appendix: Hypothetical Case Study

A.1 INTRODUCTION

This appendix applies the methodology proposed in Chapter 7 of this thesis to a hypothetical case study of the Mexican state of Colima. This region was chosen because that region's magnitude 7.6 earthquake of January 2003 provided data on demographics, building stock, resultant damage, and the cost of relief efforts.

A more complete description of the region, programs, and interest groups is given in Chapter 8 of this thesis, which also includes the implications of the results. This appendix focuses on the details of the calculations.

A.2 POPULATION AND BUILDING INVENTORY

The building inventory and population estimates for the case study are shown in Table A.1 and Table A.2. The values are estimates, based loosely on the actual 2003 values.

Table A.1. Building Inventory (thousands of units)

Building Type	*Location*	*Total (2003)*
Single family residential	Urban / Rural	120
Apartments	Urban	5
Commercial	Urban	7
Factories	Urban	0.5
Public	Urban / Rural	10

Table A.2. Population Estimate

Location	*2003 Population (thousands)*	*Percentage*
Urban residents	245	40%
Rural residents	360	60%
Total	605	100%

A.3 PROGRAMS AND INTEREST GROUPS

A brief summary of the programs and interest groups considered in the analysis is listed here. More complete descriptions are given in Chapter 8 of this thesis.

A.3.1 Programs

1) Do-it-yourself home retrofit (DIY) – The government provides vouchers to residents that allow them to obtain wire mesh and mortar from a local hardware store. These materials are then used to reinforce walls of adobe or unreinforced masonry.

2) Professional retrofit of commercial buildings (PRO) – The government provides matching grants for particularly vulnerable commercial buildings to be professionally retrofit.

3) Building code improvement / enforcement (BC) – Existing building codes are augmented with provisions for seismic loading and a concerted effort is undertaken to ensure that all new construction is designed and built to the new code standards.

4) Land-use restrictions (LU) – Based on maps of liquefaction and landslide hazards, construction is prohibited on areas particularly at risk. These restrictions increase the cost of remaining land and hence increase real estate costs for new construction in those areas in which development is permitted.

A.3.2 Interest Groups

1) Urban residents (UR) – Individuals who live in the greater metropolitan areas of the major cities. These individuals live in privately-owned, single-family dwellings or apartments.

2) Rural residents (RR) – Individuals living in the countryside or small towns. Nearly all live in small, single-family dwellings that are not governed by building codes and are often self-built.

3) Developers (DEV) – Businesses that take undeveloped land and fund the construction of residential and commercial buildings. Once built, the real estate is typically sold to others. Apartments, which exist only in urban areas, however remain under the ownership of developers, who rent the space to residents.

4) Small business (biz) – Businesses with a single location or a limited number of locations within a small geographic area. A single individual or a limited number of individuals typically owns these businesses.

5) Big business (BIZ) – Large businesses concerns with locations in multiple locations. Factory owners also fall into this interest group.

6) Government (GOV) – The formal government, including local, regional, and national officials.

A.3.3 Building Ownership and Occupancy

An essential step in the analysis is to partition the ownership and occupancy of the building inventory. Based on the inventory and population figures listed above (Table A.1 and Table A.2), the distribution assumed is shown in Table A.3. The building inventory for 2020 was estimated by extrapolating the current two percent annual growth rate. It was also assumed that urban areas grew more rapidly than rural areas.

Table A.3. Building Ownership and Occupancy

Region	*Type*	*Occupancy (people/unit)*	*Owner*	*2003 Units (thousands)*	*2020 Units (thousands)*	*New Built (thousands)*
Urban	Houses	4	UR	30	50	20
Urban	Apartments	25	DEV	5	7	2
Urban	Commercial		biz	6	9	3
Urban	Commercial		BIZ	1	1.5	0.5
Urban	Factories		BIZ	0.5	1	0.5
Urban	Public buildings		GOV	5	7	2
Rural	Houses	4	RR	90	120	30
Rural	Public buildings		GOV	5	6	1

A.4 PROGRAM EVALUATION

The first phase of the methodology evaluates the effects of individual programs and compiles the results into a set of arrays in preparation for the second phase. The five steps of this first phase are:

1. Assess program effects (known and anticipated);
2. Assess risk-perception levels for anticipated effects;
3. Compile program effects and risk perception levels into arrays;
4. Compute perceived effects; and
5. Define influence levels for the interest groups.

A.4.1 Assessment of Individual Programs

The known and anticipated effects of the four programs considered are estimated in the four subsections below. Also included are estimates of the risk perception levels that the various interest groups assign to the anticipated effects. These two sets of estimates (program effects and risk perception levels) correspond to the first two steps of program evaluations described in Chapter 7 of this thesis.

This being a hypothetical case study, the analysis procedures used are arguably crude and simplistic. The goal is merely to provide reasonable estimates of the different valuations so that the strategy evaluation phase of the methodology, addressed in the following section, has at least some realistic basis.

A.4.1.1 Do-it-yourself Home Retrofit (DIY)

In this program, the government provides vouchers to homeowners that are redeemable at local hardware and construction supply stores. The voucher is valid for wire mesh and stucco that are to be applied to walls made from adobe or unreinforced masonry, a simple retrofitting procedure that significantly reduces vulnerability to shear failure.

The known effects of this program are the costs to the government for reimbursing the stores supplying the materials. Part of these funds go to the small businesses that accept the vouchers and part goes to the factories that manufacture the materials. Calculating the valuations for these effects requires assuming the cost of the retrofit kit, a participation rate as a fraction of the building stock, and the split of these funds between the manufacturers producing the materials (big business) and the stores supplying them to the public (small businesses). We have assumed a participation rate of 10% and an even split of funds between small and big businesses. The value of the time spent installing the retrofit kit has been neglected. The calculations are shown in Table A.4.

Table A.4. Known Effects for Do-it-yourself Retrofitting (DIY)

	Urban	*Rural*
Total houses (K)	30	90
Participation rate	10%	10%
Participating houses (K)	3	9
Retrofit cost per house ($)	$40	$20
Cost to gov't ($K)	$120	$180
to stores	$ (60)	$ (90)
to manufacturers	$ (60)	$ (90)

The anticipated effects are the number of buildings that will not collapse and the lives that will be saved as a result of the retrofitting; they also include relief funds that the government will not need to spend on many of these families. These calculations are shown in Table A.5. We have assumed that 50% of buildings will not be destroyed as a result of retrofitting, that 75% of the occupants will not be killed, and that relief funds are saved for those buildings not destroyed.

Table A.5. Anticipated Effects for Do-it-yourself Retrofitting (DIY)

	Urban	*Rural*	*Total*
Participating houses (K)	3	9	12
Fraction of avoided collapses	50%	50%	
Avoided collapses (K)	1.5	4.5	6
Unit value ($)	$5,000	$500	
Value of avoided collapses ($K)	$7,500	$2,250	$9,750
Fraction of families saved	75%	75%	
Families saved (K)	2.25	6.75	9
People per house	4	4	
Number of lives saved (K)	9	27	
Relief per house ($)	$500	$250	
Relief savings ($K)	$1,125	$1,688	$2,813

It is useful to organize the above results into a table compatible with the arrays that will be compiled in the third step (Section A.4.2). These results are shown in Table A.6. The cost of the program ($30K) is borne by the government and shown in the first row as a positive value of 0.3 (millions of dollars). These program costs are ultimately received by both small and large businesses, which therefore are assigned a negative known cost. Urban and rural residents are the primary beneficiaries of the program and are assigned positive anticipated effects, that is, reduced losses, both in monetary ($) and human terms (lives). The post-disaster subsidies paid by the government will also be reduced.

Table A.6. Program Evaluation for Do-it-yourself Retrofitting (DIY)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*GOV*
Known ($M)				(0.15)	(0.15)	0.30
Anticipated ($M)	75.00	22.50				2.81
Anticipated (K lives)	9.0	27.0				

Assigning risk perception levels for each anticipated effect is the second step in program evaluation. These subjective assessments are used to transform anticipated effects – an objective assessment of the program effectiveness – into perceived effects – the valuations as viewed from the perspective of the interest group when factors such as time horizon and attitudes towards risk are considered. The values chosen are arbitrary but should be self-consistent.

The values assigned for this program are shown in Table A.7, with one value assigned for each anticipated effect. In this case, a value of 1.0 is assigned to the government representing full understanding of the risk and an arbitrarily long time horizon. Residents were assigned lower values because they may not fully be aware of the risks involved, or may be fatalistic regarding earthquake hazards. Equivalent risk perception levels were arbitrarily assigned for both monetary and human effects to residents.

Table A.7. Risk Perception Levels for Do-it-yourself Retrofitting (DIY)

	UR	RR	DEV	biz	BIZ	GOV
Monetary ($)	0.25	0.25				1.00
Human (lives)	0.25	0.25				

A.4.1.2 Professional Retrofitting of Commercial Buildings (PRO)

The government provides matching grants for professional retrofitting of particularly vulnerable commercial buildings. The known effects of this program are the retrofitting costs, which are evenly divided between the building owner and the government. Calculating the valuations requires assuming a participation rate and a retrofit cost per building. We have assumed that 5% of building owners participate, and that retrofitting costs 10% of each building's value. The calculations are shown in Table A.8.

Table A.8. Known Effects for Professional Retrofitting (PRO)

	Urban apartments (DEV)	*Urban Commercial (biz)*	*Urban Commercial (BIZ)*	*Total*
Number of buildings (K)	5	6	1	
Building value ($)	$50,000	$50,000	$250,000	
Retrofit cost (10% of building value)	$5,000	$5,000	$25,000	
Participation rate	10%	10%	10%	
Participating buildings (K)	0.5	0.6	0.1	
Total retrofit cost ($K)	$2,500	$3,000	$2,500	
** paid by owner*	$1,250	$1,500	$1,250	
** paid by gov't*	$1,250	$1,500	$1,250	$4,000

The anticipated effects are the number of buildings that will not collapse; also, the government will avoid having to spend relief funds on many of these businesses, especially smaller uninsured ones. These calculations are shown in Table A.9. We have assumed that, as a result of retrofitting, 50% of the buildings will not be destroyed, and that the government will save the relief funds that would otherwise have to be spent for those buildings.

Table A.9. Anticipated Effects for Professional Retrofitting (PRO)

	Urban apartments (DEV)	*Urban Commercial (biz)*	*Urban Commercial (BIZ)*	*Total*
Participating buildings (K)	0.5	0.6	0.1	
Avoided loss percentage	50%	50%	50%	
Buildings saved (K)	0.25	0.3	0.05	
Total value ($K)	$ 13,750	$ 16,500	$ 13,750	
Avoided relief funds (per business)	$ 1,000	$ 2,500		
Avoided relief funds ($K)	$ 250	$ 750		$ 1,000

The known and anticipated effects are summarized in Table A.10. The known effect (cost of retrofitting) is evenly divided between the government and the building owners. The distribution among building owners is based on the retrofit costs and participation rates. The anticipated effects are the value of buildings saved, attributed to the building owners, and the relief funding avoided by the government.

Table A.10. Program Evaluation for Professional Retrofitting (PRO)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*GOV*
Known ($M)			1.25	1.50	1.25	4.00
Anticipated ($M)			13.75	16.50	13.75	1.00
Anticipated (K lives)						

The assigned risk perception levels are shown in Table A.11. A value of 1.0 was used for government as the reference with progressively lower values for large businesses (0.75) and small businesses (0.50) or developers (0.50).

Table A.11. Risk Perception Levels for Professional Retrofitting (PRO)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*GOV*
Monetary ($) *Human (lives)*			0.50	0.50	0.75	1.00

A.4.1.3 Building Code Improvement / Enforcement (BC)

In this program, existing building codes are augmented with provisions for seismic loading and a concerted effort is undertaken to ensure that all new construction complies with those provisions.

The known effects of this program are the increased cost of educating the design community, enforcing compliance within the design and construction communities, and the increase in building costs due to the more stringent design requirements. Calculating the valuations requires assuming values for the increase in cost and some period of time over which those costs will accumulate. We assume a 5% increase in building cost that accumulates over a period of 17 years. Also, the new building codes are considered to exist only in urban areas. We neglect the cost to the government of enforcing the code, since it is small compared to the increase in the cost of buildings constructed by the government. The calculations are shown in Table A.12.

Table A.12. Known Effects for Building Code Improvement (BC)

	Houses (UR)	*Apartments (DEV)*	*Commercial (biz)*	*Commercial (BIZ)*	*Factories (BIZ)*	*Public (GOV)*
New buildings, 2003-2020 (K)	20	2	3	0.5	0.5	2
Original cost ($)	$5,000	$50,000	$50,000	$250,000	$500,000	$50,000
New cost ($)	$5,250	$52,500	$52,500	$262,500	$525,000	$52,500
Cost increase ($)	$250	$2,500	$2,500	$12,500	$25,000	$2,500
Total cost ($K)	$5,000	$5,000	$7,500	$6,250	$12,500	$5,000

The anticipated effects are due to the number of buildings that will not collapse as a result of the improved building codes. We assume that the improved codes will reduce the collapses to 50% of what might otherwise be anticipated for these new buildings. Assigning valuations to these avoided destroyed buildings requires assuming an avoided rate of collapse (we assume 50%). Also, fewer residents of houses and apartments will be killed, and the government will avoid relief funding for these families. We assume 75% of the new buildings will not collapse compared to otherwise. The calculations are shown in Table A.13.

Table A.13. Anticipated Effects for Building Code Improvement (BC)

	Houses (UR)	*Apartments (DEV/UR)*	*Com (biz)*	*Com (BIZ)*	*Factories (BIZ)*	*Public (GOV)*	
New buildings, 2003-2020 (K)	20	2	3	0.5	0.5	2	
Fraction of avoided collapses	50%	50%	50%	50%	50%	50%	
Avoided collapses (K)	10	1	1.5	0.25	0.25	1	
Unit value ($)	$5,250	$52,500	$52,500	$262,500	$525,000	$52,500	
Value of avoided collapses ($K)	$52,500	$52,500	$78,750	$65,625	$131,250	$52,500	
Fraction of families saved	75%	75%	75%	75%	75%	75%	
Units saved (K)	15	1.5	2.25	0.375	0.375	1.5	
People per house	4	25					
Number of lives saved (K)	60	37.5					
Relief per unit ($)	$500	$1,000	$2,500	$5,000	$10,000		total
Relief savings ($K)	$7,500	$1,500	$5,625	$1,875	$3,750		$20,250

The known and anticipated effects of this program are summarized in Table A.14. The known effects are the increased construction costs borne by each of the interest groups. The anticipated effects are the avoided building losses (attributed to the owners of the buildings), the avoided relief funding, and the avoided fatalities to urban residents.

Table A.14. Program Evaluation for Building Code Improvement (BC)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*GOV*
Known ($M)	5.00		5.00	7.50	18.75	5.00
Anticipated ($M)	52.50		52.50	78.75	196.88	72.75
Anticipated (K lives)	97.5					

The assigned risk perception levels are shown in Table A.15. Residents are given the lowest value (0.15), followed by developers and small businesses (0.25), and big business (0.50) in increasing order of time horizon and understanding of the potential benefits.

Table A.15. Risk Perception Levels for Building Code Improvement (BC)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*GOV*
Monetary ($)	0.15		0.25	0.25	0.50	1.00
Human (lives)	0.15					

A.4.1.4 Land-use Restrictions (LU)

Based on maps of liquefaction and landslide hazards, construction is prohibited on areas particularly at risk. These restrictions increase the cost of remaining land and hence increase real estate costs for new construction in those areas in which development is permitted.

The known effects of this program are the costs associated with prohibiting development on at-risk land. The land affected by these restrictions will lose value, but the remaining land will increase in value due to the reduced supply. The overall impact on developers, particularly when one considers land not immediately ready for development, should be minimal. The main effect, therefore, is the increase in development costs due to the increase in the value of land on which development is permitted. We will assume that land values increase inversely proportional to the fraction of land on which development is not restricted. For example, if 10% of the available land is removed from use, the remaining land will increase in value by approximately 10%.

Calculating valuations for known effects requires assuming values for the fraction of land removed from near-term development, land values as a fraction of the value of developed real estate, and some period of time over which increased development costs will accumulate. We assume that 10% of the available land is removed from use and that land accounts for 50% of real estate values, implying that the cost of development will increase by 6%. In Table A.16 we aggregate these increased costs over a period of 17 years.

Table A.16. Known Effects for Land-Use Restrictions (LC)

	Houses (UR)	*Apartments (DEV/UR)*	*Com (biz)*	*Com (BIZ)*	*Factories (BIZ)*	*Public (GOV)*
New buildings, 2003-2020 (K)	20	2	3	0.5	0.5	2
Original building cost	$5,000	$50,000	$50,000	$250,000	$500,000	$50,000
Cost increase (%)	6%	6%	6%	6%	6%	6%
New cost ($)	$5,278	$52,778	$52,778	$263,889	$527,778	$52,778
Cost increase ($)	$278	$2,778	$2,778	$13,889	$27,778	$2,778
Additional cost ($K)	$5,556	$5,556	$8,333	$6,944	$13,889	$5,556

The anticipated effects are the number of buildings that don't collapse and the avoided loss of lives and spending of relief funds. These calculations are shown in Table A.17. We have assumed that 75% of buildings are not destroyed as a result of land use restrictions and that the government saves the relief funds are for those saved buildings owned by small businesses.

Table A.17. Anticipated Effects for Land Use Restrictions (LC)

	Houses (UR)	*Apartments (DEV/UR)*	*Com (biz)*	*Com (BIZ)*	*Factories (BIZ)*	*Public (GOV)*	
New buildings, 2003-2020 (K)	20	2	3	0.5	0.5	2	
Fraction of avoided collapses	75%	75%	75%	75%	75%	75%	
Avoided collapses (K)	15	1.5	2.25	0.375	0.375	1.5	
Unit value ($)	$5,278	$52,778	$52,778	$263,889	$527,778	$52,778	
Value of avoided collapses ($K)	$79,167	$79,167	$118,750	$98,958	$197,917	$79,167	
Fraction of families saved	75%	75%	75%	75%	75%	75%	
Units saved (K)	15	1.5	2.25	0.375	0.375	1.5	
People per house	4	25					
Number of lives saved (K)	60	37.5					
Relief per unit ($)	$500	$1,000	$2,500	$5,000	$10,000		*total*
Relief savings ($K)	$7,500	$1,500	$5,625	$1,875	$3,750		$20,250

The known and anticipated effects are summarized in Table A.18.

Table A.18. Program Evaluation for Land Use Restrictions (LU)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*GOV*
Known ($M)	5.56		5.56	8.33	20.83	5.56
Anticipated ($M)	79.17		79.17	118.75	296.88	99.42
Anticipated (K lives)	97.5					

The risk perception levels are shown in Table A.19. Residents and small businesses, which may have shorter time horizons, are given the lowest values (0.25) while developers and large businesses have been assigned an intermediate value (0.50). The government is assigned the base value (1.0) representing full understanding and an arbitrarily long time horizon.

Table A.19. Risk Perception Levels for Land Use Restrictions (LU)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*GOV*
Monetary ($)	0.25		0.50	0.25	0.50	1.00
Human (lives)	0.25					

A.4.2 Compile Program Effects

The third step of program evaluation compiles the results from the first two steps into a set of three arrays – one for known effects, one for anticipated effects, and one for risk perception levels.

The known program effects (*KPE*) array is shown in Table A.20. The rows correspond to the programs and the columns correspond to the interest groups. Because the only monetary known effects were considered, this single layer shown is the entire array. The values in the table represent costs in millions of dollars. Reading across a row shows how the costs of a given program are distributed among the different interest groups.

Table A.20. Known Program Effects (KPE)

	UR	*RR*	*Dev*	*biz*	*BIZ*	*Gov*	
				-0.15	-0.15	0.30	*DIY*
KPE =			1.25	1.50	1.25	4.00	*PRO*
	5.00		5.00	7.50	18.75	5.00	*BC*
	5.56		5.56	8.33	20.83	5.56	*LU*

The anticipated program effects (*APE*) array is shown in Table A.21 as two layers. The first layer (APE_1) compiles monetary effects in millions of dollars.

The second layer (APE_2) represents human effects in thousands of lives. In both layers, the rows represent different programs and the columns represent different interest groups.

Table A.21. Anticipated Program Effects (APE)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*GOV*	
APE_1 =	75.00	22.50				2.81	*DIY*
($M)			13.75	16.50	13.75	1.00	*PRO*
	5.00		5.00	7.50	18.75	5.00	*BC*
	79.17		79.17	118.75	296.88	99.42	*LU*
APE_2 =	9.0	27.0					*DIY*
(K lives)							*PRO*
	97.5						*BC*
	97.5						*LU*

The risk perception levels (*RPL*) array is shown in Table A.22 as two layers. The first layer (RPL_1) represents monetary effects in millions of dollars. The second (RPL_2) layer represents human effects in thousands of lives. In each layer, the rows represent different programs and the columns represent different interest groups. Note that the non-zero cells in this array correspond to the non-zero cells in the *APE* array.

Table A.22. Risk Perception Levels (RPL)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*Gov*	
RPL_1 =	0.25	0.25				1.00	*DIY*
			0.50	0.50	0.75	1.00	*PRO*
	0.15		0.25	0.25	0.50	1.00	*BC*
	0.25		0.50	0.25	0.50	1.00	*LU*
RPL_2 =	0.25	0.25					*DIY*
							PRO
	0.15						*BC*
	0.25						*LU*

A.4.3 Compute Perceived Program Effects

Perceived program effects represent the valuations of anticipated effects – those realized in the event of an earthquake – as viewed from the perspective of the individual interest groups. These values are calculated from the anticipated effects and the risk perception levels element by element:

$$PPE_{ijb} = APE_{ijb}\, RPL_{ijb} \qquad i=1..m,\ j=1..n,\ b=1..q \qquad (A\text{-}1)$$

The resultant values, computed using the estimates in Table A.21 and Table A.22, are given in Table A.23.

Table A.23. Perceived Program Effects (PPE)

	UR	*RR*	*DEV*	*biz*	*BIZ*	*Gov*	
PPE_1 =	18.8	5.6				2.8	*DIY*
($M)			6.9	8.3	10.3	1.0	*PRO*
	7.9		13.1	19.7	98.4	72.8	*BC*
	19.8		39.6	29.7	148.4	99.4	*LU*
PPE_2 =	2.3	6.8					*DIY*
(K lives)	0.0						*PRO*
	14.6						*BC*
	24.4						*LU*

A.4.4 Define Political Influence Levels

The political influence level assigned to an interest group represents the fraction of influence that the group contributes to the overall policy-making process. As such, individual values are bounded between zero and unity, and the values must sum to unity over all interest groups. If each of the six interest groups in this case study contributed equally to this process, then each would an influence level of 1/6 = 0.17.

The political influence levels chosen for this case study assume that large businesses have the greatest voice in the policy-making process, followed by developers and the government, small businesses, and residents. Using the equal influence value of 0.17 as a starting point, values for individual groups were increased or decreased while maintaining the requirement that the values sum to unity. These values are listed in Table A.24.

Table A.24. Political Influence Levels

	UR	*RR*	*DEV*	*biz*	*BIZ*	*Gov*	
PIL =	0.10	0.10	0.20	0.15	0.25	0.20	$\Sigma = 1.0$

A.5 Strategy Evaluation

The second phase of the methodology is strategy evaluation. A strategy is defined as a combination of programs that are implemented together. Each possible strategy is a unique combination of the possible programs evaluated in the first phase of the methodology. In this second phase, the effects of the possible strategies are computed, relevant constraints are defined, application of these constraints identifies potentially feasible strategies, and these strategies are ranked by the value of total effects. Each of these four steps is addressed in the following subsections.

A.5.1 Evaluate Effects of Possible Strategies

The effects of all possible combinations of programs are computed in this step. Each unique combination of programs is a unique strategy. These calculations are performed as matrix manipulations in which a strategy matrix is used to transform program effects to strategy effects.

The strategy matrix is a Boolean matrix (consisting only of zeros and ones) that defines all possible combinations of programs. It has as many rows as possible strategies and as many columns as possible programs. The number of possible strategies is 2^n, where *n* is the number of possible programs. In this hypothetical case study, the four possible programs produce sixteen possible strategies including both the zero-case strategy of doing nothing and the unconstrained case of doing everything. The strategy matrix is shown in Table A.25.

Table A.25. Strategy Matrix

	DIY	*PRO*	*BC*	*LU*	*Strategy*
SM =	0	0	0	0	*1*
	0	0	0	1	*2*
	0	0	1	0	*3*
	0	0	1	1	*4*
	0	1	0	0	*5*
	0	1	0	1	*6*
	0	1	1	0	*7*
	0	1	1	1	*8*
	1	0	0	0	*9*
	1	0	0	1	*10*
	1	0	1	0	*11*
	1	0	1	1	*12*
	1	1	0	0	*13*
	1	1	0	1	*14*
	1	1	1	0	*15*
	1	1	1	1	*16*

Each row of this matrix defines a unique strategy. Within the row representing each strategy, a value of 1 in a particular column means that the program corresponding to that column is included in the strategy; a value of 0 means that it is not included. Note that S_1 defines the zero-case strategy of implementing no programs, and S_{16} represents the unconstrained case in which all four programs are implemented.

Arrays that summarize the strategy effects are then computed from arrays that summarize program effects (*KPE* and *PPE*). This computation is a matrix manipulation in which the strategy matrix is multiplied by each layer of the program effects arrays. The results, when combined into arrays, are the known strategy effects array (*KSE*) and the perceived strategy effects array (*PPE*):

$$KSE = [SM][KPE] \qquad (A\text{-}1a)$$

$$PSE = [SM][PPE] \qquad (A\text{-}1b)$$

In this case study, known effects are valued only in monetary terms, thus *KPE* and *KSE* have only a single layer. The *KSE* array is shown in Table A.26, where zero-valued elements are omitted for clarity. Perceived effects are valued in both monetary and human terms. The two layers of this array (PSE_1 *and* PSE_2) are shown in Table A.27.

Table A.26. Known Strategy Effects (KSE)

	UR	RR	DEV	biz	BIZ	GOV	Strategy
KSE =							1
	5.6		5.6	8.3	20.8	5.6	2
	5.0		5.0	7.5	18.8	5.0	3
	10.6		10.6	15.8	39.6	10.6	4
			1.3	1.5	1.3	4.0	5
	5.6		6.8	9.8	22.1	9.6	6
	5.0		6.3	9.0	2	9.0	7
	10.6		11.8	17.3	40.8	14.6	8
				-0.2	-0.2	0.3	9
	5.6		5.6	8.2	20.7	5.9	10
	5.0		5.0	7.4	18.6	5.3	11
	10.6		10.6	15.7	39.4	10.9	12
			1.3	1.4	1.1	4.3	13
	5.6		6.8	9.7	21.9	9.9	14
	5.0		6.3	8.9	19.9	9.3	15
	10.6		11.8	17.2	40.7	14.9	16

Table A.27. Perceived Strategy Effects (PSE)

PSE_1 =

UR	RR	DEV	biz	BIZ	GOV	Strategy
						1
19.8		39.6	29.7	148.4	99.4	2
7.9		13.1	19.7	98.4	72.8	3
27.7		52.7	49.4	246.9	172.2	4
		6.9	8.3	10.3	1.0	5
19.8		46.5	37.9	158.8	100.4	6
7.9		2	27.9	108.8	73.8	7
27.7		59.6	57.6	257.2	173.2	8
18.8	5.6				2.8	9
38.5	5.6	39.6	29.7	148.4	102.2	10
26.6	5.6	13.1	19.7	98.4	75.6	11
46.4	5.6	52.7	49.4	246.9	175.0	12
18.8	5.6	6.9	8.3	10.3	3.8	13
38.5	5.6	46.5	37.9	158.8	103.2	14
26.6	5.6	2	27.9	108.8	76.6	15
46.4	5.6	59.6	57.6	257.2	176.0	16

PSE_2 =

UR	RR	DEV	biz	BIZ	GOV	Strategy
						1
24.4						2
14.6						3
39.0						4
						5
24.4						6
14.6						7
39.0						8
2.3	6.8					9
26.6	6.8					10
16.9	6.8					11
41.3	6.8					12
2.3	6.8					13
26.6	6.8					14
16.9	6.8					15
41.3	6.8					16

The overall strategy effects – total known strategy effects (*TKSE*) and total perceived strategy effects (*TPSE*) – are also computed in this step of the process.

This computation is accomplished using the influence levels assigned above (Table A.24). The multiplication is performed as follows:

$$TKSE = n\left[KSE\right]\left[I^{T}\right] \qquad (A\text{-}2a)$$

$$TPSE = n\left[PSE\right]\left[I^{T}\right] \qquad (A\text{-}2b)$$

In both of these arrays the rows correspond to the different strategies and the columns correspond to the different types of effects considered. In this case study, there is only one type of known effect – monetary – thus this array is a column vector. There are two types of perceived effects – monetary and human – thus this array has two columns. These two arrays are shown in Table A.28.

Table A.28. Total Known and Perceived Strategy Effects

	TKSE = $M	TPSE = $M	TPSE = K lives	*Strategy*
				1
	64.7	499.4	17.1	*2*
	58.2	318.7	10.2	*3*
	122.8	818.1	27.3	*4*
	11.1	37.7		*5*
	75.8	537.1	17.1	*6*
	69.3	356.4	10.2	*7*
	134.0	855.8	27.3	*8*
		21.0	6.3	*9*
	64.7	520.4	23.4	*10*
	58.2	339.7	16.5	*11*
	122.8	839.1	33.6	*12*
	11.1	58.7	6.3	*13*
	75.8	558.1	23.4	*14*
	69.3	377.4	16.5	*15*
	134.0	876.8	33.6	*16*

A.5.2 Define Relevant Constraints

After assessing the effects of each of the strategies, the relevant constraints must be defined. Some of these constraints represent an assessment of what known effects (typically costs) are acceptable to each of the interest groups. Other constraints are applied to perceived effects (typically benefits) and similarly represent acceptable levels to for the group to "buy in" to the risk-mitigation effort. While no hard-and-fast rules are offered here, the general goal is to balance costs and benefits among the different interest groups so that strategies with broad-based support are identified. Three constraints appropriate to this case study are the following:

1) KSE (GOV) < 10
2) PSE_1 (all interest groups) > 0
3) PSE_2 (UR and RR) > 0

The first constraint represents a budgetary maximum for government spending – the known strategy effect to the government must be less than $10 million dollars. The second constraint (actually a set of constraints) requires feasible strategies to offer some positive perceived monetary effect, that is, some positive benefit in the event of an earthquake. The third constraint requires feasible strategies to also provide some positive perceived human effect to residents.

A.5.3 Apply Constraints

The constraints defined in the previous step are then collectively applied to the strategy effect matrices, sequentially eliminating strategies that do meet the constraints. This elimination process can be accomplished with commercially available spreadsheet or database software or with specialized software written for application of the methodology.

For this appendix, the elimination process is shown graphically in Table A.29. The left hand side of this table lists the possible strategies and the programs included in each of these strategies. The columns on the right hand side of this table correspond to the different constraints defined in the previous step. An **X** in this column implies that the strategy corresponding to that row satisfies the constraint.

Consider the first constraint – the budgetary constraint of the government. The strategies that satisfy this constraint have an X in the column headed by *KSE(GOV)<10*. This constraint eliminates Strategies 4, 8, 12, and 16. These are the strategies that include both building code improvement/enforcement (BC) and land use restrictions (LU), the two most costly programs from in terms of government outlays.

Next, consider the constraint that perceived monetary effects for rural residents is positive. This constraint is represented by the column headed $PSE_1(RR)>0$. This constraint eliminates Strategies 1 through 8. These are the strategies that do not include Do-it-yourself retrofitting (DIY), the only program that provides some perceived benefit to rural residents.

This process continues until all unfeasible strategies have been eliminated. The remaining strategies are considered feasible. In this table, the feasible strategies are those that have **X**'s in all of the constraint columns. These are Strategies 10, 11, 13, 14, and 15.

Table A.29. Identification of Relatively Better Strategies

				Effect Type	*KSE*	*PSE-1*						*PSE-2*	
				Interest Group	*GOV*	*UR*	*RR*	*Dev*	*biz*	*BIZ*	*Gov*	*UR*	*RR*
Strategy	*Included Programs*				**<10**	**>0**	**>0**	**>0**	**>0**	**>0**	**>0**	**>0**	**>0**
1					X								
2				LU	X	X		X	X	X	X	X	
3			BC		X	X		X	X	X	X	X	
4			BC	LU		X		X	X	X	X	X	
5		PRO			X			X	X	X	X		
6		PRO		LU	X	X		X	X	X	X	X	
7		PRO	BC		X	X		X	X	X	X	X	
8		PRO	BC	LU		X		X	X	X	X	X	
9	DIY				X	X	X				X	X	X
10	DIY			LU	X	X	X	X	X	X	X	X	X
11	DIY		BC		X	X	X	X	X	X	X	X	X
12	DIY		BC	LU		X	X	X	X	X	X	X	X
13	DIY	PRO			X	X	X	X	X	X	X	X	X
14	DIY	PRO		LU	X	X	X	X	X	X	X	X	X
15	DIY	PRO	BC		X	X	X	X	X	X	X	X	X
16	DIY	PRO	BC	LU		X	X	X	X	X	X	X	X

A.5.4 Rank Feasible Strategies

The feasible strategies identified in the previous step provide a starting point for focus-group discussions. To provide additional information to the coordinator of these discussions, it is useful to rank these feasible strategies in terms of their total effects on society. There is more than one type of total effect. In this case study, there is one type of known effect (monetary) and two types of perceived effects (monetary and human). There are therefore three types of total effects.

In Table A.30, the five feasible strategies are listed along with the programs included in those strategies, the total effect valuations, and the rankings based on these valuations. Known effects are defined as positive when a cost, and therefore the most desirable strategies are those with the lowest values for total known strategy effects (*TKSE*). Conversely, perceived effects are defined as positive when they are an avoided loss. The most desirable strategies are those with the greatest values for total perceived strategy effects (*TPSE*).

Table A.30. Ranking of Potentially Feasible Strategies

Strategy	*Included Programs*				*TKSE ($M)*	*Rank*	*$TPSE_1$ ($M)*	*Rank*	*$TPSE_2$ (K lives)*	*Rank*
10	DIY			LU	65	3	520	2	23	1
11	DIY		BC		58	2	340	4	17	3
13	DIY	PRO			11	1	59	5	6	5
14	DIY	PRO		LU	76	5	558	1	23	1
15	DIY	PRO	BC		69	4	377	3	17	3

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CURRICULUM VITÆ

The author was born in Morristown, New Jersey, on May 2, 1967, the first child of Mani and Ruth Subramanian. After completing high school, he attended The University of Texas at Austin, where he obtained an undergraduate degree in Mechanical Engineering in 1991. This education was augmented by real-world experience in the cooperative engineering program through which he spent one semester at the NASA Jet Propulsion Laboratory in Pasadena and four additional semesters at Los Alamos National Laboratory.

His first professional position was with the Institute for Advanced Technology of The University of Texas at Austin, where he conducted experimental research in impact physics and penetration mechanics. This experience provided a strong background in analytical thinking and quantitative analysis.

A two-year hiatus from this career path included extensive travel in the United States, Mexico, and Central America, during which he improved his language skills and met individuals from a wide range of backgrounds. Follow-on visits to Honduras included participating in construction projects and organizing an impromptu relief program for flood victims of Hurricane Mitch.

He then returned to his research position at The University but also enrolled in the Civil Engineering/Public Affairs dual-degree Master's program at The University of Texas at Austin, with the goal of applying his skills and experience toward international disaster relief and mitigation efforts. This thesis is a step in that direction.

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