PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

The Use of Benefit-Cost Analysis for Evaluation of Performance-Based Earthquake Engineering Decisions

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A report on research conducted under
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ABSTRACT

This report provides an overview of benefit-cost analysis (BCA); an application of benefit-cost analysis to the performance-based earthquake engineering (PBEE) framework; consideration of critical issues in using benefit-cost analysis for PBEE; and a discussion of issues, criticism, and limitations of benefit-cost analysis. Our objective is to provide an understanding of the economic dimensions of PEER's framework equation. A focus on economic evaluation will broaden the framework so that facility damage in earthquakes can be related to functionality, business interruption and revenue loss, and to repair costs. Such an analysis needs to consider issues such as the time value of money, uncertainty, and the perspectives of different stakeholders.

The application of BCA to PBEE has produced a number of important findings. First, an example is developed that illustrates the way in which performance criteria can be operationalized in an economic context. Next, a number of benefit categories are identified (cost of emergency response and loss of long-term revenue) that have not been previously considered in studies of seismic mitigation decision making. Additionally, several critical issues are examined, most notably multiple stakeholders and uncertainty, that need to be considered when carrying out a benefit-cost analysis in a performance-based engineering context.

Throughout the report, particular attention is paid to issues of concern to PEER researchers and the seismic-mitigation community, most notably, the differences between BCA and life cycle cost analysis (LCCA). These differences are extensively discussed and illustrated. Finally the ways in which the value of human life can be economically evaluated are examined.

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PREFACE

The Pacific Earthquake Engineering Research Center (PEER) is an Earthquake Engineering Research Center administered under the National Science Foundation Engineering Research Center program. The mission of PEER is to develop and disseminate technology for design and construction of buildings and infrastructure to meet the diverse seismic performance needs of owners and society. Current approaches to seismic design are indirect in their use of information on earthquakes, system response to earthquakes, and owner and societal needs. These current approaches produce buildings and infrastructure whose performance is highly variable, and may not meet the needs of owners and society. The PEER program aims to develop a performance-based earthquake engineering approach that can be used to produce systems of predictable and appropriate seismic performance.

To accomplish its mission, PEER has organized a program built around research, education, and technology transfer. The research program merges engineering seismology, structural and geotechnical engineering, and socio-economic considerations in coordinated studies to develop fundamental information and enabling technologies that are evaluated and refined using test beds. Primary emphases of the research program at this time are on older existing concrete buildings, bridges, and highways. The education program promotes engineering awareness in the general public and trains undergraduate and graduate students to conduct research and to implement research findings developed in the PEER program. The technology transfer program involves practicing earthquake professionals, government agencies, and specific industry sectors in PEER programs to promote implementation of appropriate new technologies. Technology transfer is enhanced through a formal outreach program.

PEER has commissioned a series of synthesis reports with a goal being to summarize information relevant to PEER's research program. These reports are intended to reflect progress in many, but not all, of the research areas in which PEER is active. Furthermore, the synthesis reports are geared toward informed earthquake engineering professionals who are well versed in the fundamentals of earthquake engineering, but are not necessarily experts in the various fields covered by the reports. Indeed, one of the primary goals of the reports is to foster cross-discipline collaboration by summarizing the relevant knowledge in the various fields. A related purpose of the reports is to identify where knowledge is well developed and, conversely, where significant gaps exist. This information will help form the basis to establish future research initiatives within PEER.

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1.1 INTRODUCTION

This report considers the use of benefit-cost analysis (BCA) for the evaluation of performance-based earthquake engineering (PBEE) decisions. Our objective is to provide an understanding of the economic dimensions of PEER's framework equation, which relates measures of ground motion to measures of damage and system performance. For the most part, research that utilizes this or similar frameworks tends to focus on physical damage and the resultant financial and life-safety losses (Cornell and Krawinkler 2000). A more explicit economic analysis will broaden the framework so that facility damage in earthquakes can be related to functionality, business interruption and revenue loss, and to repair costs. Such an analysis needs to consider issues such as the time value of money, uncertainty, and the perspective of different stakeholders.

The report provides an overview of benefit-cost analysis; an application of benefit-cost analysis to the performance-based earthquake engineering framework; consideration of critical issues in using benefit-cost analysis for PBEE, and a discussion of issues, criticism, and limitations of benefit-cost analysis. This report should prove useful to a wide variety of PEER researchers and industry and government partners, including those who are not experts. In addition to providing a theoretical and methodological primer on the use of BCA, we explicitly consider how BCA can be adapted to the performance-based earthquake engineering framework. The application of benefit-cost analysis to a hypothetical PBEE scenario provides a clear illustration of how to implement this type of analysis. It also demonstrates the types of parameters (inputs and outputs) required in order to incorporate a benefit-cost component into an integrated computer application.

The application of BCA to PBEE has produced a number of important findings. First, an example is developed that illustrates the way in which performance criteria can be operationalized in an economic context. A number of benefit categories are identified (cost of emergency response and loss of long-term revenue) that have not been previously considered in studies of seismic mitigation decision making. Additionally, several critical issues are examined, most notably multiple stakeholders and uncertainty, that are essential to carrying out a benefit-cost analysis in a performance-based engineering context. Throughout the report, areas are suggested for further development and coordination with other PEER researchers.

Chapter 1 of the report provides an overview of benefit-cost analysis. We begin by offering a brief review of the theoretical underpinnings of BCA that focuses on BCA as a method to economically evaluate seismic mitigation decisions. We then provide a more practical view of BCA, with a step-by-step procedure for applying the BCA framework and by explaining key concepts (time value of money, present value, discount rate, treatment of inflation, evaluation criteria, and uncertainty). A simplified example is used to illustrate the steps of the BCA framework. Additionally, we discuss the current use of BCA in governmental agencies and the seismic mitigation community. Throughout this introductory section, particular attention is paid to issues of concern to PEER researchers and the seismic mitigation community, most notably to the differences between BCA and life-cycle cost analysis (LCCA), a commonly used method of evaluation for seismic mitigation decisions. The ways in which the value of human life can be economically evaluated are also discussed and illustrated.

Chapter 2 demonstrates how BCA can be adapted to accommodate the performance-based earthquake engineering framework. For the most part this section provides an overview of a protocol developed by the PEER Zerbe and Chang project. This protocol, complete with a hypothetical example, is attached as an appendix to the report. Although the specifics of the protocol and hypothetical example focus on marine ports, both the conceptual framework and methodological approach can be generalized to other types of seismically vulnerable systems. Currently, the protocol is being developed into a booklet for distribution to various port agencies. The application of BCA to PBEE provides a clear illustration of how to implement this type of analysis. More important, it has produced a number of significant findings. The analysis that is undertaken in Appendix B utilizes performance standards provided by the Port of Oakland. We operationalize the criteria in order to specify the benefits and costs of seismic mitigation options in performance-based terms. While we do not claim to have developed a definitive methodology for operationalizing and specifying performance criteria, our effort can serve as the basis of discussion among PEER research and industry and government partners. Our research with the Port of Oakland, supplemented by reviews of seismic decision making, benefit-cost analysis, and ports literature, also identified a number of benefit categories not previously considered. We define benefits as savings on costs that would not have occurred without mitigation. Traditionally, seismic BCA considers only benefits associated with savings on facility repair costs. We demonstrate that the cost of measures taken in order to respond to a seismic emergency are not insignificant and should be considered as part of the analysis. Additionally, loss of revenue needs to be considered with respect to both the structure of the economic market in which the facility operates and the time value of money. Consequently, we distinguish between short-term revenue loss (that lost during repair to a facility) and long-term revenue loss (permanent revenue loss due to loss of customers). In terms of BCA, these categories are "discounted" differently in order to correctly account for the time value of money.

Our analysis of the application of BCA to PBEE indicates that several critical issues need to be considered further. These are discussed in Chapter 3. At this time, many of these issues are being addressed by research in progress. While traditional BCA considers only the perspective of the "primary" stakeholder, a variety of groups are differentially affected by the benefits and costs associated with performance-based earthquake engineering decisions. The Zerbe-Chang PEER project is developing a new framework that will theoretically and methodologically incorporate the perspective of multiple stakeholders — the owner of the structure, the user(s)/tenant(s) of the structure, the local economy, the regional economy, and "society." This type of analysis will provide the opportunity for collaboration with a number of PEER researchers and partners. A second critical issue that needs to be addressed is uncertainty. Wilkie's PEER project (Caltech) is considering the probabilistic aspects of uncertainty in terms of performance-based mitigation options, while the Zerbe-Chang project is addressing the proper use of other techniques for considering uncertainty.

Chapter 4, the final substantive section of the report, considers criticism and limitations of BCA. Both technical and ethical issues are outlined, discussed, and in some cases resolved. Additionally, several suggestions are made for improving the BCA process.

1.2 THEORETICAL FOUNDATIONS

Benefit-cost analysis (BCA) is a subset of policy analysis. It involves an accounting framework in which benefits and costs associated with decisions are set out for purposes of information and discussion.[1] The details of the framework are of course important and while there is significant agreement about them, there is room for improvement. BCA attempts to provide decision makers with preferred policy alternatives, including the alternative of doing nothing.

Life-cycle cost analysis (LCCA), which is commonly used in the evaluation of *seismic mitigation decisions,* may be properly viewed as a subcategory of benefit-cost analysis. It is simply another way of expressing the results of a benefit-cost analysis. LCCA involves the determination of the costs of all options. When these options are compared the results are similar to the results of benefit-cost analysis.

Another subcategory of BCA is *cost-effectiveness analysis*. Cost-effectiveness analysis *presumes* that a policy decision about the goal or objective to be reached has already been made and that the only matter to resolve is the best way of meeting the specific policy chosen. For example, consider a policy discussion about whether to dam a river to produce electricity or to leave it alone to provide recreation benefits. A BCA would consider all of the alternatives. However, if a decision already had been made in favor of the dam, then a cost-effectiveness analysis would determine the most economically efficient dam to build (i.e., the one providing the greatest net benefits). Other important examples of cost-effectiveness analyses are air and water pollution standards. Normally, the question that arises with these standards is how to achieve them at the least cost.

1.2.1 Benefit-Cost Analysis as Economic Evaluation

BCA provides a means of economically evaluating a project that involves seismic mitigation decisions. Economic evaluation is performed in order to determine the most economically efficient mitigation option, the option that maximizes the difference between benefits and costs. In terms of seismic mitigation decisions, this simply involves the maximization of net revenues.

The economic theory perspective is that such analysis should be done from a national perspective that comprises the values of all affected. This view has a certain naiveté when compared with practice, where the cost of considering all affected may limit the extent of values and people considered. Drawing upon current issues, difficult questions arise: Should a policy affecting the costs of abortions count the costs to fetuses? Should the public education benefits

[1] Benefit-Cost Analysis and Cost-Benefit analysis are used identically. We prefer the former term as closer to its theoretical roots in economics and as implying perhaps a less mechanistic version.

to the children of illegal aliens be included in an analysis of the educational policies? Should the benefits criminals receive from crime be counted in considering policies affecting criminal behavior? Should the existence value of environmental amenities be counted? Should harm to animals receive economic weight? These types of questions are called “issues of economic standing” (Whittington and Macrae 1986; Zerbe 2002). Although some types of BCAs are usually done from the perspective of a single entity, such as a public utility district or the owner of a building, without any pretense of a national perspective, the benefits and costs associated with performance-based earthquake engineering decisions will differentially affect a wide variety of parties, or stakeholders. Traditionally, BCA considers only the perspective of the “primary” stakeholder. The new framework under development in the Zerbe-Chang PEER project will in theory and methodology incorporate the perspective of multiple stakeholders — the owner(s) of the site, the user(s)/tenant(s) of the site, the local economy, the regional economy, and “society” (see Chapter 3.1).

1.2.2 Efficiency Criteria

BCA is based on a normative standard that economists call the Kaldor-Hicks (KH) criteria, or the potential Pareto criteria. The latter is derived from the notion of Pareto efficiency but is fundamentally different in that only a potential Pareto improvement is required. According to Pareto efficiency a policy is justified when someone gains and no one loses. According to the KH criteria it is sufficient if the losers can be compensated, even if they are not, so that in principle the Pareto requirement can be met while ignoring the costs of actually making income transfers.[2] A policy is then said to be KH efficient when the winner from the project could *potentially* compensate the project loser.[3] The KH efficiency criteria have existed as an important concept in both economics and law for more than 60 years. A computerized search of law reviews and legal journals finds nearly 2,000 citations to Kaldor-Hicks or its synonyms.[4] Thus

[2] Pareto efficiency is more or less useless for practical policy work as examples of policies that met the criterion are not generally to be found.

[3] For a more precise definition see Zerbe 2001. The Kaldor and Hicks are actually slightly different criteria.

[4] I found 425 references to “Kaldor-Hicks” directly; 92 more are found under the rubric “potential Pareto,” and 1416 cites are to some form of “wealth maximization.” The numbers reported here were generated by three Westlaw searches on October 29, 1997, all of which were conducted using the “Journals of Law Reviews” database.

not only has BCA contributed to project evaluation but also to legal reasoning both in the United States and in Europe.

The criteria arose out of discussions in the late 1930s among prominent British economists concerning whether or not repeal of the Corn Laws was good.[5] Lionel Robbins (1938, p. 640) had asserted that economists could not claim that policies that had losers were desirable, as would be created by repeal of the Corn Laws, as this claim was necessarily based on interpersonal comparisons.

Kaldor (1939, pp. 549–50) acknowledged Robbins's point about the inability to make interpersonal utility comparisons, but suggested its irrelevance. He suggested that where a policy led to an increase in aggregate real income:

> the economist's case for the policy is quite unaffected by the question of the comparability of individual satisfaction, since in all such cases it is possible to make everybody better off than before, or at any rate to make some people better off without making anybody worse off.

Kaldor goes on to note (1939, p. 550) that whether such compensation should take place "is a political question on which the economist, qua economist, could hardly pronounce." Kaldor then proposed a potential compensation test and Hicks followed with a similar test. [6]

These two tests are known as the Kaldor-Hicks compensation tests,[7] or, alternatively, as the potential compensation — or potential Pareto — tests.[8] They represent what economists and

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[5] These are Robbins, Hicks, and Kaldor all writing in the Economic Journal.

[6] Kaldor's (1939) suggestion was later formalized as the proposition that:

"state a is preferable to another state if, in state a, it is hypothetically possible to undertake costless (lump-sum) redistribution and achieve an allocation that is superior to the other state according to the Pareto criterion" (Boadway and Bruce 1984, p. 96).

Hicks (1939) suggested a parallel test, which is formally stated as:

"state A is preferable to another state if, in the other state, it is not possible, hypothetically, to carry out lump-sum redistribution so that everyone could be made as well off as in state A." See Boadway and Bruce (1984, p. 97).

[7] Chipman (1987, p. 524) suggests that the compensation principle may be traced back to Dupuit in 1844, and, later, to Marshall (1890). Marshall used the concept of consumer surplus to compare losses of consumers to gains to the government. Hotelling (1938) anticipated the KH test by suggesting that a new public investment is justified, given its benefits, if its costs could — in theory — be distributed in order to make everyone better off. Anticipating issues of distribution, Hotelling (1938) noted that where extreme hardship resulted from a policy, actual compensation was needed.

[8] The term "Kaldor-Hicks" was used at least as early as 1951, by Arrow (1951, p. 928), and in 1952, by Mishan (1952, p. 312).

lawyers mean by "economic efficiency."[9] Posner (1985, pp. 88–89; 1986, pp. 12–13; 1987, p. 16) as indicated that a term of his creation, "wealth maximization," is identical to KH. Although he has not always been consistent, this definition is assumed here.[10]

1.3 CURRENT USE OF BCA IN THE UNITED STATES

1.3.1 Federal Government

BCA rose to prominence at the federal level with the analysis of water projects during the 1940s and became more widespread in use under Presidents Carter and especially Reagan and Bush. President Clinton reaffirmed a commitment to BCA.[11] For example, as a response to Executive Order No. 12291 and subsequent orders, federal executive agencies are required to use BCA as part of the regulatory process. Under these executive orders, the Office of Management and the Budget (OMB) has created a set of guidelines that should be the starting point for any governmental unit considering adopting benefit-cost guidelines.[12] Recent attempts to pass benefit-cost legislation show the continuing appeal of a methodology that holds out the promise of introducing greater rationality into the regulatory process.[13] In terms of earthquake mitigation, FEMA has issued a set of BCA guidelines. Our final draft will summarize and comment upon these guidelines.

[9] The other concept, of course, is that of Pareto optimality, but this is a concept ill suited to discussion of economic changes and is, therefore, of limited practical application.

[10] "Wealth maximization" appears to have an imprecise meaning. Posner (1987) sometimes uses wealth maximization to mean KH, but at other times seems to use it to mean an increase in GDP or the maximization of monetary wealth. In this regard, Posner uses it to support his tastes in favor of a work ethic and the importance of production as compared with consumption. This is, however, a different meaning from KH. The fact that economic efficiency is not the same as national income was shown by Harberger (1971, p. 785). Economic efficiency is the opposite of common but narrow concepts, such as workplace efficiency in which people are to be managed as machines (Kanigel 1997).

[11] See Executive Order No. 12,866, 3 C.F.R. 638 (1994) reprinted in 5 U.S.C. s 601 (1994) ; Executive Order No. 12,498, 3 C.F.R. 323 (1986) reprinted in 5 U.S.C. s 601 (1988); Executive Order 12291, 3 C.F.R. 127 (1982) reprinted in 5 U.S.C s 601 (1988) (revoked in 1993). For a delineation of the criticism of these orders and a discussion, *see* Pildes and. Sunstein 1995.

[12] Circular A-94.

[13] 1995 US HB. 1022 (SN). The House bill was called "The Risk Assessment and Cost Benefit Act of 1995." According to the statute, the purpose of the legislation is to "reform regulatory agencies and focus national economic resources...through scientifically objective and unbiased risk assessments and through the consideration of costs and benefits in major rules." The floor debate suggests that an implication of this requirement is that a criterion would be adopted so that only those regulations with a net positive outcome would be promulgated. This is an example of attempting to use the result of a BCA as the decision itself.

1.3.2 State Governments

The extent to which BCA is used among state governments is not wholly known. Eight states have statutes requiring the application of some cost analysis, economic impact analysis, or BCA. These are Arizona, California, Colorado, Florida, Illinois, Oregon, Virginia, Washington, and Wisconsin. The State of Washington, for example, requires nine enumerated agencies to[14]

> Determine that the probable benefits of the rule are greater than its probable costs, taking into account both the qualitative and quantitative benefits and costs and the specific directives of the statute being implemented.[15]

The rulemaking criteria section of the act requires that the mandated agencies also consider alternatives to the rule, including the consequences of not adopting the rule. The agency is required to adopt the "least burdensome" rule that gives positive net benefits.

1.3.3 Municipal Governments

Dively and Zerbe (1991) conducted a survey of the practices of municipal governments to make investment and policy decisions. This survey used telephone and written questionnaires for a randomly selected sample of 72 American cities with populations over 100,000 in the fall of 1990 and the spring of 1991. The authors found that almost 60% of the cities surveyed did not use *discount rates;* in fact, in some of these cities, officials did not understand the meaning of the term. The use of the discount rate shows an appreciation for the time value of money (see section 1.5.4 and Appendix A), this concept is critical to BCA.

By examining the effects of city age, population, growth in population, presence of municipally owned utilities, bond rating, presence of independently elected officials, and geographical location, Dively and Zerbe (1991) attempted to explain why some cities but not others use discount rates. The only variable that showed statistical significance in prediction was "independently-elected financial officials"; cities with such officials are more likely to use discount rates. Officials in older cities also appear more likely to use discount rates although this variable did not quite reach statistical significance.

[14] Chapter 403, Washington Law, 1995 (Engrossed Substitute House Bill 1010, partially vetoed) effective July 23, 1995.

[15] This requirement applies only to those rules that are not procedural or interpretive.

The importance of independently elected financial officials was found to be consistent with answers provided by city officials after informal questioning about why program budgeting and discount rates were not used. The most common answer was that the use of these techniques imposed a constraint on decisions that were based primarily on political considerations. That result is also consistent with the finding of Rauch (1995) that the professionalism of the state bureaucracy during the Progressive Era had a positive effect on the share of municipal expenditure allocated to investment in infrastructure (probably greater efficiency in allocation). These results suggest that increasing the number of cities with independently elected financial officials would increase the use of discount rates and associated capital budgeting techniques, with a probable increase in economic efficiency.[16]

1.3.4 Seismic Decision Making

As was noted above, FEMA has issued a set of BCA guidelines. Additionally, many entities concerned with seismic mitigation decisions, especially public agencies, often use some type of BCA in the decision-making process. However, this analysis is often performed in a way that does not consider critical issues in a structured and systematic manner. The following sections will provide a framework that outlines, considers, and illustrates a number of issues that we consider to be crucial to the benefit-cost analysis.

1.4 UNDERSTANDING THE ROLE OF BENEFIT-COST ANALYSIS

BCA is an accounting framework that provides an understanding of the ways in which the benefits and costs associated with seismic mitigation will affect the revenue of a particular entity over time. However, the particular way in which BCA is performed can affect the context in which decisions will be discussed and made. While BCA does not directly determine decisions, it sets the framework for the decision-making process. Politics also plays a role in this process. In addition, benefit-cost analysis, as every rational decision process, has limitations because it necessarily deals with uncertainty, measurement problems, and limited funds for evaluation. Given these considerations, it should be recognized that within a policy context, BCA provides information for decision makers and not just the decision itself.

[16] Our hypothesis is that the presence of such officials leads to a higher standard of review. Interestingly, the use of

1.5 STEPS OF BENEFIT-COST ANALYSIS

While BCA is often performed in an ad hoc manner, it is most useful when the process follows a set of well-defined steps. Adherence to these steps ensures that all assumptions, calculations, and criteria are clearly acknowledged.

1.5.1 Clarifying the Perspective

The results of a benefit-cost analysis will depend on the perspective from which it is performed. Although in its most economically supportable use the analysis is done from a national perspective, more often than not the perspective used is that of the agency performing the analysis or the perspective of the particular branch of government. Given the sensitivity of results to the perspective, this should be made clear at the outset.

1.5.2 Set Out Assumptions

The precepts of good policy analysis require that assumptions be set out early. This is especially the case with BCA, where one purpose is to contribute information to the discussion. Among the assumptions that need to be addressed are (1) the perspective from which the analysis is done (step 1.5.1 above); (2) what parties, values, and interests are included and which are excluded; (3) the discount rate used; (4) how robust the results are with respect to other assumptions; and (5) uncertainty.

1.5.3 Determine Benefits and Costs, Relevant Data, and Cash Flows

Benefits and costs have traditionally been based on the willingness to pay (WTP) and the willingness to accept (WTA). These concepts have been related in turn to measures of welfare changes that use either final (after-project) prices or initial (before-project) prices and are referred to as "compensating variation" and "equivalent variation measures." These complex relationships will not be explored here. Table 1.1 relates benefits-costs to gains and losses and to WTP and WTA measures. In the tradition of pure benefit-cost analysis, the WTP and WTA of all parties affected are to be counted with legal rights to determine whether or not the WTP (for non-owners) or WTA (for owners) is more appropriate. As previously stated, because benefit-

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discount rates by cities with independently elected officials is double the rate for a sample of cities as a whole.

cost analyses are often done from particular perspectives, in terms of performance-based earthquake engineering, gains and losses will likely depend on whose perspective is being addressed. From the perspective of a public utility district, for example, efficiency might be defined in terms of changes in net revenues.

Table 1.1 Benefits and Costs in Relation to Gains and Losses

Benefit: Gain	***WTP**:* amount one is willing to pay for positive change—limited by income (a positive amount)	***Example***: the amount an entity would pay to reduce the probability of earthquake damage
Cost: Loss	***WTA**:* minimum amount one is willing to accept as compensation for a negative change—could be infinite (a negative amount)	***Example***: the amount an entity spends to reduce the probability of earthquake damage.

According to Table 1.1, gains should be measured by the willingness to pay for them (WTP) and losses by the willingness to accept payment (WTA) for them.[17] Where goods are valued only for their ability to create revenues, the WTP and WTA measures will be the same. Such goods have been called "commercial goods" (Zerbe 2001). For commercial goods the value of the good is essentially the present value of the commercial cash flows. For example, the value of a truck to an entity concerned with seismic mitigation will be the same whether or not one uses WTP or WTA. For other goods, however, ownership or rights matters. As valued by environmentalists, the value of a pristine park that might be damaged by an earthquake would be quite different if measured by the WTP instead of the WTA. If an environmental group were given the right to be compensated for loss of a park, for example, the relevant measure would be the group's WTA, which in principle could be infinite. If the group had no such right, the correct measure would be the WTP, which would be limited by what the group could pay.

[17] A loss restored is a benefit, but in psychological terms is not a gain but a restoration to some status quo. A gain forgone can be a cost, but again it is not a loss from a psychological reference point.

(a) Benefits and costs of mortality and morbidity: Evaluation of lives saved

The damages saved by the investment project may include lives saved. The standard approach is to assign a value to a statistical life and to then incorporate this value directly into the benefit-cost analysis as another benefit. There are about 71 studies that estimate life values. These studies estimate the value of life generally from estimates of how much people pay (WTP) to avoid risk or how much they must be paid (WTA) to accept risk. These analyses fall into four classes: (1) wage-risk studies, which analyze compensating wage differentials associated with risky jobs, (2) market studies, which analyze the market for products that affect health and safety, (3) behavioral studies that examine risk-avoidance behavior in risky situations, and (4) contingent value studies, which attempt to determine how much people are willing to pay for small changes in risk.

The literature includes several good summaries of the value of life (Miller 1990; Farrow et al. 2000). Medium estimates are around $5 million per life in year 2000 dollars but the standard deviation of these estimates is about $1 million (Farrow et al. 2000).

The standard approach involves discounting statistical lives, which has been criticized on moral grounds not only in the literature of philosophy but also in economics. This criticism has been addressed by Cropper and Portney (1990) and by Zerbe (2001, 2002).

The value of life literature has been used by Zerbe (2001) and others to help determine the value of the quality of life lost from injury. The procedure is as follows. A figure for the value of life is converted to an equivalent annuity for the life in the study from which the value was extracted. For example, the mean age of the subject of the studies appear to be about 40 years. The life expectancy of a 40-year-old is about 47.3 years. If the value of life is $5 million, then the equivalent annuity over the 47-year period, using a 3% discount rate, is about $250,000 per year. A determination is then made for a potentially injured worker as to the percentage of life-quality loss. A table like that below can be used.

Table 1.2 Quality of Life Ratings

Distress Rating⇒ *Disability Rating⇓*	*A. No distress*	*B. Mild*	*C. Moderate*	*D. Severe*
1. No disability		0.995	0.990	0.967
2. Slight social disability	1.00	0.986	0.973	0.932
3. Severe social disability and/or slight physical impairment	0.980	0.972	0.956	0.912
4. Physical ability severely limited (e.g. light housework only)	0.964	0.956	0.942	0.870
5. Unable to take paid employment or education, largely housebound	0.946	0.935	0.900	0.700
6. Confined to chair or wheelchair but able to move around in house with assistance	0.875	0.845	0.680	0.00
7. Confined to bed	0.677	0.564	0.000	-1.468
8. Unconscious	-1.028	n/a	n/a	n/a

Source: Kind et al., 1982. Notes: healthy = 1; dead = 0.00; n/a = not applicable; the negative figures indicate a life worse than death.

The numbers in Table 1.2 are the percentage of normal quality of life (1.00). Thus, a rating of 0.70 suggests that a person unable to take paid employment who is largely housebound and who suffers from severe distress has about 70% of the quality of life of a normal person. Thus with a potential injury lasting for 5 years and during which time one-half of the quality of life is lost, then the calculation would show a loss of 0.5 (the quality of life lost) times the value of life of $250,000 per year.

1.5.4 Present Value and Discount Rate

Many of the evaluation criteria for BCA require that future benefits and costs be reduced to a *present value* so that comparisons between different projects or alternatives will be consistent. The present value of a given cash flow is just the sum of money that if invested today at some relevant interest rate will yield that cash flow. For example, $100 invested today at a 10% will yield $10 each year forever. Thus, the present value of a cash flow of $10 per year forever, *discounted* at 10%, is just $100. (To find the present value of a cash flow that continues forever, called a *perpetuity*, the amount of the cash flow is divided by the interest rate. In this case we have $10/(0.10) = $100. When the interest rate is used in this fashion we call it the *discount rate.*

The larger the interest rate or discount rate, the smaller will be the present value of positive cash flows. For example, the present value of $100 to be received in 20 years is $81.95 at a 1% discount rate but is $14.86 at a 10% rate. *The choice of discount rate can have a major impact on the present value of a cash flow*.

While an extensive technical literature discusses the appropriate choice of discount rate (See Appendix A),[18] there is nevertheless a growing expectation that the appropriate discount rate will reflect the cost of capital for a term similar to the life of the project for the government organization considering a project. This rate is approximately the rate on government bonds that mature at about the time the project is to be completed. Thus, in the above example, 7% is used as the nominal (not adjusted for inflation) discount rate.

1.5.5 Treatment of Inflation

The cash flows (constant dollars) listed in Table 1.2 do not account for inflation, but cash flows adjusted for inflation are also used in a BCA. Whichever type of discount rate is used must be consistent with the type of dollars represented by the cash flows. A discount rate reflecting constant or *inflation-adjusted* dollars is called a *real discount rate*; one that reflects current or *nominal* dollars is called the *market* or *nominal discount rate*.

Since the current example uses constant dollars, we would use a discount rate of 7% (i.e., 10% – 3%) as the discount rate for the cash flows listed in Table 1.2; that is, the difference

[18] A comprehensive discussion of discounting can also be found in Lind (1982).

between 10% and 3% gives the inflation-adjusted discount rate of 7%. Using the current dollar amounts, 7% would be the discount rate. The results would be the same.[19]

1.5.6 Choosing a Criterion

After setting out the cash flows, benefits and costs need to be compared. Several different evaluative criteria in widespread use (Zerbe and Dively, 1994) include the net present value (NPV), benefits-costs (B/C) ratios, the internal rate of return (IRR), payback period, and the wealth maximizing rate (WMR). Each has certain advantages and disadvantages, shown below in Table 1.3, and discussed in greater length by Zerbe and Dively (1994).

Table 1.3 Advantages and Disadvantages of Evaluation Criteria*

	NPV	B/C	PAYBACK	IRR	WMR
always gives right answer for a single project	X	X	0	0	X
gives right answer when comparing projects	X	0	0	0	0
widely used	X (econ)	X (business)	X (elect. industry)	X	0 (newly developed)
answer is easily understood	0	X	X	X	X
easily adjusted to give right answer for single or multiple projects	NA	X	0	0	X
can be adjusted to give right answer	NA	NA	0	X	NA

**NA= not applicable; X= yes and 0= no*

All of these criteria can be used efficiently except that the payback period is inappropriate where time periods are very different or cash flows uneven. The NPV can be used generally without adjustments or special attention. Note that the benefit-cost ratio may not rank projects correctly when comparing them.

[19] They will be approximately the same where subtraction is used to find the real rate. They will be exactly the same where the more accurate approach of division, as shown in the previous footnote, is used to find the real discount rate.

1.5.7 Applying the Criterion

Once a criterion is chosen, the benefits and costs are compared by calculations.

1.5.8 Dealing with Uncertainty

Uncertainty addresses the ways in which the costs and benefits would differ if the conditions or circumstances of analysis were altered. In general, uncertainty analysis requires realistic estimates of benefit and cost categories as well as variance around these estimates. While traditional approaches to uncertainty analysis are important components of any BCA, PEER research is currently exploring uncertainty analysis in the context of PBEE. More specifically, Wilkie's project is considering the probabilistic aspects of uncertainty in terms of mitigation options, and the Zerbe-Chang project is addressing the relationship between risk and uncertainty (see Chapter 3.2).

(a) Methods of approach

While several standard techniques consider uncertainty, such as sensitivity analysis, stochastic dominance, and risk-adjusted interest rates, there are no clear guidelines for when to use a particular technique. This raises a particularly egregious issue in considering risk-adjusted interest rates. The risk-adjusted interest rates technique is commonly used by businesses for evaluating projects, but is less often used by governments. This issue will be addressed further in connection with a protocol we developed that also provides guidelines for the proper use of other techniques for considering uncertainty.

(b) Sensitivity analysis

Uncertainty is of particular concern given the probabilistic nature of natural disasters. A useful and straightforward way to handle uncertainty is to perform a sensitivity analysis. Such an analysis gives some insight into how the project would perform were conditions or circumstances different from those anticipated, for example, the effect if the capital costs were higher by 20% and the probability of a seismic event were lower by 10%. The result of this would be to reduce the benefits and to increase the costs.

1.5.9 Decision

The BCA should be regarded as information relevant to the decision process, and not just the decision (Zerbe and Dively 1994; Zerbe 1998b; Hahn 1986). Even though the financial analysis may suggest that the project is a good one, there may be factors not captured by this analysis. For example, an entity considering seismic mitigation may be concerned with environmental objections to the proposed project.

Sometimes benefits or costs can not be quantified. In these cases the analyst should point to this out and stress that these uncertainties should be part of the decision-making process.

1.5.10 Feedback

Once a project is complete it is uncommon but quite helpful to reevaluate the benefit-cost predictions in terms of what actually happened so that the analyst can improve the BCA technique in the future.

1.5.11 General Equilibrium

Most benefit-cost analyses are "partial equilibrium," that is, they examine the effects on supply and demand in one or few markets. "General equilibrium" analyses model the interactions between markets and account for the simultaneous determination of prices and incomes throughout an economy. For example, a 50-cent-per-gallon gas tax nationwide will have an economic impact far beyond the gasoline market. First, it will affect the demand for related goods such as automobiles. Second, it will affect the demand for productive resources such as automobile workers, which might in turn affect the supply of workers for related industries. Finally, how the government spends tax money will in turn affect various markets. A BCA that considers the effects of an earthquake can account for the effects on a region or the nation. Each might be either partial or general equilibrium. Within a region there will be many goods; an analysis that accounts for them just within the region would be a "limited general equilibrium analysis." In examining the effects on the nation, just a single good might be considered and not account for effects from markets that would otherwise be affected. In this case the analysis might bear more resemblance to partial equilibrium.

It is possible to account for general equilibrium welfare effects by examining only those markets directly affected and those indirectly affected that have distortions. A distortion is an effect that drives a wedge between supply and demand. The primary examples are taxes and monopoly power, so indirectly affected markets with these distortions need to be examined.

1.6 SUMMARY BCA FRAMEWORK

1. The role of BCA is to provide information and structure to the decision process, not just to provide the decision.
2. When analyzing even simple projects, a number of questions must be answered. These include the choice of interest or discount rate, treatment of inflation and uncertainty, and the choice of evaluation criteria.
3. The following steps are required as a minimum as part of BCA:
   - Make clear the client for whom the analysis is being performed.
   - Set out the assumptions of the analysis.
   - Set out relevant data and the cash flows (benefits and costs).
   - Choose the appropriate discount rate appropriately adjusted for inflation.
   - Choose an appropriate evaluation criterion, e.g., NPV.
   - Apply the chosen criterion, e.g., reduce to NPV.
   - Allow for uncertainty: Perform a sensitivity analysis.
   - Make a decision.
   - Provide feedback: Perform a post-perspective analysis.

1.7 PERFORMING BCA: A SIMPLIFIED EARTHQUAKE EXAMPLE

A simple use of BCA might the case of a building owner who is considering a seismic retrofit. The owner wishes to determine whether the investment would be wise from a financial standpoint.

Even with this seemingly straightforward problem, a number of important issues are present, including the treatment of uncertainty, the determination of relevant cash flows, the appropriate discount rate, the data assumptions, and the choice of evaluation criteria.

Suppose that the improvement costs $1 million. One way to pose the question of the improvement is to ask, “Will the investment of $1 million yield more for the building owner than an alternative investment?” Another is, “Will the savings the owner expects from buying the improvement represent a return greater than what it could otherwise earn, for example, by putting the money in the bank?"[20] To answer these questions, consider the basic steps of a BCA.

1.7.1 Make Clear for Whom the Analysis Is Performed (Who is the Client/Stakeholder?)

In this case the client is the owner of the building in question.

1.7.2 Set Out Assumptions[21]

(a) The analysis is from the perspective of the owner of a building in question;

(b) The relevant real discount rate is 7%;

(c) The value of life used is $5 million;

(d) The probability of an earthquake in any year is 1%;

(e) The damage caused is invariant with the magnitude of the earthquake;

(f) Improvements will cost $1 million in present value terms;

(g) The damage from an earthquake will be $28.476 million in constant dollars;

(h) The expected life span of the improved facility is 10 years with no expected scrap value;

(i) With the improvement there will be no damage over the 10 years should an earthquake occur;

(j) Damage will occur only in the year that an earthquake occurs and this would be the same regardless of the magnitude of the earthquake;

(k) It is appropriate to use the net present value (NPV) or the benefit-cost ratio criterion as the evaluation measure; and

(l) Adjustment for uncertainty assumes costs may be 20% higher than expected.

[20] This is another way of determining what economists call the *opportunity cost* of the investment decision.
[21] These are highly simplified assumptions. More realistic examples are provided in Chapter 2 and Appendix B.

1.7.3 Determine Relevant Data and Set Out Cash Flows

By purchasing the improvement, the owner will not have to incur expenditures to repair damage from an earthquake. Should an earthquake occur, the damage is expected to be $28.476 million in the year of the event and zero thereafter. This amount is expected to increase with inflation, as measured by the Gross Domestic Product Implicit Price Deflator. The real discount estimate is based on an estimate of 10% for the cost of capital and a foreseeable expected inflation of 3% annually; this is accounted for by the 7% real discount rate (10%–3%).

The second part of this step is to determine the annual cash flows associated with each alternative. These are shown in Table 4 (below). We make the conventional assumption that the cash flows are received at the *end* of each time period (here years) except for the initial expenditure. (If one has information to the contrary such as, for example, that benefits will be received in the middle of the period, this can be accounted for in setting out the cash flows.)

Table 1.4 Cash Flows and Present Values (Adjusted for Inflation)

YEAR	*COST (in millions)*	*DAMAGE (in millions)*	*PROBABILITY OF DAMAGE*	*SAVINGS IN DAMAGE (millions)*	*PRESENT VALUE OF SAVINGS (millions)*
0	-1.0000				
1		28.4755	1%	0.2848	0.2661
2		28.4755	1%	0.2848	0.2487
3		28.4755	1%	0.2848	0.2324
4		28.4755	1%	0.2848	0.2172
5		28.4755	1%	0.2848	0.2030
6		28.4755	1%	0.2848	0.1897
7		28.4755	1%	0.2848	0.1773
8		28.4755	1%	0.28476	0.1657
9		28.4755	1%	0.28476	0.1548
10		28.4755	1%	0.28476	0.1447

Table 1.5 summarizes the results of Table 1.4 into two summary criteria, the NPV and the benefit-cost ratio.

Table 1.5 Net Present Value

PRESENT VALUE OF BENEFITS (Sum from Table 1.4 (millions))	*PRESENT VALUE OF COSTS (millions)*	*BENEFITS MINUS COSTS (NPV)*	*BENEFIT-COST RATIO (B/C)*
2.000	1.000	1.000	2.00

One source of confusion is the distinction between constant and current dollars. Benefits and costs are listed in *constant dollars,* that is adjusted for the effects of inflation. *Current dollars,* are not adjusted for inflation. The benefits from avoiding earthquake damage are listed in constant dollars. The actual amounts will increase with inflation. By listing the constant dollar amount and adjusting the discount rate for inflation, the results are the same as if inflation were included and a 10% rather than a 7% discount rate were used.

1.8 LIFE-CYCLE COST ANALYSIS

Life-cycle cost analysis (LCCA) has received much attention in recent years within the earthquake engineering community and as a potential framework for use by PEER in evaluating increased performance of earthquake engineering measures. Illustrations of the potential applicability of this decision framework for seismic risk reduction include discussion of applicability to port facilities (e.g., Taylor and Werner 1995; Werner et al. 1997) bridges, (e.g., Chang and Shinozuka 1996), water systems (e.g., Chang et al. 1998), and buildings.

More generally, the U.S. Department of Transportation has encouraged states to employ life-cycle cost analysis for evaluating major transportation projects in keeping with federal highway legislation and executive orders (see U.S. Federal Highway Administration 1996). Life-cycle cost analysis has also been heavily promoted by the federal government as a tool for evaluating investments in energy-efficient devices.

The above problem is considered as a simple example of the relation between BCA and LCCA. For a particular structural design, life-cycle costs consist of the present value of expected costs from construction of the facility to the end of the structural life-span (Chang and Shinozuka, 1996). Life-cycle costs include construction, maintenance and, when done from a broader perspective, user costs. User costs for a transportation project, for example, might include increased travel time, increased accident costs, and increased vehicle-operating costs.

Items that in one case might appear as costs, such as increased travel time, might in another appear as benefits, such as decreased travel time.

LCCA is simply another way of expressing the results of a benefit-cost analysis and generally involves the determination of costs of all options. When these options are compared, the result is the same as that of a benefit-cost analysis. Consider the following example of a performance standard to reduce earthquake damage. Table 1.6 gives a summary BCA analysis of the Port of Seattle performance standard project; Table 1.7 uses life-cycle costs.

Table 1.6 Summary of Benefit-Cost Analysis

Net Present Value (NPV)	+$1. 00

Table 1.7 Life-Cycle Costs

	Performance Standard A	***Do Nothing Option***	***Value of Performance Standard A over Do Nothing***
Costs of Construction	-$1.00	$0	-$1.00
Costs of Earthquake	-$0.00	-$2.00	+$2.00
Total Life Cycle Costs	-$1.00	-$200.	+$1.00

Life-cycle cost approach is another way of presenting the results of a benefit-cost analysis. No information is lost in LCCA; one need simply keep in mind that benefits are the costs of options forgone.

One problem that can arise with LCCA that is more easily avoided with benefit-cost analysis is that economic measures of benefits are generally different from those for costs. Benefits are measured by WTP and costs by WTA. In some cases these measures can diverge significantly. Thus, in benefit-cost analysis issues arise about what count as benefits or costs. Life-cycle cost analysis can obscure this distinction.

Where benefits and costs are considered for commercial goods—goods for which there is no divergence between the WTP and the WTA, such as occurs when gains and losses are borne by corporations, this issue is not likely to arise. It is most likely to be an issue when gains and losses involve important non-market goods such as an environmental good.

One advantage of LCCA over benefit-cost analysis lies in its emphasis of comparison of alternatives. LCCA may make it more likely that alternative courses of action are actually considered. In addition, many analysts favor LCCA because it more clearly sets out the future maintenance cost implications of an investment decision.

The life-cycle and benefit-cost decision frameworks are appealing for a number of reasons. First, they draw attention to long-run costs. This makes it possible to consider trade-offs such as higher up-front costs and reduced downstream repair costs or costs of business disruption. Second, they provide a single metric — dollars, appropriately discounted, for evaluating choice outcomes. This overcomes the difficulties of comparing outcomes with respect to discrete, incommensurate objectives (e.g., lives lost, business interrupted, injuries). But there is still the problem of how to monetarize lives lost, etc. This also provides a continuous scale for making relative comparisons of value of different choices. Third, the frameworks are flexible enough to allow for incorporation of different time horizons, discounting factors, and changing components for benefit or cost streams.

1.9 CONTRIBUTIONS OF BCA

Over the years, the quality of BCA has improved: the government uses more appropriate interest or discount rates; values such as environmental values that once were not considered are now included; assumptions are made clearer. These improvements have arisen from the structure of BCA. A principal advantage of BCA is that it provides a framework for rational discussion and allows for a critique of information relevant for the decision-making process. Similarly, the use of efficiency analysis in legal reasoning has contributed to an understanding of law and allowed a critique of efficiency reasoning in the law (Zerbe 1998b). A careful student of the use of BCA (Lave 1996, p. 130) notes that "...I praise it for forcing analysts to think systematically about social issues, collect data, and do analyses to clarify the implication of decisions." Farrow (2000, p. 2) notes that the use of BCA as part of executive office review is associated with rejecting some regulations that would have been economically inefficient.

Nevertheless, the extent to which BCAs have improved the policy process remains somewhat unclear. What is clear is that improvement is possible.

1.10 GAINS FROM FURTHER APPLICATION OF BCA

Consensus among prominent commentators suggests that substantial gains exist from further application of BCA at every level of government. BCA has been used to stop a number of unappealing projects. Criticism by economists of project analyses done by the U.S. Army Corps of Engineers, the Bureau of Reclamation, and the Tennessee Valley Authority, for example, has prevented the funding of inefficient projects but has also improved the quality of the benefit-cost analyses done by these organizations.

Work by Graham (1995) and Tengs et al. (1996) suggests that even in the United States a reallocation of resources to more cost-effective programs could save 60,000 lives per year at no increased cost to taxpayers or to industry.[22] The use of BCA, just beginning at the state level, is used by less than one half of the municipal governments with populations over 100,000. Thus one may conclude that there is substantial room for expanding the use of BCA in the U.S (and even more so in Europe).[23]

Hahn (1996, p. 239) finds that about one half of the regulatory rules in the U.S. would not pass a benefit-cost test, even using numbers provided by government agencies, which he finds overstate benefits. According to Hahn (p. 231), EPA regulations are relatively poor in terms of their cost-effectiveness as measured by the cost per life saved.

He finds further that ". . .agencies could improve regulations by implementing a strategic planning process that uses net economic benefits as a criterion in deciding how to allocate agency resources." Hahn (p. 243) concludes that "performed well and taken seriously cost-benefit analysis can and should aid in the selection and design of more economically efficient policies."

[22] Graham 1995, 62.

[23] This is not to suggest that all regulations should be based strictly on benefit-cost tests. It makes little sense to subject policies whose primary goals are non-economic, e.g., the improvement of human rights or the rights of nature, to strict economic analysis. Of course, in a secondary sense, any such policies should be implemented as efficiently as possible.

1.11 LIMITATIONS OF BENEFIT-COST ANALYSIS

(a) Expensive and data-intensive

Sometimes benefit-cost analysis may be done simply and informatively. Often, however, formal benefit-cost analysis, particularly from a national perspective, requires considerable data and extensive analysis that can be both time consuming and expensive. As with any problem, a correspondence must exist between the analytic technique and expected answers. Sometimes a simpler technique may be adequate. In many cases the benefit-cost contribution is to furnish a way of thinking about a problem even if the full formal technique is not used.

(b) Analysis may be manipulated

Lies or biases can occur in many forms as shown by the history of benefit-cost analysis. The best safeguard against abuse is a formal technique, such as BCA, that better lends itself to outside and public review than does an informal technique.

(c) May be intimidating or opaque

A formal technique may be intimidating especially if the presentation method is not clear and overly complex.

(d) Hard numbers may drive out soft

Benefit-cost analysis tends to quantify only what may easily be quantified. As a result values that may be important but difficult to quantify may be ignored. For example, the value of reducing fear of an earthquake may be important but we are unaware of any attempt to provide it. Sometimes such unquantified values should be an important part of public discussion *before* the benefit-cost analysis is complete because once done, the hard numbers tend to exclude anything unquantified. This problem can be overcome by a sensitive treatment within the benefit-cost analysis, but unfortunately this rarely occurs.

(e) The problem of uncertainty should focus on a single number such as NPV

A formal benefit-cost analysis provides a decision criterion such as NPV. If this is positive the project is said to be desirable; if negative then undesirable. But the reality is that the results of a benefit-cost analysis more properly resemble those of a weather forecast, or an earthquake prediction: they are probability estimates with variances. This feature of benefit-cost analysis is often missed.

2 Application of Benefit-Cost Analysis to the Performance-Based Earthquake Engineering Framework

A detailed protocol has been developed complete with a hypothetical example that demonstrates how benefit-cost analysis can be applied to performance-based earthquake engineering (see Appendix B). This chapter provides an overview of that protocol. While the protocol utilizes the BCA framework outlined and illustrated in Chapter 1, it has been adapted in order to accommodate the performance-based earthquake engineering framework. Although the specifics of the protocol and hypothetical example presented in Appendix B focus on marine ports, both the conceptual framework and methodological approach can be generalized to other types of seismically vulnerable systems. The protocol and integrated hypothetical example are being provided, in booklet form, to various port agencies.

As previously discussed, benefit-cost analysis is simply an accounting framework; therefore applications can be easily carried out using basic spreadsheet packages. Computer programs and applications that are able to interface with spreadsheets can easily integrate a benefit-cost component. Alternatively, benefit-cost analysis can be performed using any language or application that allows for easy and straightforward algebraic manipulation of variables.

The following subsections provide an overview of the framework and procedures that have been developed in order to evaluate the economic efficiency of earthquake risk mitigation decisions made within a performance-based earthquake engineering environment. For each step, the information needed to carry out the procedure is described as well as the information that will be produced by the analysis.

2.1 ECONOMIC EVALUATION OF SEISMICALLY VULNERABLE SYSTEMS

In order to apply benefit-cost analysis to the performance-based earthquake engineering framework, seismically vulnerable facilities (ports, bridges, roadways, and buildings) are conceptualized as economic systems made up of various components, some or all of which are seismically vulnerable. For example, wharfs and cranes are the most seismically vulnerable components of the port system; therefore our analysis focuses on decisions related to these components.

Benefit-cost analysis also involves the specification of all parties (stakeholders) who will be affected by the cost and benefits of the proposed project. While interviews with port officials and a review of the literature on ports identified a number of stakeholders that would be directly affected by seismic safety decisions at the port (the port, port tenants, laborers, citizens, regional industries, etc), our analysis focuses exclusively on the perspective of the port itself.

Our interviews with Port of Oakland officials revealed that in addition to identifying the components and stakeholders to be included in an analysis, a benefit-cost analysis of marine ports also needs to specify the types of cargo handled at the port facility, and the cargo territory served by the facility. After further research with these officials, it was decided to focus the analysis on the decision to build a new wharf that, for the most part, handles non-local containerized cargo.

While the specification of the systems and stakeholders included in an analysis does not require any data to be input into a benefit-cost model, data are essential to the process for determining the relevant cash flows (streams of benefits and costs) that will be considered. Information pertaining to the system and stakeholders under consideration can be obtained from a variety of sources including relevant management officials and academic literature.

2.2 ECONOMIC EVALUATION OF PERFORMANCE CRITERIA

In order to evaluate the economic efficiency of earthquake risk mitigation decisions, benefit-cost analysis involves the identification of all options under consideration, including the option to retain the status quo. When this framework is applied to PBEE, options are defined in performance-based terms. The analysis undertaken in Appendix B utilizes performance standards provided by the Port of Oakland (1999). These standards specify the expected level of damage and capacity to operate following various levels of earthquakes.

The Port of Oakland provided the following performance levels:

"Minor damage" = The facility suffers only minor repairable damage and remains fully functional.

"Repairable damage" = The facility suffers economically repairable damage and operations may be limited and/or interrupted for up to 8 months.

The port then defined the following performance criteria:

Performance criterion 1 = In the case of a relatively common seismic event, or "Operating Level Earthquake" (OLE), damage to the facility does not exceed "minor damage." An OLE is defined as a seismic event that has a 50% probability of exceedance in 50 years.

Performance criterion 2 = In the case of a relatively rare seismic event, or "Contingency Level Earthquake" (CLE), damage to the facility does not exceed "repairable damage." A CLE is defined as a seismic event that has a 10% probability of exceedance in 50 years.

Table 2.1 indicates that the OLE event (50% exceedance probability in 50 years) corresponds to a PGA level of 0.15g. The CLE event (10% in 50 years) corresponds to a PGA level of 0.40g. It should be noted that the performance criteria are minimum standards that could be exceeded.

Table 2.1 Hypothetical Seismic Hazards Curve

Damage Threshold (PGA Level)	*Annualized Probability of Exceeding Damage Threshold (P_1)*	*50-Year Probability of Exceeding Damage Threshold (P_{50})*[24]
.15g	.01390	.503353
.25g	.00630	.270938
.40g	.00217	.102927
.50g	.00167	.080173

[24] 50-year probability of exceedance was calculated using the following formula:
$P_{50} = 1- (1- P_1)_{50}$. This assumes that earthquakes occur randomly according to a Poisson process, where the seismic events are independent and the average number of events over a given time period is a known constant.

The following seismic mitigation options are defined with reference to the performance criteria and the hypothetical seismic hazards curve:

(M0) status quo: do nothing.
(M1) 0.15g used to determine the lateral design force for performance criterion 1.
(M2) 0.20g used to determine the lateral design force for performance criterion 1.
(M3) 0.40g used to determine the lateral design force for performance criterion 2.
(M4) 0.75g used to determine the lateral design force for performance criterion 2.

This example is provided for illustrative purposes only. The precise manner in which performance criteria and mitigation options are defined will vary from project to project. We envision that this information, which structures the entire benefit-cost analysis, will be provided by the client for which the project is being performed.

2.3 EARTHQUAKE MITIGATION COSTS AND BENEFITS FOR PORTS

Seismic mitigation has associated costs and therefore, in the short term, negatively impacts the revenue flow of the system. However, in the event of an earthquake the cost of implementing seismic mitigation may be substantially outweighed by the savings on costs that would have occurred without mitigation. These cost savings are referred to as *benefits*. The framework that has been developed specifies the ways in which the benefits and costs associated with each mitigation alternative for each seismic component affects the revenue flow of the system being examined.

The analysis presented in Appendix B specifies the benefits and costs associated with each of the above mitigation options (M0–M4). Costs, for the most part, are determined by the construction cost associated with each option. Three types of benefits were also considered: facility repair cost, cost of response, and loss of revenue. These categories were determined by analyzing the relationship between the component being considered (wharf-crane) and the revenue structure of the system in question (the port).

The way in which our framework considers the relationship between the benefits and costs of seismic mitigation decisions and the revenue flow for marine ports is illustrated in Figure 2.1:

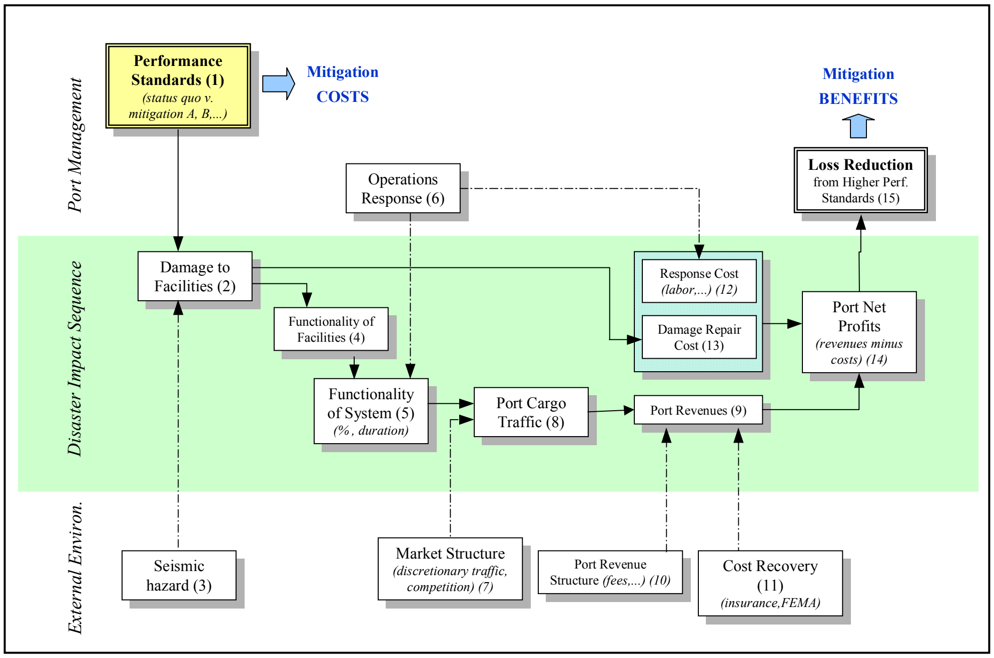

Fig 2.1 Earthquake Mitigation Costs and Benefits for Ports

In this model, costs represent the construction cost associated with each mitigation option (Box 1). Damage to a particular component of a system (Box 2), in this case the wharf-crane facility of the port system, is a function of both the mitigation decision undertaken (Box 1) and the extent of the seismic event (Box 3). The cost of repairing this damage (Box 13) will reduce the port's net profits (Box 14). The magnitude of the damage to a component is measured in terms of functionality or capacity to operate (Box 4), which in turn affects the functionality of the entire system (Box 5). This can be mitigated, to some extent, through measures that can compensate for the damaged facility (Box 6). Such measures represent a cost in that implementation will negatively impact port profits (Box 14). In terms of a marine port, reduction in system functionality may lead to a reduction in cargo traffic (Box 8) and a loss in port revenue (Box 9) and profits (Box 14). The extent of this reduction is, in part, determined by external forces, such as the market structure within which the specific port operates (Box 7) and the particular ways in which the port derives its revenue (Box 10). Some of these financial losses may be recouped through insurance and federal disaster assistance (Box 11).

The first benefit category that is considered is the facility repair costs. These are costs required to either restore a facility to full functionality or to make it structurally sound. The second benefit category, cost of response, considers the way in which emergency measures and administrative restructuring of port operations can compensate for the damages facility. The cost of response is proportional to the number of days needed to repair a facility. The third category of benefits takes into account loss of revenue at the port as a result of reduced operations. Once again, this is determined in large part by the number of days needed to repair damaged facilities. We distinguish between short-term revenue loss (revenue lost while a facility is being repaired) and long-term revenue loss (permanent revenue loss that results from loss of customers). In terms of BCA, these categories are "discounted" differently in order to correctly account for the time value of money.

3 Critical Issues in Using Benefit-Cost Analysis for PBEE

In this section, we identify several critical issues that need to be considered when performing a benefit-cost analysis in a performance-based engineering context. Currently, many of these issues are being addressed by ongoing PEER research projects, i.e., Zerbe and Chang, and Wilkie.

3.1 SCALE / MULTIPLE STAKEHOLDER ANALYSIS

In most cases, a variety of groups are differentially affected by the benefits and costs associated with performance-based earthquake engineering decision. However, traditional BCA considers only the perspective of the "primary" stakeholder. The PEER Year 5 Zerbe-Chang project is developing a new framework that will in theory and methodology incorporate the perspective of multiple stakeholders — the owner(s) of the site, the user(s)/tenant(s) of the site, the local economy, the regional economy, and "society." A multiple-stakeholder BCA framework will provide a new way of approaching the seismic mitigation decision-making process. We are interested in understanding how the results of a multiple stakeholder analysis differ from those of a more traditional BCA analysis, what kinds of data a multiple stakeholder analysis will require, what new types of questions it will address, and how it will change the decision-making process.

3.2 UNCERTAINTY

As explained in Section 1.5.8, uncertainty addresses the ways in which the costs and benefits would differ if the conditions or circumstances of analysis were altered. We will discuss the traditional ways that uncertainty is handled (i.e., sensitivity analysis and Monte Carlo simulation). In general, uncertainty analysis requires realistic estimates of the benefit and cost categories as well as variance among these estimates. For example, in the case of the marine port, described in Appendix B, the cost of seismic mitigation and the cost of facility repair are both highly variable. The treatment of uncertainty incorporates these variations in the benefit-cost analysis. In addition to the overview presented of traditional types of uncertainty analysis and the associated data needs, we will draw on both Wilkie's PEER project, which is considering the probabilistic aspects of uncertainty in terms of mitigation options, and the Zerbe and Chang project, which is addressing the relationship between risk and uncertainty.

4 Issues, Criticism, and Limitations of Benefit-Cost Analysis

The aggregate criticism of the foundations of BCA is substantial. It comprises technical and ethical criticism, criticism about the process, and about issues of practice. We shall briefly consider these.

4.1 FOUNDATIONAL ISSUES FOR BCA

Technical Limitations:

- Scitovsky reversals
- Failure to pass a potential compensation test
- Status quo bias
- The inability to allocate goods or rights under uncertainty

Moral or Ethical Limitations

- The foundation of benefit-cost is utilitarianism, which is outdated.
- The allegation that BCA does not take into account rights.
- The allegation that BCA misses important values in its calculations.

4.2 CRITICISM EXPLAINED

4.2.1 Technical Limitations

(a) Scitovsky reversals

In a famous article in 1942, Scitovsky pointed out that the benefit-cost criteria (the Kaldor-Hicks criteria) could give inconsistent results. For example, the Kaldor criteria could indicate that a move from state A to state B was desirable on the grounds of economic efficiency. But having arrived at state B, the criterion could indicate that a move back to A was cost beneficial. Some commentators, e.g., Coleman (1980), assert that this issue is sufficient to justify abandoning the benefit-cost criteria.

(b) Potential compensation test

The justification for the Kaldor-Hicks criteria has long been the supposition that it ensures that a project meeting its standards will pass a potential compensation test. This means that a desirable project would be one in which the winners from the project could compensate the losers from the project and still retain some gains. Boadway and Bruce (1984), however, showed that the usual measure of the Kaldor criterion (the sum of compensating variations) was a necessary condition to pass a potential compensation test but not a sufficient condition. The usual measure of the Hicks criterion (the sum of the equivalent variations) was a sufficient but not a necessary condition. This meant that a project that satisfies both (neither) criteria would pass (fail) a potential compensation test. However, for those projects that passed one test but not both, one would remain uncertain whether or not they were good projects by the potential compensation criteria. This issue becomes important only when the difference between the two measures of efficiency is liable to be fairly different, and this will occur when the goods in question are non-commercial goods that are expensive or unique.

(c) Status quo bias

There are two sorts of status quo bias. When the two measures, compensating and equivalent variations differ, the bias is deemed to be a status quo in that no move is justified by benefit-cost standards even though it is possible that such a move would improve economic welfare. This is in fact another variation of the difference between the necessary and sufficient conditions mentioned above.

The second form of status quo bias rests on the fact that the measures of gains and losses depend on the status quo allocation of income, wealth, and rights.

(d) Inability to allocate goods or rights under uncertainty

Where rights are uncertain, it has been held that the efficient allocation of resources can also be unclear because the efficient outcome will depend on who is allocated the right, which begs the question under consideration.

4.2.2 Moral Criticism

(a) Foundation of benefit-cost analysis is utilitarianism

To some the absence of moral considerations in benefit-cost analysis means that it is an unsatisfactory criteria. Examples are given in which benefit-cost analysis is alleged to give an efficient but immoral result.

(b) Benefit-cost analysis does not take into account rights

The usual sort of example here is one in which it appears efficient to take property from one party and give it to another. When under law such transfer is held to be theft or immoral, the benefit-cost analysis is held to recommend an immoral result.

(c) Benefit-cost analysis misses important values in its calculations

This criticism is essentially the same as number 4.2.2(a) but without the reference to utilitarianism. The widespread, trenchant, and important criticism here is that benefit-cost analysis fails to take into account the effects of projects on income distribution and fails to consider the importance of compensating losers under some conditions. It is held that moral values, such as personal integrity or concern for others, are missing from the standard BCA analysis.

4.3 FOUNDATIONAL CRITICISM RESOLVED

Zerbe (2001) has provided a response and perhaps a resolution to this criticism by creating a variation of the Kaldor-Hicks criteria, called "KHZ." Zerbe shows that much of the foundational criticism is implicitly of KH criteria and only by extension of benefit-cost analysis. The grounding of KH he proposes appears to eliminate most technical and moral but not process criticism.

4.3.1 KHZ Criterion as an Answer to Moral and Technical Criticism

In BCA an action or decision is defined as efficient if (1) there is a positive sum for the willingness to pay (WTP) for gains and the willingness to accept payment (WTA) for losses; (2) gains and losses are measured from psychological reference points (Kahneman and Tversky

1979) which will mean that they are in the main to be measured from established legal rights; (3) all goods for which there is a WTP are economic goods; and (4) the transaction costs of operating within a state of the world are included in costs for purposes of determining efficiency, but the political transaction costs of changing from one state of the world to another to are not to be included.[25] An approach based on these axioms creates a new paradigm called KHZ (Zerbe 2001).

4.3.2 KHZ Characteristics

KHZ efficiency recognizes that any normative criterion is necessarily a moral and ethical concept. Its justification rests, therefore, only on its acceptance as a moral criterion. Such acceptance is enhanced if the role of determining efficient action is seen as providing valuable information to decision makers. Thus the determination of the efficient action is not in itself the decision but rather information relevant to the decision (Zerbe 1998).

KHZ efficiency has the following characteristics: (1) it is not subject to preference reversals; (2) it satisfies a compensation criterion; (3) it defines all goods for which there is a WTP as economic goods (Zerbe 1998b);[26] (4) thus, it includes income distribution as well compensation or its lack, as economic goods, so that a project that provides compensation may be valued differently in efficiency from one that does not (Zerbe 1998a); (5) it obviates important ethical objections that have been made to KH (Zerbe 1998b, 2001); and (6) by incorporating transactions costs, it eliminates the practice of finding market failure or inefficiency in situations in which there is no superior alternative (Zerbe and McCurdy 1999)[27].

It is beyond the scope of this paper to consider fully the extent to which KHZ puts to rest moral and technical criticism. In Section 4.3.3a, however, KHZ is considered as it affects the problem of missing values and the discount rate question. This topic has relevance for discounting future values, which is of concern to earthquake mitigation analysts.

[25] It seems obvious that to require economists to include the costs of persuasion in their pronouncements of what is efficient would be stupefying at best.

[26] For additional requirements that apply to KHZ, see Zerbe 2001.

[27] For a full elaboration of these characteristics, see Zerbe 2001.

4.3.3 Missing Values

Examples of missing values are legion (Zerbe 1998a). Among the most prominent are the absence of consideration of compensation or of effects on income distribution. Since these are, however, goods for which there is a WTP, these are economic goods. For example, consider a BCA of the efficient location of a municipal incinerator. Typically an analysis will be done without considering the sentiments of those not directly affected by the decision. The decision to locate the incinerator in the poorest neighborhood will then typically not take into account the sentiments of those who care about equity effects but are not otherwise involved. Since these sentiments about equity are part of KHZ, and logically part of KH also, they should in principle be considered. Hence under KHZ a project to locate the incinerator in a poor neighborhood without compensation to the residents who will suffer as a result is a different project from that when the residents are to be compensated.

(a) Missing values and the discount rate problem[28]

In BCA, future benefits and costs are discounted using an interest rate referred to by economists as the discount rate. This rate is traditionally used to reflect the preferences of those affected by a decision. A widespread criticism of the use of the discount rate and, by implication of BCA, is that the use of a discount rate is unethical (e.g., Parfit 1992, 1994; Schultze et al. 1981). The discount rate is held to be unethical because it discounts the benefits to be gained and the costs to be borne by future generations whereby the utility to future generations counts equally to that of the present generation (Schultze et al. 1981; Pearce 1989). For example, Parfit (1992, p. 86) argues that "the moral importance of future events does not decline at n% per year. . . . ." This sort of criticism has been noted with favor by economists (e.g., Schultze et al. 1981; Pearce et al. 1989), lawyers (Plater et al. 1998, pp. 107–9), and philosophers (Parfit 1992, 1994).

The following example is a typical shortcoming of this kind:

A project would produce substantial benefits of about $50 billion, at a cost of about $20 billion but, in addition, would also produce a toxic time-bomb that would cause enormous

[28] The use of the terms "missing values" here refers to moral values that are not taken into account. This term is also used in econometrics as a technical term referring to missing data points.

environmental costs in the distant future.[29] (Questions of uncertainty are omitted from this example.) Suppose that current waste-disposal technology will contain this waste for 400 years but that the material will remain toxic for 10,000 years. Sometime after 400 years the waste will leak from its container. If the waste leaks in 500 years, the estimated cost of future environmental damage in constant, year 2000 dollars will be about $8 trillion, about the size of the current U.S. GDP. The present value of this damage discounted at a 3% real social rate of time preference (SRTP), assuming that the waste leaks earlier, after 400 years, is about $59 million, not insignificant, but far less than the damage that will occur in 500 years and far too small to affect the results of the BCA. Discounting this damage then still results in the project going forward. The benefits exceed the cost by almost $30 billion.

The project is then said to be justified by BCA but leading to a bad result and therefore making the BCA deficient. Since this result would be unfair to future generations, and on this basis it is argued that the use of BCA of the discount rate is inappropriate, unfair, or unethical.

A commonly proposed solution (e.g., Schulze et al. 1981) is to argue that lower, or possibly zero (or even negative), discount rates should be used, as they can avoid such time-bomb results. Another suggested solution is to not use discount rates at all (Parfit 1994). This sort of argument is often a moral plea about what our sentiments should be toward future generations but not an effective statement about whether discount rates should be used and what their value should be. The proposed solution of using no or low discount rates is ad hoc and, if generally applied, will lead to other ethical problems — for example, the adoption of projects that give fewer benefits to both present and future generations.

To arrive at a correct approach, consider why we find the result in the earlier time-bomb example unacceptable. The argument for unacceptability is not based on the preferences of future generations, which we cannot know exactly, but on our own preferences, based on our empathy with future generations. There are, then, missing values —our own — in the form of our regard for others.

A solution (Lesser and Zerbe 1995) is inherent in the criteria for KHZ. What is missing from the traditional analysis is our *regard for others*. The current generation will have a WTP or a WTA to prevent this unfair result. The missing values incorporated in the regard for others can

[29] Cases in which this sort of issue has risen include Baltimore Gas & Electric vs. Natural Resources Defense Council, Inc. 462 U.S. 87, 1983, and Pacific Gas and Electric Co et al. v. State Energy Resources Conservation and Development Commission et al. 461 U.S. 190, 1991.

be expressed in terms of the willingness to accept (or pay) and are, therefore, a required part of a KHZ analysis.

By applying KHZ analysis to the above example the use of the discount rate might suggest that if we invest \$59 million today, we create sufficient wealth to compensate all harm inflicted 500 years from now. It might also suggest that we expect future generations to be richer than we are. If we were to invest the \$20 billion benefits today, the net wealth creation in 400 years would be about \$2.7 quadrillion, or about 330 times the current U.S. GDP. This information about the future amount that could be available for compensation is useful but not definitive.

The economic efficiency of the project will depend upon the sentiments of the present generation. For example, the present generation may feel that future generations should be free of problems caused by the current generation. An unfair result is a loss to those who expect and care about fairness. Thus, in a caring society, harm to future generations would be a loss to the present generation, and the WTA would be the correct measure of value of this loss. Evidence from Kunreuther and Easterling (1992, p. 255) and from Svenson and Karlsson (1989) suggests that at least as regards nuclear waste disposal, individuals tend to place a high weight on future consequences.

KHZ departs from KH with respect to the issue of whether future generations will, in fact, be compensated. For KH, only potential compensation is considered. All that the traditional BCA shows is that the future generations could, in principle, be more than compensated. They may, of course, not be actually compensated. On the other hand, given a likelihood that future generations will be richer, for this reason, the present generation may find that compensation for the environmental harm is unwarranted. By KHZ standards, then, a project in which future generations are compensated is different from one in which they are not. KHZ requires that we consider two projects, one in which future generations are compensated and one in which they are not.

The value to be attached to the current generation's consideration of future generations will depend on whether or not the provision of compensation is a gain to the current generation, in which case the WTP is to be used, or whether the failure to provide compensation is regarded by the current generation as a loss, in which case the WTA, which could be infinite, should be used.

Suppose that present individuals care little about fairness or ethical outcomes—their WTA is so small that, as a result, the non-compensated project passes the benefit-cost test. One can view this as an unethical result, but the result arises not from the use of the discount rate but from the sentiments of society. The task of the critic of discount rates is to reform the sentiments of society, not to suggest that using the discount rate is improper.

Table 4.1 shows the KHZ solution to the discount rate problem. The relevant choice set includes a project with compensation and one without. The moral issue is not the discount rate or the use of BCA, but what people care about.

Table 4.1 The Discount Rate Problem Resolved

	If People Care About Harming Future Generations		***If People Don't Care About Harming Future Generations***	
	A. The Project **With** Compensation (billions)	B. The Project **Without** Compensation (billions)	C. The Project **With** Compensation (billions)	D. The Project **Without** Compensation (billions)
Present Value of Benefits	\$50	\$50	\$50	\$50
Present Value of Ordinary Costs	-\$20	-\$20	-\$20	-\$20
Present Value of Harm to Future Generations	-\$0	-\$0.058	-\$0	-\$0.006 (standing) \$0.00 (no standing)
Present Value Required to Compensate Future Generations	-\$0.058	-\$0	-\$0.058	-\$0
Present Value of Ethical Harm to Present Generation	0	-X	0	0
Net Present Value (billions)	**\$29.94**	**<\$29.94**	**\$29.94**	**\$29.94 (standing) \$30 (no standing)**

When people care about harming future generations, project A is always superior to project B. If people of the current generation do not care about future generations, then it raises an issue of standing as to whether the values of the future generations should be counted at all (Whittington and Macrae 1986). Thus, if the current generation cares nothing about future generations, then the project without compensations, project D, is never inferior and could be superior.[30]

A number of often elegant approaches to calculating future value involve manipulation of the discount rate. These are often suggested in connection with protecting current environmental assets for future generations (Portney and Weyant 1999). Yet all of these admirable suggestions are attempts to incorporate the sentiments of their authors into a discount rate approach. Ethical concerns, however, are better incorporated directly, as KHZ suggests. This keeps the accounting clear. Ethical concerns about future consequences can be treated by giving value to these ethical concerns, rather than by adjusting the discount rate.

The solution to the ethical dilemma of the discount rate problem is to acknowledge ethical concerns and to seek ethical solutions, while acknowledging the values that commend the use of a discount rate. To not use the discount rate is simply to ignore a fact arising from the productive aspect of nature. To use a discount rate that is below the rate at which people will trade off present for future consumption, i.e., a rate of time preference, will lead to economic inefficiency, by justifying investment with insufficient returns. To use a rate that is too low attempts to cope with inequity by adjusting prices. The result is that an inequity appears to be an inefficiency.

4.4 PROCESS ISSUES AND CRITICISM

Process criticism may be divided into two groups of critics, those that seek to improve the use of current benefit-cost analysis and those that find the use of benefit-cost analysis inherently biased and wish to abandon it.

The first group cites in order of severity (1) a lack of uniformity of treatment in BCA even within the federal government and little or no uniformity among different governments; (2) the less objectionable criticism that sometimes benefit-cost analysis is treated as the answer rather than as part of the decision and discussion process. One variant of this criticism is the argument that the results of any benefit-cost study should be subject to public process and decision. (3) Quantification of values as part of BCA removes attention from non-quantified values (hard numbers drive out soft).

[30] It would be superior as long as future individuals have no standing. See Whittington and Macrae 1986.

Those critics who argue for abandoning or for significantly limiting use of BCA assert that BCA ignores values that are difficult to quantity and that BCA tends to be an inferior substitute for the political process.

4.5 PROCESS CRITICISM ADDRESSED: SUGGESTIONS FOR IMPROVING PROCESS

There is substantial consensus that BCA should be improved if it is to play a greater role in agency decision making (Hahn 1996, p. 240; Lave 1996, p. 108f). At a practical level, the greatest need is for standardization of analyses. There is probably rough agreement among benefit-cost analysts about the appropriate standardization. An outline of the standardization might include the following five requirements:

1. Agencies should use common practices where possible; among these are the following:
    - All assumptions should be made explicit and placed at the beginning of analyses.
    - The social discount rate used should be common to different agencies.
    - WTP should be used for gains and WTA for losses.
    - Assumptions about legal rights should be made clear.
    - Agreement should be reached on common treatment for variables that are not quantified.
    - Sensitivity analysis should be used as a matter of course.

2. Outside peer review should be used as a matter of course (see Hahn 1996, p. 241).

3. Regulatory review should be expanded and should involve a specialized, technically competent agency other than the proposing agency or the agency that performed the BCA.

4. The burden of proof should reside with the results of the BCA, so that to carry forward a project that does not satisfy a BCA test should require special dispensation.

5. Interested parties should be allowed legal standing to participate in the BCA evaluation process if they can provide evidence that some alternative to the proposed regulation is superior.

6. Where non-quantified values are apt to be important, the BCA should treat them seriously and should attempt to determine whether these would be likely to reverse the BCA conclusion.

7. Every important BCA should have provision for public discussion of the draft results. Benefit-cost analysis is not a substitute but a part of the political process.

4.6 ISSUES OF PRACTICE

A number of technical challenges exist for extending the life-cycle cost or benefit-cost framework to evaluating seismic improvements, particularly for application to buildings. These include incorporation of different levels of tolerance for risk among decision makers; the uncertainties associated with the incidence, timing, and magnitude of earthquake damage and its impact, valuing impact (especially injuries and deaths); and projecting timing and costs of repairs or other responses. (These considerations are identified, and considered to varying degrees, in the discussions cited above.) The most salient point about these technical challenges for this discussion is that such calculations are very imprecise. Thus one research area is figuring out ways to measure and report the degree of confidence in results (Cullen and Frey 1999).

4.6.1 Discount Rate

Very often the discount rate is not an issue from an agency perspective because most agencies have a discount rate they use as a matter of practice. The same is true for private firms.[31]

[31] There is a well-developed finance literature that explains in considerable detail the discount rate to be used by private firms (Breeley and Myers 1988). The answer given is that firms should use the cost of capital as the discount rate. A discussion of this issue is beyond the scope of this paper.

The issue arises when benefit-cost analysis is considered from the social perspective, the welfare of many different parties. For many years there has been controversy about the correct discount rate to use for government projects where the social perspective was to be sought. There were two primary schools of thought.

(a) Opportunity Cost of Capital School (OCC)

The reasoning of this school of thought is generally that government investing will use funds that could have been used for private investing. Therefore the government discount rate should be the same as the private rate, because otherwise the wealth of society is not maximized because of a failure to invest in the most profitable projects.

To this argument can be added a second that is mainly implicit in the literature. If the government is considering investing in projects that could be performed by the private sector and the government is using a lower discount, the government may appear to be the more efficient provider of the project even though it may not be, since the net present value of the projects will appear higher when the government performs it rather than the private sector.

(b) Rate of Time Preference School

The rate at which consumers are willing to trade off present for future consumption is called the rate of time preference. This rate is usually considered to be lower than the opportunity cost of capital. The reasoning in this school is that as long as a project has a rate of return greater than the time preference rate it will if undertaken provide gains to consumers. To ensure that such projects are carried out, the government should use the time preference rate as its discount rate.

(c) Shadow Price of Capital: Discount Rate Issue Resolved

Bradford (1975) resolved the debate showing that considerations of both the OCC and time preference schools of thought can be properly taken into account. From Bradford's work it is possible to derive discounting equations for benefits and costs in which the time preference rate is the discount rate (e.g., 3% real) but the ordinary benefits and costs are adjusted to take into account the extent to which costs raise interest rates in the capital market or the extent to which benefits may lower such rates. Lesser and Zerbe (1998) show that in an open economy, such as that of the U.S., in which capital flows are international, almost any project is too small in the context of the capital market to have an effect on interest rates, so that the adjustments can be ignored. The bottom line then is that time preference rates should be used for government projects from a public policy perspective. These rates can be reasonably said to be between 2% and 4% in real (inflation-adjusted) terms.

4.7 LIMITATIONS OF BENEFIT-COST ANALYSIS

Even if we eliminate or overlook the foundational questions of benefit-cost analysis on both the moral and technical sides and even if we improve the process, the question remains: When is this the appropriate technique? No technique, including benefit-cost analysis, is completely satisfactory in all circumstances. In general benefit-cost analysis is more appropriate where (1) rights are clear, (2) where relevant data are available, (3) where most goods under consideration are commercial goods, and (4) where fundamental moral concerns are not at issue. Where BCA is used a number of practical issues remain:

- from what perspective should the analysis be performed?
- how should non-quantitative values be treated?
- what is the role of moral sentiments?
- what is the best way to treat uncertainty and variability?

Despite the above, our judgment is that if used according to its best principles, greater use of benefit-cost analysis has the potential to materially improve existing decision making.

4.8 CONCLUSIONS

Benefit-cost analysis has a substantial history in the United States as a tool for decision making. BCA reasoning has also played an important role in legal reasoning in the U.S. and in Europe. Although BCA appears to improve the decision process a definitive answer to when if is most appropriate question is not yet available.

Criticism of both the practice and theoretical foundations of BCA and BCA reasoning have accumulated. Criticism of practice can primarily be addressed by process changes that incorporate the best practice suggestions of the literature and that increase uniformity of practice and allow for greater review. Criticism of theory can best be addressed by some modification to the basic paradigm. The modification we have proposed is called KHZ.

Appendix A Discount Rate

Benefit-cost analyses require that future benefits and costs be reduced to present values for comparisons by use of an interest rate called a discount rate by which the present value of a project or proposal is the worth of that project in today's terms. For example, a project that grants a one-time benefit of $100 at the end of 10 years discounted at 10% yields $38.55 (PV = FV/(1 + DR)^T = $100/(1 + .10)^10 = $38.55). This $38.55 equates to the amount that one could invest today to yield $100 in ten years at a 10% interest rate. A large discount rate places more weight on the present versus future benefits and costs. The financial evaluation of a project is sensitive to the choice of discount rate. Thus choice of discount rate is important. A discount rate that reflects inflation-adjusted dollars is called a real discount rate and a discount rate that reflects nominal dollars is called the nominal discount rate.[32] A large body of literature discusses the appropriate choice of discount rates; further readings are listed at the end of this section.

A.1 STANDARD PRACTICE

The following assumptions are consistent with standard practice:

1. Use the same discount rate for benefits as for costs.
2. Use sensitivity analysis by evaluating the effect of using a range of discount rates.
3. Use the same rate regardless of project length.
4. For government projects do not adjust the rate for risk or uncertainty.

[32] Lesser, Jonathan and Zerbe, Richard O. Jr., "A Practitioner's Guide To Benefit-Cost Analysis," in Handbook of Public Finance, by Thompson, Fred and Green, Mark T. (eds.), Marcel Dekker, Inc., 1998.

A.1.1 Rates for Private Firms

Private firms generally use discount rates based on their cost of capital. The cost of capital is the rate set by the firm as a "hurdle," or "trigger," rate required. These terms signify the rate by which a project's future payoffs surpass comparable investment alternatives. The return forgone by investing in the project rather than investing in securities is called the opportunity cost of capital (OCC).[33] The OCC has been approximately at a 7% real rate in recent years.[34] Standard practice is for firms to adjust the rate to reflect market risk (covariance risk). Although this is not done generally when analysis is by federal agencies, it would be consistent with standard private practice. The adjustments are commonly done using the Capital Asset Pricing Model (CAPM).

A.1.2 Rates for Government Agencies

Government agencies use different rates even within the same level and branch of government, and the rate used by a single agency may change over time. For example, the rates used by the U.S. Army Corp of Engineers have varied from as low as 2.5% to as high as 10% from 1950 through 1980. The Office of Management and the Budget (OMB) for many years used a real rate of 10%, but lowered this to 7% in 1992 (See OMB circular A-94 revised 1972–1992). This rate approximates the marginal pretax rate of return on an average investment in the private sector in recent years.[35] The Congressional Budget office uses a rate of 2%[36] (Thompson and Green 1998). Municipal governments generally use a rate in the 2.5% – 3.5% range.[37] There also have been very peculiar practices required of the Army Corps and the Bureau of Reclamation by which real rates are used with nominal benefits and costs. In general little analysis is available to different government agencies for the selection of different rates. Additionally there is a lack of consistency as well as rationale for most government use of discount rates; therefore the range of federal rates used by these agencies is anywhere from 2% to 7% in real terms. The justification for government rates has ranged from using the rate on

[33] Office of Management and Budget, Circular A-94.
[34] Brealey, Richard A., and Myers, Stewart C., "Principles of Corporate Finance," 3d ed., McGraw-Hill, Inc., 1988.
[35] See Footnote 34.
[36] See Footnote 32.
[37] Dively, Dwight D., Zerbe, Richard O., "Benefit Cost Analysis in Theory and Practice," Harper Collins College Publishers, 1994.

government bonds (the government cost of capital) to using the rate on private capital to using the social rate of time preference.)

A.1.3 Recommendations

1. Use the standard practice assumptions.
2. Use a discount rate ranging from 2.5% to 7% in real terms.
3. Adjust the rate for market risk using the CAPM.

A.2 A BETTER APPROACH[38]

A.2.1 Rates for Government Agencies

There is growing acceptance that the appropriate discount value for government projects is the social rate of time preferences which, practically speaking, is approximated by the cost of capital. Thus we suggest using the cost of capital for both private and public projects. The cost of capital for government is approximately given by the rate of return of long-term government bonds. This rate, in real or inflation-adjusted terms, has varied between about 2.5% and 5% per year.[39]

The justification for the simple approach of using the rate on long-term government bonds comes from the sophisticated social rate of the time preference approach. The social rate of time preference (STRP) is widely accepted as the correct approach after adjusting for the effect on private capital.[40] (For a derivation and a rationale for this approach, see Zerbe and Dively 1994, Chapter 13.) The SRTP is the rate at which society is willing to trade off present for future consumption. Although the discounting equation using the SRTP is somewhat complex, it reduces to an ordinary discounting equation when public investment does not affect the dollars available for private investment. It has been argued that this is in fact the case.[41] We adopt this assumption here. Nevertheless a fuller treatment is given in the following section.

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[38] There is literature that would support some alteration in all of the standard assumptions except for the use of sensitivity analysis—which is just good methodology. For the user who wishes to explore additional complexity with respect to these assumptions see further readings.
[39] See Footnote 32.
[40] See Footnote 37, for a derivation and a rationale for this approach see Zerbe and Dively, 1994, Chapter 13.
[41] See Footnote 37.

A.3 DISCOUNT RATES: TECHNICAL TREATMENT

There is growing acceptance that the appropriate discount value for government projects as for private projects is the cost of capital so long as the project investment funds do not substitute for private funds. This rate is equal to the rate of return for government bonds. In real terms the discount rate yields on long-term government bonds are between 3% and 5%.[42] The use of the cost of capital as a discount rate is based upon the correct rate being the social opportunity cost of capital, which takes into account time preferences and the displacement of private capital.[43]

The justification for the simple approach of using the rate on long-term government bonds comes from the sophisticated social rate of time preference approach. The Social Rate of Time Preference (STRP) is widely accepted as the correct approach after adjusting for the effect on private capital.[44] (For a derivation and a rationale for this approach see Zerbe and Dively 1994, Chapter 13.) The SRTP is the rate at which society is willing to trade off present for future consumption. Although the discounting equation using the SRTP is somewhat complex, it reduces to an ordinary discounting equation when public investment does not affect the dollars available for private investment. It has been argued that this is in fact the case.[45]

The SRTP approach yields the following discounting equation with B_t and C_t representing the benefits and costs of year t:

$$\text{Net PV} = (B_t[\theta_c V_t + (1-\theta_c)] - C_t[\theta_b V_t + (1-\theta_b)]) / (1+i)t \quad \text{(A.1)}$$

Where:

$$\text{Shadow Price of Capital} = V_t = (1 - s)r / (i - sr) \quad \text{(A.2)}$$

V_t is the present consumption value of \$1.00 of private investment. In other words, V_t converts those public investments that displace private funds to consumption equivalents ("crowding out").[46] The \$1.00 public investment yields future benefits and may also return funds

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[42] Thompson, Fred and Green, Mark T. (editors), "Handbook of Public Finance", Marcel Dekker, Inc., 1998. References used in this analysis are from Zerbe, Richard O. Jr., and Lesser, Jonathan, "A Practitioner's Guide To Benefit-Cost Analysis," Chapter 7.
[43] See Footnote 32.
[44] See Footnote 37.
[45] See Footnote 32.
[46] See Footnote 37.

used in private investment, so V_t applies to benefits of public projects as well as to the costs. V_t incorporates both benefits and costs of an investment in consumption terms.

When, however, the θ_c and θ_b are zero or, practically small, then no adjustment need be made to ordinary benefits and costs and the use of the SRTP, i.e., i is the correct discount rate. When θ_c and θ_b are zero, the above equation reduces to the following:

$$\text{Net PV} = (B_t - C_t) / (1+i)t \qquad \text{(with sum from } t = 0 \text{ to } T) \qquad (A.3)$$

The term V_t drops out. This is just the ordinary equation for discounting at rate i, which is the social rate of time preference.

V_t arises because of the possibility that a government project might affect the interest rate at which private capital is available. Lind (1982) and Lesser and Zerbe (1994) have argued that for most projects investment amounts will be small relative to financial markets and that, therefore, crowding out and crowding in are not factors in most project evaluation.[47] This is particularly the case now that financial markets are worldwide. The conclusion then is that θ_c and θ_b are essentially zero so that no adjustment is necessary to ordinary costs and benefits.

To provide additional background into the shadow price of capital and the SRTP, the formulas and a derivation of its value will be provided. Table A.1 provides the five variables used to calculate the SRTP and the shadow price of capital.

TABLE A.1 SRTP and Shadow Price of Capital[48]

r =	the private investment rate of return, the Opportunity Cost Rate (OCR)
s =	the fraction of the proceeds of an investment that are reinvested in the excess of the amount needed to maintain capital
i =	the social rate of time preference (SRTP)
θ_c =	the fraction of a dollar of public spending that displaces private investments; i.e., the extent to which government project crowded out private capital
θ_b =	the fraction of a dollar of public spending returned to private capital; i.e., the extent to which government projects crowded in private capital (Include references with formulas etc for these variables)

[47] See Footnote 32.
[48] See Footnote 37.

The following table shows estimates of the ranges for *i, r*, and *s*.

TABLE A.2 Variable Ranges[49]		
Variables	Expected Values	Bounds (2 std. dev.)
i	3%	2.5%-4.2%
r	7%	6.0% - 10%
s	7.2%	5.5%-10%

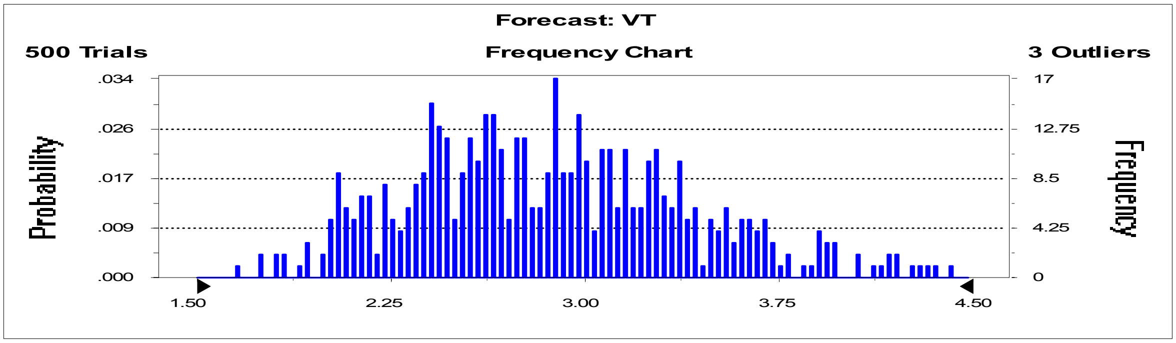
To approximate the shadow price of capital, Monte Carlo simulations were employed using Crystal Ball. The variables presented in Table 2 were represented with triangular distributions. For example, the minimum and maximum for R were set at 6% and 10% and the peak at 8%. With θ_c and θ_b set at zero, *t* set at 50 years, and B_t and C_t set at one, the Crystal Ball simulation yielded after 500 trials the characteristics for V_t comparable to the discount rate on long-term government bonds between 3% and 5%, thus supporting the Best Practice approach advocated by Ferat.

TABLE A.3 Ferat Trials

Trials	500
Mean	2.88
Median	2.85
Mode	---
Standard Deviation	0.55
Variance	0.31
Skewness	0.52
Kurtosis	3.17
Coeff. of Variability	0.19
Range Minimum	1.67
Range Maximum	4.85
Range Width	3.17
Mean Std. Error	.02

49 See Footnote 37.

TABLE A.4 V_t Frequency Distribution



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Appendix B A Benefit-Cost Protocol for Evaluating Performance-Based Earthquake Engineering Decisions at Marine Ports

B.1 INTRODUCTION

This document provides a set of guidelines for evaluating earthquake risk mitigation decisions made within a performance-based earthquake engineering framework. More specifically, a benefit-cost analysis protocol is presented for evaluating performance-based earthquake engineering decisions at marine ports. From the perspective of a marine port, this protocol can help to answer questions such as, What is the most cost-efficient level of seismic safety design? In approaching this question we consider not only the cost of implementing various mitigation measures, but also the ways in which different levels of mitigation will defray the costs associated with a seismic event. In general, three types of loss savings are considered: facility repair costs, the cost of responding to the seismic emergency, and loss of port revenue due to business interruption and long-term loss of traffic.

The guidelines that have been developed involve a five-step procedure:

1. identify systems and parties that will be affected by the proposed mitigation options;
2. identify alternative mitigation options under consideration;
3. specify the benefits and costs of each of the proposed mitigation options;
4. valuate the benefits and costs of each of the proposed mitigation options; and
5. choose among the alternative mitigation options.

Most other research that has approached this problem has focused almost exclusively on the benefits and costs associated with individual facilities within the port (Taylor et al. 1995; Werner et al. 1997; Werner 1998). In contrast, the primary contribution of this work centers on the relationship between various performance standards and business interruption loss at the port. To this end, our interviews with both academic port experts and port executives at the Port of Oakland have focused on the relationship between damage to particular facilities, the functionality of the port, and business interruption loss at the port. Such a focus is consistent with recent experience at marine ports, which has shown that the greatest risk posed by a seismic event is an interruption of the port's business and the resultant loss of traffic to competitor ports. For example, as a result of the 1995 Great Hanshin earthquake in Japan, the Port of Kobe suffered such severe damage that it was forced to curtail its business activity for more than two years. As a result, it dropped from the sixth largest container port worldwide, in terms of container throughput, to the seventeenth (Chang 2000).

In addition to the interviews at the Port of Oakland, our conceptual framework also draws upon literature on risk perception and conflict, port economics, port politics, seismic mitigation of port structures, and benefit-cost analysis (Slovic et al. 1980; Hershman 1988; FEMA 1994; Zerbe and Dively 1994; Eidinger and Avila 1998).

B.2 PROCEDURAL GUIDELINES FOR EVALUATING PERFORMANCE-BASED EARTHQUAKE ENGINEERING DECISIONS AT MARINE PORTS

B.2.1 Step 1: Identify Systems and Parties That Will Be Affected by Proposed Mitigation Options

The first step in the analysis involves specification of the components of the system to be evaluated for seismic reinforcement. It is also necessary to identify all parties who will be affected by the costs and benefits of the proposed project.

B.2.1.1 Identify and Define Systems Affected by Mitigation Decisions

All systems that will be affected by seismic mitigation decisions must be identified and the components of these systems must be defined.

(a) Identify port facilities included in the analysis

While many facilities are necessary for the operations of a marine port, some facilities are more critical than others. Additionally, our research at the Port of Oakland has revealed that some components, such as the storage yard, can be easily and quickly repaired after a seismic event, while others, i.e., wharves and cranes, will involve costly and time-consuming repairs. Given these considerations, our analysis focuses on the "wharf system." Wharves and cranes are considered to constitute an interdependent unit within this system; consequently, damage to either component may result in a loss of functionality.

> Example: Port Risky has decided to build a new wharf, Wharf X, and is concerned with implementing the most cost-efficient seismic mitigations.

(b) Identify cargo type(s) included in the analysis

Since the analysis is concerned with loss of revenue as a function of business interruption loss and long-term loss of traffic, it is necessary to specify what type of cargo is being considered. The port earns different revenue rates from different types of cargo. We focus here on one of the most important cargo types for many ports, containerized cargo.

> Example: The new wharf, Wharf X, which Port Risky has decided to build, will handle containerized cargo.

(c) Identify cargo territory considered in the analysis

Cargo is considered either local or non-local. Local cargo consists of containerized goods that are trucked within approximately a 400-mile radius. Such cargo is regarded as non-discretionary, meaning that it is "tied" to the local port in question. While loss of port functionality may cause these goods to be diverted to a competing port for a time, this cargo will return as soon as it can be accommodated at the affected port.

Non-local cargo originates from and is destined for areas outside the port's immediate territory. This includes containerized goods that are trans-shipped or moved intermodally via railroad and ship. This type of cargo is considered discretionary, meaning that it is not tied to the local port in question. Loss of port functionality that causes these goods to be diverted to a competing port is associated with the risk of losing this cargo permanently. We assume that the longer the time period of diversion, the greater the risk of long-term loss of business.

> *Example:* Port Risky serves a relatively small hinterland area, consequently 70% of the cargo passing through Wharf X will be non-local or discretionary cargo. Given such a high volume of discretionary cargo, Port Risky is particularly vulnerable to the loss of traffic to competitors that may accompany business interruption.

B.2.1.2 Identify Stakeholders Affected by Mitigation Decisions

All parties that will be affected by seismic mitigations decisions must be identified. Our research indicates that the following stakeholders are directly affected by seismic safety decisions at ports: the port, port tenants, laborers directly employed by the port, citizens of the political jurisdiction that comprises the port, businesses that provide the goods shipped through the port, businesses that provide services to the port, regional laborers and businesses indirectly related to the port via economic multiplier effects, and extra-regional firms for whom the port is the least cost/most efficient trans-shipment point.

While each of these stakeholders will be affected by decisions made as a result of the benefit-cost analysis, at this time our analysis is limited to the perspective of the port itself. However, much of our analytic framework can easily be extended in order to include the other stakeholders.

> *Example:* Port Risky is concerned with identifying the various parties who will be affected by seismic mitigation decisions at Wharf X; however, it is most interested in the ways in which these decisions will affect its own future costs and revenues.

B.2.2 STEP 2: IDENTIFY ALTERNATIVE MITIGATION OPTIONS UNDER CONSIDERATION

The next step in the analysis involves identifying all relevant options, including the option to retain the status quo. Each option is defined in performance-based engineering terms, that is, with reference to the expected level of damage and operationality for a specified level of earthquake.

While the performance standards used in these guidelines are based on information provide by the Port of Oakland, the actual design levels, performance criterion, and associated damage levels should be considered as illustrative examples. In order to perform an actual benefit-cost analysis of performance-based earthquake engineering at a marine port, the port must provide specific information concerning design levels, performance criterion, and associated repair times.

It should be noted that the manner in which this analysis is structured is most appropriate when analyzing the benefits and costs of a project in which an *a priori* decision has been made to either build a new facility or upgrade an existing one. However, in some cases it may be necessary to compare the benefits and costs of upgrading an existing facility to the benefits and costs of building a new facility. Throughout these guidelines we suggest ways in which the analysis can be modified in order to accommodate the latter case.

B.2.2 PERFORM PROBABILISTIC SEISMIC HAZARD ANALYSIS

A probabilistic seismic hazard analysis is performed in order to establish the range of possible seismic events to which the region is vulnerable. The output of this analysis should indicate the probability that a given PGA (Peak Ground Acceleration) level or other measure of ground motion will be exceeded within a given number of years. This actual information, for a given region, is commonly available from the United States Geological Society or a local state geological society.

Example: Port Risky's probabilistic seismic hazard analysis has produced the following information:

Table B.2.1 Hypothetical Seismic Hazards Curve

Ground Motion Threshold (PGA)	*Annualized Probability of Exceeding Ground Motion Threshold (P_1)*	*50-Year Probability of Exceeding Ground Motion Threshold (P_{50})*[50]
.15g	.01390	.50335
.25g	.00630	.27094
.40g	.00217	.10293
.50g	.00167	.08017

B.2.2.2 Define Performance Criteria

The expected performance of the facility is defined in terms of the damage the facility will sustain during a seismic event and the resultant operationality.

<u>Example:</u> Port Risky first defined the following performance levels[51]:

"Minor damage" = The facility suffers only minor repairable damage and remains fully functional.

"Repairable damage" = The facility suffers economically repairable damage and operations may be limited and/or interrupted for up to 8 months.

The port then defined the following performance criteria:

Performance criterion 1 = In the case of a relatively common seismic event, or "Operating Level Earthquake" (OLE), damage to the facility does not exceed "minor damage." An OLE is defined as a seismic event that has a 50% probability of exceedance in 50 years.

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[50] 50-year probability of exceedance was calculated using the following formula: $P_{50} = 1 - (1-P_1)^{50}$. This assumes that earthquakes occur randomly according to a Poisson process, where the seismic events are independent and the average number of events over a given time period is a known constant.

[51] These performance criteria were defined following the guidelines set forth by the Port of Oakland (Port of Oakland 1999).

Performance criterion 2	=	In the case of a relatively rare seismic event, or "Contingency Level Earthquake" (CLE), damage to the facility does not exceed "repairable damage." A CLE is defined as a seismic event that has a 10% probability of exceedance in 50 years.

Table B.2.1 indicates that for Port Risky, the OLE event (50% exceedance probability in 50 years) corresponds to a PGA level of 0.15g. The CLE event (10% in 50 years) corresponds to a PGA level of 0.40g. It should be noted that the performance criteria are minimum standards that could be exceeded.

B.2.2.3 Define Seismic Mitigation Options

Seismic mitigation options are defined with reference to the performance criteria specified in Section B.2.2.2 and the probabilistic hazard analysis performed in Section B.2.2.1.

Example: Port Risky has defined 5 mitigation alternatives[52] for Wharf X:

(M0) status quo: do nothing

(M1) 0.15g used to determine the lateral design force for performance criterion 1.

(M2) 0.20g used to determine the lateral design force for performance criterion 1.

(M3) 0.40g used to determine the lateral design force for performance criterion 2.

(M4) 0.75g used to determine the lateral design force for performance criterion 2.

B.2.3 STEP 3: SPECIFY THE BENEFITS AND COSTS OF EACH OF THE PROPOSED MITIGATION OPTIONS

Figure B.2.1 presents a graphical representation of the relationship between the costs and benefits of seismic mitigation at marine ports. The damage that a facility sustains (Box 2) during a seismic event is a function of the magnitude of the seismic event (Box 3) and the level of mitigation employed by the port (Box 1). This relationship is considered in Step 2 of the five-step procedure, identify all relevant options under consideration. The specific facilities and

[52] Following the guidelines set forth by the Port of Oakland (Port of Oakland 1999), we have associated four increasing levels of design with two performance criteria.

systems (Box 4 and Box 5) affected by seismic mitigation are defined in Step 1 of the guidelines. This step, Step 3, specifies the costs and benefits of various mitigation measures. The costs of implementing different levels of mitigation are largely capital costs due to additional necessary construction (Box 1). Benefits are savings, or loss reductions, on costs that would have occurred without mitigation (Box 15). The areas of loss reduction are facility repair costs (Box 13), the costs of responding to the seismic emergency (Box 12), and loss of port revenue due to business interruption and long-term loss of traffic (Box 9).

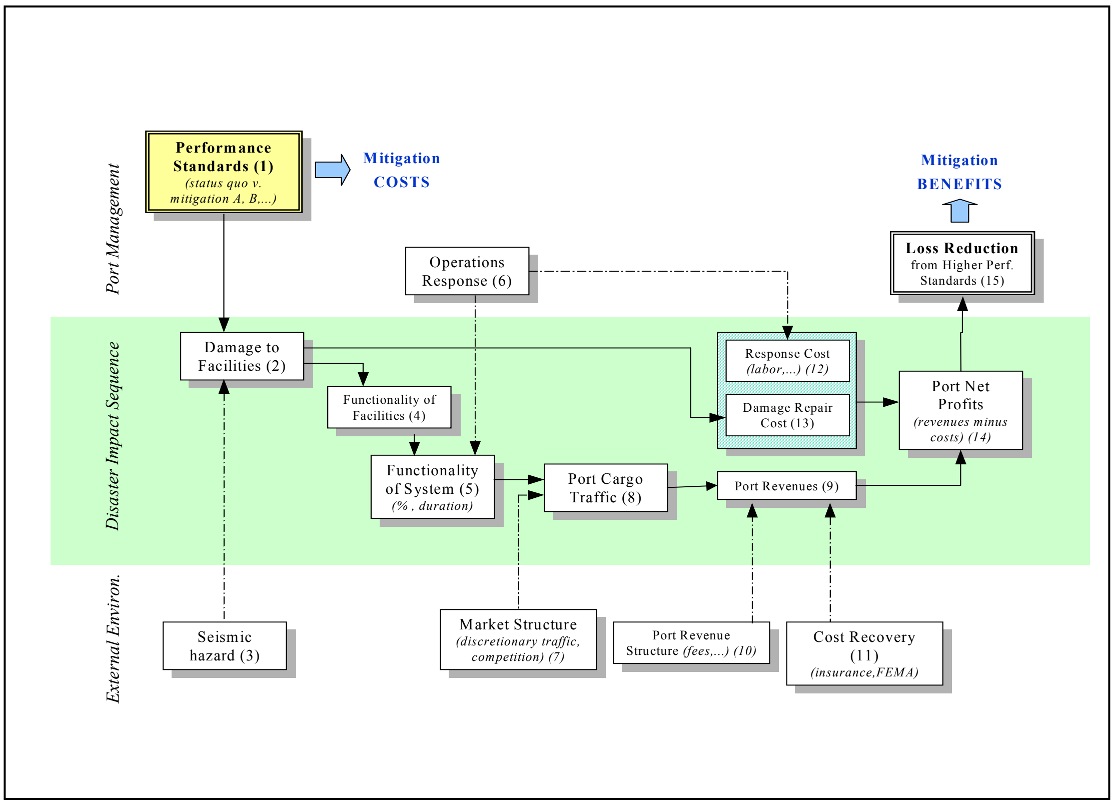

Figure B.2.1 Earthquake Mitigation Costs and Benefits for Ports

B.2.3.1 Identify Mitigation Costs

Each alternative option defined in Section B.2.2.3 is associated with a different cost of mitigation. These costs are a function of the cost of designing to meet a given performance criterion. Costs are considered with respect to the life span of the facility and the expected rate of return on the investment.

(a) Determine the seismic construction cost associated with each mitigation alternative

The major cost associated with earthquake mitigation is the seismic construction cost associated with each alternative option. The seismic construction cost is defined as the cost over and above the "base" construction cost in order to design to a certain level. The seismic construction cost for the status quo option is $0, since this alternative involves building a new facility without any seismic safety measures.

As was discussed in Section B.2, the analysis will need to be modified if it is necessary to compare the benefits and costs of upgrading an existing facility to the benefits and costs of building a new facility. In this case, a portion of the base (non-seismic) construction cost needs to be included in the analysis when the option to build a new facility is considered. The amount included is a function of how much earlier the structure is being built than without seismic considerations.

The costs specified in the following example, which are for illustrative purposes only, refer to the options defined in Section B.2.2.3.

<u>Example:</u> Port Risky has determined that the following seismic construction costs are associated with each mitigation alternative (defined in Section B.2.2.3):

Table B.2.2 Hypothetical Seismic Construction Cost for Each Mitigation Option[1]

Alternative Options	*Estimated Seismic Construction Cost ($ million)*
(M0) status quo: do nothing	0.0
(M1) 0.15g used to determine lateral design of performance criterion 1	0.4
(M2) 0.20g used to determine lateral design of performance criterion 1	2.0
(M3) 0.40g used to determine lateral design of performance criterion 2	2.1
(M4) 0.75g used to determine lateral design of performance criterion 2	6.5

Note: (1) Costs are loosely based on an example in Taylor and Werner (1995).

(b) Determine other costs associated with each mitigation alternative

In addition to the seismic construction costs identified in the section above, each mitigation alternative may involve other costs.

B.2.3.2 Identify Mitigation Benefits

Each mitigation option is also associated with a different benefit level. Benefits are savings on costs that would have occurred without mitigation (Figure B.2.1, Box 15). In general three types of loss savings are considered: facility repair costs (Box 13), cost of response (Box 12), and loss of revenue (Box 9).

(a) Determine reduction in property damage associated with each mitigation alternative

Property damage here refers to the costs required to either restore a facility to full functionality or to make it structurally sound. Estimates of damage level, costs of repair, and expected federal assistance are needed in order to calculate the net cost of property damage. Damage estimates and corresponding repair costs should be calculated for a range of plausible regional events. Since there is a good deal of uncertainty associated with repair costs, it is necessary to calculate mean and standard deviation of these costs. It may be decided that the repair costs should take into account risk transfer arrangements and FEMA reimbursement. In this case, repair costs included in the analysis are net repair costs that reduce the port's out-of-pocket payments for repairs.

The damage level and associated repair costs and repair time can be estimated through a component vulnerability analysis. Such analysis takes as input both the range of possible seismic events that may occur in the region, i.e., probabilistic seismic hazard analysis (see Section B.2.2.1), and the proposed design level of the facility. The results of the model indicate the damage state of the facility, repair costs, and time needed for repair.

> <u>Example:</u> Component vulnerability analysis conducted by Port Risky has produced the following results:

Table B.2.3 Hypothetical Outputs of Component Vulnerability Analysis[1]

Mitigation Option	*Seismic Event*	*Repair Cost ($ million)*	*Cost Savings ($ million)*	*Repair Time (work days)*
M0	OLE[2]	4.10	0	365
	CLE[3]	6.60	0	365
M1	OLE	0	4.10	0
	CLE	3.79	2.81	365
M2	OLE	0	4.10	0
	CLE	2.85	3.75	365
M3	OLE	0	4.10	0
	CLE	2.60	4.00	200
M4	OLE	0	4.10	0
	CLE	0	6.60	0

Note: (1) Cost estimates are loosely based on Taylor and Werner (1995); (2) OLE = operating level earthquake; (3) CLE = contingency level earthquake.

Cost Savings are benefits, or savings, accrued as a result of implementing a certain level of earthquake mitigation (M1~M4) for a given seismic event (OLE or CLE), as opposed to M0 (do nothing). For example, if no mitigation measures are taken (M0), repair cost will be $4.1 million in the event of an OLE. However, for the same event, given the M1 level of mitigation, repair cost would be $0. Therefore, implementing the M1 mitigation would result in a savings of $4.1 million for the OLE event.

(b) Determine cost of response

As illustrated in Figure B.2.1, these costs (Box 12) result from measures taken by the port in order to respond to a seismic emergency (Box 6). While the operations response has an associated cost, measures taken by port officials as part of this response can compensate for damaged facilities (Box 2). The way in which such costs affect the net profits of the port (Box 14) is a function of the structure of the port under consideration (Box 10). For example, at a landlord port, costs resulting from a substitution of labor for damaged capital are assumed by tenants. However, under the same structure, the costs associated from an intensified use of capital, e.g., accommodating two tenants within one facility, may be borne directly by the port.

The response by the Port of Oakland to the 1989 Loma Prieta earthquake provides an example. A wharf at the Port of Oakland was rendered inoperable as a result of the earthquake. Nonetheless, the port was not forced to divert any traffic because port personnel were able to accommodate the affected tenants at another terminal within the port. The cost associated with this response included increased labor costs associated with additional security and draying cargo within the port. Since the Port of Oakland is a landlord port, these costs were assumed by the tenants. However, the Port of Oakland did assume the expense of accommodating two tenants within one terminal. This cost primarily consisted of a "revenue splitting" agreement negotiated between the port and the primary tenant of the terminal.

Example: Port Risky has determined that the following operations response costs are associated with each mitigation alternative[53]:

Table B.2.4 Hypothetical Cost of Response for Each Mitigation Option (1)

Mitigation Option	*Seismic Event*	*Cost of Response ($ million)*	*Cost Savings ($ million)*
M0	OLE	3.65	0
	CLE	3.65	0
M1	OLE	0	3.65
	CLE	3.65	0
M2	OLE	0	3.65
	CLE	3.65	0
M3	OLE	0	3.65
	CLE	2.00	1.65
M4	OLE	0	3.65
	OLE	0	3.65

Note: (1) Assumes response cost is $10,000 per day over the duration of the repair time.

(c) Calculate loss of functionality within port system

Facilities rendered inoperable as a result of a seismic event (Figure B.2.1, Box 4) will reduce the overall functionality of the port as a system (Box 5). However, the extent to which system functionality is reduced can be mitigated by the port management's operations response to the

[53] The cost of response is proportional to the number of days needed to repair the facility (see Table B.2.3).

emergency (Box 6), for instance, by "doubling up" cargo at wharves that remain functional. Thus, *effective* system functionality loss may be considerably smaller than *initial* system functionality loss. This step requires estimating the loss of system functionality that would occur in each of the seismic events identified in Section B.2.2.2 above for each of the mitigation options identified in Section B.2 2.3 above.

Initial system functionality loss for the seismic events can be estimated as the normal annual cargo volume handled at the damaged facility relative to the normal annual cargo volume handled at the port as a whole. It should be measured in percentage terms.

Effective system functionality loss should be estimated by port managers after taking into account the port's ability to handle extra cargo at undamaged facilities in the event of a disaster. This ability will be constrained by factors such as the physical layout of facilities at the port, contractual arrangements with port tenants, current capacity of the port, and excess capacity at the time of the disaster. While this ability will vary across facilities, ports, and situations, it is interesting to note that based on its experiences in the 1989 Loma Prieta earthquake, the Port of Oakland estimates that it could handle up to roughly 20% loss of initial functionality by "doubling up" or implementing similar responses. If data and models are available, effective system functionality loss can be more rigorously evaluated by developing a queuing model that could simulate the absorption of displaced cargo by undamaged facilities at the port.

> Example: Port Risky handles 2 million TEU (twenty-foot equivalent units) of container cargo each year. Some 10% of this cargo will be handled at Wharf X. Since Port Risky operates 365 days a year, this amounts to 200,000 TEU/year or 548 TEU/day handled at Wharf X. If Wharf X were rendered inoperable in an earthquake, initial system functionality loss would be 10%. However, port management believes that in an emergency situation, up to 5% of cargo at the port could be accommodated by "doubling-up" at an undamaged wharf in an adjacent berth. Therefore, if Wharf X were rendered inoperable, effective functionality loss would be 5% (= 10% - 5%). The effective daily loss of cargo in this situation would be 274 TEU/day.
>
> Note that in this example, in the interest of simplicity, it is assumed that no other facilities at the port are damaged in an earthquake. However, a complete analysis would evaluate port system functionality by expanding the scope of analysis to include the seismic vulnerability of other facilities at the port.

(d) Calculate short-term loss of revenue

Reduction in port functionality (Figure B.2.1, Box 5) will lead to a reduction in cargo traffic at the port (Box 8). However, the extent of traffic reduction will also be determined by the external business environment, specifically, by market structure factors such as the prevalence of discretionary traffic at the port and competition with other ports (Box 7). Reduction in cargo traffic at the port will lead to loss of port revenues (Box 9), the extent of which will depend upon the port's revenue structure (Box 10), that is, its contractual agreements with its users or tenants. For example, if the majority of a port's revenue derives from wharfage fees, assessed on a per-container basis, then loss of cargo could have a direct and significant impact on port revenue.

It is also important to account for sources of new revenue deriving from disaster cost recovery (Box 11), in particular, insurance claims and disaster assistance from government agencies such as the Federal Emergency Management Agency (FEMA). There may be considerable uncertainty associated with the extent of disaster assistance and the time lag before it becomes available.

We distinguish between short-term and long-term loss of revenue. The latter is discussed in the next step, below. For present purposes, short-term revenue losses are those experienced during the time that repairs are being made. Long-term loss consists of business that does not return to the port even after repairs are completed. Short-term loss is estimated as the effective loss of traffic multiplied by unit revenue.

> Example: Analysis in Section B.2.3.2 (c) above has indicated that Port Risky would lose 5% of its cargo while Wharf X is inoperable, or 274 TEU per day. Port Risky earns $40 per TEU of container cargo that it handles. For mitigation option M0 (no mitigation) in an OLE event, Wharf X would be inoperable for 365 days, whereas with option M1 in the same event, it would be down for 0 days. Accordingly, short-term revenue loss for M0 and M1, respectively, is calculated as follows:
>
> M0: Loss = (365 days) x (274 TEU/day) x (40 $/TEU) = $4.0 million
>
> M1: Loss = (0 days) x (274 TEU/day) x (40 $/TEU) = $0
>
> Cost savings = $4.0 million

Table B.2.5 Short-Term Loss of Revenue Associated with Each Mitigation Option

Mitigation Option	*Seismic Event*	*Short-Term Loss of Revenue ($ million)*	*Cost Savings($ million)*
M0	OLE	4.0	0
	CLE	4.0	0
M1	OLE	0	4.0
	CLE	4.0	0
M2	OLE	0	4.0
	CLE	4.0	0
M3	OLE	0	4.0
	CLE	2.2	1.8
M4	OLE	0	4.0
	CLE	0	4.0

(e) Calculate long-term loss of business

Loss of port functionality that cannot be compensated for by operations response will cause cargo to be diverted to a competing port for a time. Generally, local or non-discretionary cargo, as identified in Section B.2.1.1(c) above, will return as soon as it can be accommodated at the port. However, non-local or discretionary cargo is at risk of being permanently lost to a competitor. It is assumed that the longer the period of diversion (i.e., downtime at the damaged facility), the greater the risk of long-term loss of port business. The actual relationship between estimated repair time and long-term business loss is an empirical relationship that the port will need to specify. Similarly, the rate at which lost business is regained after repairs are completed will also need to be specified by the port. The port's marketing division may be helpful in arriving at these estimates.

Example: As noted earlier, 70% of the container cargo handled at Port Risky is discretionary and consists of intermodal cargo that is transported by rail and sea. It is assumed here that this same percentage applies to Wharf X alone. Based on experiences of ports in other recent disasters, port management estimates that where damage is severe enough to put Wharf X out of operation for over 3 months, shipping lines may decide to invest in new arrangements with a competing port and not return. However, if damage is less severe and they can be assured that Wharf X will be functional in 90 days or less, the shippers will agree to interim arrangements at Port Risky, such as berth sharing. Thus in an OLE event, mitigation option M0 (no mitigation), with a 365-day estimated downtime at Wharf X. Long-term loss of revenue could be estimated as follows:

M0: Long-term loss of revenue

= (274 TEU/day) x (40 \$/TEU) x (70% discretionary) x (365 days/year)

= \$2.8 million per year

M1: Long-term loss of revenue = \$0

Cost savings = \$2.8 million per year

Table B.2.6 Long-Term Loss of Revenue Associated with Each Mitigation Option

Mitigation Option	*Seismic Event*	*Gross Long-Term Loss of Revenue (\$ million/year)*	*Gross Annual Savings (\$ million/year)*	*Total Gross Savings(1) (\$ million)*	*Total Net Savings(2) (\$ million)*
M0	OLE	2.8	0	0	0
	CLE	2.8	0	0	0
M1	OLE	0	2.8	40.0	36.0
	CLE	2.8	0	0	0
M2	OLE	0	2.8	40.0	36.0
	CLE	2.8	0	0	0
M3	OLE	0	2.8	40.0	36.0
	CLE	2.8	0	0	0
M4	OLE	0	2.8	40.0	36.0
	CLE	0	2.8	0	36.0

Notes: (1) Present value of total stream of annual savings (indefinitely into the future); (2) Total gross savings (for long-term revenue loss) less savings for short-term revenue loss.

The fourth column of Table B.2.6 indicates savings in long-term revenue loss on an annual basis. In order to reflect revenue losses in future years, the fifth column of the table converts annual savings to total savings in present value terms. This is done by dividing the long-term loss of revenue by the discount rate, in this case, 7% (discussed below). Here, it is assumed that long-term revenue losses would never be recovered.

The final column of the table adjusts gross long-term savings to net savings by subtracting short-term revenue loss savings (Table B.2.5). This is to avoid double-counting.

B.2.4 STEP 4: VALUATE THE BENEFITS AND COSTS OF EACH OF THE PROPOSED MITIGATION OPTIONS

In general, benefits and costs in a social analysis consist of (1) consumer and producer surpluses through changes in prices; (2) changes in these surpluses through changes in amounts of unpriced goods (externality effects); and (3) changes in net government revenues. Since we adopt, for present purposes, the perspective of the port, the analysis may be simplified. We simply examine changes in the cash flows to the port deriving from implementing a particular mitigation measure and implementing no mitigation measure. Where they are positive, such as reductions in future losses, they are benefits; where negative, such as expenditures for mitigation, they are costs.

The cash flows associated with benefits and costs will occur over time. For example, benefits will occur sometime in the future after the mitigation costs are incurred. A comparison can be made by taking into account the time value of money as determined by the discount rate. This requires the choice of a discount rate and a treatment of how far in the future the benefits will be realized. (See Appendix A: Discount Rate). The relevant discount rate from the port's perspective is simply the rate the port itself uses for financial evaluation.

In this analysis, benefits are considered probabilistic for two reasons. First, the probability of a seismic event will determine the probability of there being benefits, and this will vary by the expected magnitude of the seismic event. Therefore, the benefits from mitigation will, in part, depend on the life span of the proposed facility. The greater the life span, the greater the probability of a seismic event and the greater the expected value of benefits. Second, even for a specific level of seismic event and a given level of mitigation, there will also be uncertainty associated with the magnitude of each benefit category, such as facility repair costs. For example, each future year will have some probabilistic benefit. This probabilistic benefit will itself be the mean of a probability distribution that depends on the distribution of repair costs. One approach is to discount the probabilistic benefits for each year. A simpler approach is to take the median value of the probability distribution and treat all benefits as occurring at that point with a cumulative probability representing the total probability of the event over the life of the facility.

The process described in Sections B.2.3 and B.2.4 can be illustrated and illuminated through use of a decision tree (Figure B.2.2). A decision tree shows decisions points (decision nodes) and probable consequences (probability nodes). For a given mitigation decision (M_i), there will be probabilities associated with various levels of seismic events (E_i). The probabilities sum to one, since "no earthquake" (E_0), is part of the probable outcomes. For each given level of mitigation (M_i) and magnitude of seismic event (E_i), there will be several probable levels of damage to facilities[54] (D_i). Again, these probabilities sum to one, since no damage (D_0) is a possibility. For each given level of damage (D_i), there will be repair costs (R_i). The repair costs themselves are also probabilistic, depending on the time value of money and expected unit cost. A Monte Carlo simulation procedure can be used to handle the required calculations.

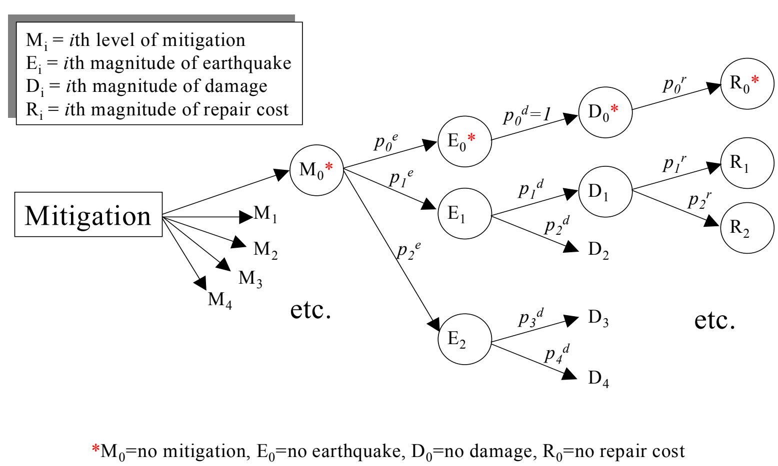

Figure B.2.2 Probabilistic Valuation Model

Example: Port Risky uses a 7% nominal discount rate, and assumes a 50-year facility life span, in order to value the benefits and costs of the seismic mitigation options being considered for Wharf X.

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[54]This analysis uses the damage state in order to assess the number of days needed to repair the facility (see Table B.2.3).

In order to calculate the present value of the benefits, the total amount of accrued savings needs to be calculated. This simple procedure is accomplished by adding together the cost savings (Tables B.2.3-B.2.36) for each mitigation option for each seismic event. For example, for mitigation M1, in the event of an OLE, the total cost saving is the sum of the cost savings for repair cost (Table B.2.3), cost of response (Table 4), short-term revenue loss (Table B.2.5) and long term revenue loss (Table B.2.6). Therefore, the total savings accrued in the OLE event as a result of implementing M1 is \$47.75 million, which is equal to \$4.1 million (repair savings) plus \$3.65 million (cost of response savings) plus \$4.0 million (short-term revenue loss savings) plus \$36.0 million (net long-term loss of revenue savings). This assumes that lost business will never return or be replaced. If it is determined that business will return or be replaced within a specified time period, this calculation can be easily modified. Total benefits are shown in the third column of Table B.2.7 below.

Table B.2.7 Calculation of Expected Value of Benefits of Each Mitigation Option

Mitigation Option	*Seismic Event*	*Total Benefits ($ million)*	*Probability of Event*[(1)]	*Expected Value of Benefits ($)*
M0	OLE	0	.01173	0
	CLE	0	.00217	0
M1	OLE	47.75	.01173	559,000
	CLE	2.81	.00217	6,000
M2	OLE	47.75	.01173	559,000
	CLE	3.75	.00217	8,000
M3	OLE	47.75	.01173	559,000
	CLE	7.46	.00217	16,000
M4	OLE	47.75	.01173	559,000
	CLE	50.25	.00217	111,000

Note: (1) Probability of exceedance. In the case of the OLE, this is net of the probability of exceedance for the CLE.

In Table B.2.7, total benefits are converted to expected values by multiplying by the respective probabilities of exceedance for the event. As shown in Table B.2.1 above, the annual probability of exceedance for the CLE (0.40g) is 0.00217. For the OLE (0.15g), the Table 1 probability is 0.01390. The CLE probability is subtracted from this value to yield a net exceedance probability for the OLE for use in Table B.2.7 (0.01173 = 0.01390 – 0.00217). This is done to avoid double-counting.

The next step involves calculating the present value of the expected benefits. This is done dividing the expected value of the benefits by $(1+r)^n$, where r is the discount rate and n is the year in which the benefit is realized. As was discussed above, the discount rate is .07. The calculation is carried out over the entire life span of the proposed facility, in this case 50 years. For example, for the M1 event:

Table B.2.8 Calculation of Present Value for the M1 Mitigation Option

Year (n)	*Expected Value OLE ($)*	*Expected Value CLE ($)*	*$(1+r)^n$*	*Present Value OLE ($)*	*Present Value CLE ($)*	*Sum PV ($)*
1	559,000	6,000	1.07	522,430	5,607	528,037
2	559,000	6,000	1.14	488,252	5,241	493,493
3	559,000	6,000	1.23	456,311	4,898	461,208
4	559,000	6,000	1.31	426,458	4,577	431,036
5	559,000	6,000	1.40	398,559	4,278	402,837
6 **..........**	…	…	…	…	…	…
.... 50	…	…	…	…	…	…
Sum PV Year 1-50						7,797,422
Costs						- 400,000
NPV						7,397,422

The present value of the benefits associated with each event, OLE and CLE, is summed in order to obtain the present value of the benefits for each year.

B.2.5 STEP 5: CHOOSE BETWEEN ALTERNATIVE MITIGATION OPTIONS

Several different criteria are used in financial evaluation. These include (1) net-present value, (2) benefit-cost ratios, (3) internal rates of return, and (4) pay-back periods. Our treatment will proceed in terms of net present value (NPV) and the internal rate of return (IRR). The NPV is most widely used in academic analysis and the IRR is commonly used in the private sector. Due to deficiencies in the IRR, occasionally it produces an incorrect result, which is different from the result obtained from the NPV.

<u>Example:</u> The net present value is calculated by summing the present value of the benefits for each year of the life of the facility and then subtracting out the cost of the mitigation (see Table B.2.8 above). Performing this calculation for each of the mitigation options produces the following distribution of NPVs:

Table B.2.9 Distribution of NPVs for Each Mitigation Option

Mitigation Option	*NPV ($ million)*	*Meets Performance Criterion 1?*	*Meets Performance Criterion 2?*
M0	0	No	No
M1	7.4	**Yes**	No
M2	5.7	**Yes**	No
M3	5.8	**Yes**	**Yes**
M4	2.7	**Yes**	**Yes**

The option that maximizes the net present value is M1. If the port's objective is to select the most cost-effective option, it would choose M1. However, as indicated in Table B.2.9, while option M1 meets Performance Criterion 1 (Section B.2.2.2 above), it does not meet Performance Criterion 2. The mitigation option that maximizes net present value while meeting both performance criteria is option M3.

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