Program Plan

PLANNING OF UNIFIED LIFELINE RISK/RELIABILITY PLATFORM FOR SEISMIC RISK DECISION MAKING

by

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Prepared under Research Project entitled

Scoping Study for Unified Lifeline Risk/Reliability Models for Seismic Risk Decision Making (Subagreement SA3072JB with Regents of UC-Berkeley)

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FOREWARD

A program plan has been formulated for a future two-year PEER research program for initial development and demonstration of a modular, technically sound, and practical unified risk/reliability platform to: (a) evaluate seismic risks to as-built lifeline systems with no seismic improvements; (b) evaluate seismic risks to modified lifeline systems with physical and/or operational seismic improvements now included; and (c) provide results from the evaluations that can guide decision makers as they assess and then select seismic improvement strategies that limit risks to their system to acceptable levels. This future project will focus on the need for unification and commonalties of modeling methods for electric power and highway transportation systems. During future PEER research, this can be extended to other lifelines as well.

This is one of two companion reports submitted as an end product of this program-planning project. It describes the plan for this two-year research program. The companion report describes the process used to develop the plan.

The plan contained in this report describes the major goals and features of this research program, the common platform or methodology for unified lifeline risk/reliability modeling that will be the basis for the program, and the six projects that will be carried out during the two-year program. Project 1 will develop two separate but parallel software platforms -- one for electric power systems and the other for highway transportation systems. It will also apply the platforms in a demonstration analysis that will illustrate their applicability and the types of results they will provide. Projects 2 through 5 will establish the seismic hazard models, electric power component and system models, highway transportation component and system models, and decision guidance models that will be integrated into the two platforms.. Project 6 will synthesize research needs identified during this two-year research program into recommendations and priorities for further development of the two platforms and their integration into a single platform during future PEER research.

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The investigators for this project acknowledge Dr. Clifford Roblee of the California Department of Transportation (Caltrans) and Dr. William (Woody) Savage of the United States Geological Survey (and formerly with the Pacific Gas & Electric Company) who, as members of the PEER Lifelines Joint Management Committee and as monitors for this project, provided helpful guidance and encouragement throughout this research. The investigators also acknowledge the many representatives of electric power utilities and Caltrans and the consulting engineers and academics who were interviewed during this research, as well as the many participants of the various PEER coordination meetings attended by the project investigators. The information provided by these individuals and meetings was instrumental in the evolution of the program plan developed during the course of this project.

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1 INTRODUCTION

1.1 BACKGROUND

This program plan has been prepared under PEER Project 601 entitled "Scoping Study Unified Lifeline Risk/Reliability Models for Seismic Risk Decision Making.." It is a companion to a second report that summarizes the procedures used to develop the plan. This work was carried out by a Project Team consisting of Stuart Werner (highway transportation systems), Dennis Ostrom (electric power systems), and Craig Taylor (risk analysis). Project monitors for this work were Clifford Roblee and William (Woody) Savage of the PEER Joint Management Committee (JMC). The project was initiated in December 2000.

This current project has formulated a plan for a two-year PEER research program that will carry out initial development and demonstration of a technically sound and practical unified risk/reliability platform to: (a) evaluate seismic risks to as-built lifeline systems with no seismic improvements; (b) evaluate seismic risks to modified lifeline systems with physical and/or operational seismic improvements now included; and (c) provide results from the evaluations that will guide decision makers as they assess and then select seismic improvement strategies that limit risks to their system to acceptable levels. This research program will focus on the need for unification and commonalties of modeling procedures for electric power and highway transportation systems, and eventually for other lifelines as well.

1.2 PLAN ORGANIZATION

The remainder of this plan is organized into three chapters and one appendix. Chapter 2 discusses major goals and features of the program. Next, Chapter 3 summarizes the common platform or methodology for a unified lifeline risk/reliability model that is to be developed during the remaining years of this research program. This common platform provides the major steps envisaged, but does not include detailed subtasks nor does it purport to cover the temporal order of decision-making (which can vary considerably within and among lifeline organizations). At this time, the platform focuses on two lifelines -- electric power and highway transportation. However, the platform will be developed as modular software that can be readily extended to also include other lifelines in the future.

Chapter 4 provides the objectives and scope of the overall two-year research program, and also summarizes the scope and budget allocations for each of the six projects that will comprise this research. Appendix A provides more detailed information on these six projects, including their objective, scope, staffing requirements, and task descriptions.

2 PLAN OVERVIEW

2.1 OBJECTIVE

This program will carry out initial development and demonstration of a modular, technically sound, and practical unified risk/reliability modeling platform that will: (a) evaluate seismic risks to as-built lifeline systems with no seismic improvements; (b) evaluate seismic risks to modified lifeline systems with physical and/or operational seismic improvements included (planned or actual); and (c) provide results from the evaluations that can guide decision makers as they assess and then select seismic improvement programs and initiatives that limit risks to their system to acceptable levels. The program will address the need for unification and commonalities of modeling procedures for electric power and highway transportation systems, and eventually for other lifelines as well.

2.2 SCOPE: RESEARCH PLAN

This research program will have a duration of two years.. During this time, an initial version of this platform will be developed as two separate but parallel software packages that model system and component details for electric power and highway transportation systems that are either under development elsewhere or are used in current practice. These packages will be improved through close interaction between the various developers, and through inclusion of the latest existing models and procedures from current practice and from relevant PEER research results. They will then be used together in a demonstration application to an actual highway transportation system and electric power system in California[1]. This application will illustrate (a) the commonality of the risk analysis process for these two lifeline systems; (b) interactions between the seismic performance of these systems; and (c) the types of results that can be obtained. The application will also serve to identify additional development needs that can be addressed during future PEER research efforts.

[1] Because of security concerns, it may be necessary to use a hypothetical rather than an actual electric power system in this demonstration application.

2.3 FEATURES

In accordance with the above project objective and research plan, this platform will:

- Build on existing research and practice for evaluating seismic risk to electric power and highway/roadway systems.
- Focus on system performance rather than merely component performance.
- Be developed not as a decision making tool, but instead as a decision-guidance tool that provides useful information for decision-makers.
- Accommodate a wide range of decision-making approaches and contexts.
- Be initially developed as separate but parallel software packages for electric power and highway transportation systems within the two-year time frame for this research program.
- Be provided in a form to facilitate its further development into a more sophisticated platform during future PEER research.
- Be applied in a demonstration application to an actual electric power and highway transportation system in California.

The following discussion elucidates each of the above features envisioned for this unified lifeline system risk/reliability modeling platform.

2.3.1 Building on Existing Research and Practice

Of special interest are seismic risk analysis models that are already developed and that (a) have been used in actual decision-making for seismic improvement of actual electric power and transportation lifelines; (b) have been developed over many years to specifically provide results that can facilitate and guide risk reduction decision-making; and (c) may be adapted to other lifelines in the future.

Over this two-year research program, it is also of paramount concern that products of PEER and other pertinent investigations be incorporated into the proposed unified lifeline system risk/reliability modeling platform. Typically, pertinent PEER investigations will serve as component elements or components in the overall platform. For instance, results of PEER investigations into directivity effects of strong ground motions can be incorporated into strong ground motion attenuation functions used. For another instance, results of PEER and other ongoing investigations of the seismic performance of retrofitted highway bridge structures can be incorporated into bridge structure vulnerability models, and can further be used to illustrate how the unified platform can provide valuable information for assistance in decision-making.

2.3.2 Focus on System Performance

Following practices for building structures, many lifeline projects and attempts to construct seismic guidelines, standards, and codes for lifelines have focused on individual components and sites. This focus has provided models and results that, by themselves, have been insufficient for guiding lifeline decision makers in their selection of appropriate seismic risk reduction strategies. This is because: (a) a primary focus of lifeline operators is to assure acceptable performance of their overall system after an earthquake, rather than individual components; and (b) an earthquake can affect the entire spatially distributed lifeline system, and not merely individual components at individual sites. Therefore, the lifeline risk evaluation platform to be developed under this PEER research program will focus on system performance, in accordance with the way in which many lifeline system operators have actually made decisions that have led to seismic improvement programs.

This need to focus on system performance, in turn, implies that many previous products and much ongoing research may need to be adapted in order to fit into this unified lifeline system risk/reliability modeling platform. Furthermore, the fact that research has been performed or is being performed on a specific seismic hazard or component performance issue does not necessarily imply that such research can be readily adapted into this proposed lifeline system platform.. For instance, incorporation of directivity effects of strong ground motions requires adjustments of how earthquake scenarios (defined by fault rupture locations and magnitudes) are characterized and strongly suggests the need to characterize the orientation of key structures relative to possible incoming seismic waves. Therefore, during this project, it will be particularly important to assess the applicability of lifeline research projects completed and underway to this platform.

2.3.3 Development as Decision-Guidance (and not Decision-Making) Tool

This unified risk/reliability modeling platform will be a scientific/engineering tool that will not purport to provide final decisions for selecting seismic improvement strategies. This is because the quantitative results provided by this tool should be regarded as estimates, with uncertainties, that comprise only part of the information needed for seismic improvement decision making. Lifeline system risk-reduction decisions will often depend on other issues that cannot be quantified, such as legal, political, administrative, and social issues. Therefore, such decisions, including those related to seismic improvement, are best placed in the hands of those lifeline owners, operators, and stakeholders who have the perspective and responsibility for considering all of these aspects of the decision-making process. Results from scientific/engineering tools such as this proposed lifeline system risk/reliability modeling platform can help to guide but not actually make these decisions.

2.3.4 Accommodation of Wide Range of Decision-Making Approaches and Contexts

This unified risk/reliability model must not implicitly bias the decision, or provide only a limited range of results that can also bias the decision. For this reason, and building on existing platforms, a flexible and comprehensive unified risk/reliability tool will be developed that can accommodate a wide range of decision-making approaches and contexts. At a minimum, this tool will:

- Enable users to evaluate the system performance "as is" (with no seismic improvement) and for each seismic decision alternative identified by the user.
- Provide users with the ability to assess diverse decision alternatives, by comparing the resulting costs and risks for each alternative with those for the "as is" system.
- Enable decision-makers to establish system performance criteria that represents levels of residual seismic risk (in terms of repair costs, loss of service to customers, or other measures important to the decision-maker) that the user determines to be acceptable.
- Permit decision-makers to employ investment decision criteria[2] for multiple scenario earthquakes and simulations.
- Accommodate both deterministic and probabilistic methods. To distinguish between deterministic analysis and (probabilistic) risk analysis, the following definitions are adopted

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[2] As one approach for applying investment decision criteria, the mean value and the variance of the total life cycle cost for each seismic decision alternative are computed from the costs estimated for all of the earthquakes and simulations. The total life-cycle (TLC) cost is the sum of the cost to implement the decision alternative plus the present value of the losses due to earthquake damage to the system. Then, each seismic decision alternative is evaluated by considering that: (a) the mean value of its TLC cost is a measure of the "financial yield" of an investment in that decision alternative; and (b) the variance of its TLC cost is a measure of the "volatility" of that investment. The mean values and variances of the total life-cycle cost for each decision alternative are then compared, from the perspective of a prudent investor who would consider the potential volatility as well as the potential financial yield of a given investment, when deciding whether to proceed with that investment.

here: (a) deterministic analysis methods are defined as those methods that employ user-specified earthquake scenarios, in which scenarios are initiating events defined by fault rupture location and earthquake magnitude; and (b) risk (probabilistic) analysis methods are defined as those methods that employ a random distribution of earthquake scenarios. Both types of analysis methods can include uncertainties in estimation of seismic hazards, component performance, and/or system performance.

Through this flexibility and comprehensiveness of the general approach, users will not be limited to information that confines and potentially biases their decisions.

2.3.5 Rapid Knowledge Transfer over Two-Year Time Period

A basic version of the unified lifeline risk/reliability model platform will be transferred to users over a two-year period, as two separate but parallel software packages that will be developed for electric power and highway transportation systems. The development of these two packages will follow parallel and linked paths. It will also require close coordination with users, which will benefit both users and model platform developers in the following ways: (a) it will familiarize users with the modeling platform as soon as possible; and (b) it will enable platform developers to obtain user feedback for improving the models and software to better meet user decision-making needs.

2.3.6 Development into More Refined Platform during Future PEER Research

After completing basic process for electric power and highway transportation systems during this two-year project, recommendations and priorities for further developing the platform during future research will be provided. These recommendations will address efforts for incorporating new knowledge and research findings from PEER and elsewhere, as well as additional steps to improve the initial platform developed during this two-year time frame.

2.3.7 Demonstration Application of Modeling Platform

As part of the development of the basic modeling platform, it will be used in a demonstration application to an actual highway transportation system and an actual or hypothetical electric power system in California. This analysis will: (a) demonstrate the adaptation of existing platforms and models to make them workable for real-life application; (b) demonstrate the types of results that can be obtained for each system; (c) demonstrate commonalities in the overall modeling process as applied to electric power and highway transportation systems; (d) illustrate interactions between the performance and functionality of these systems during and after an earthquake; (e) facilitate interaction between developers and users, who will have a key role in implementing this analysis; and (f) identify how new or ongoing PEER research may be undertaken or continued to improve the platform.

3 OVERVIEW OF RISK/RELIABILITY MODELING PLATFORM

This section outlines how this unified seismic risk/reliability modeling platform fits into an overall decision framework. This discussion does not purport to mirror actual decision processes, or the temporal order in which decisions are made. Nor does it purport to define the questions asked in a specific decision context. Instead, it addresses basic and logical elements of a decision framework. Next, we define the overall unified seismic risk/reliability modeling platform. Again, logical elements of this unified platform are of interest rather than the specific temporal order in which technical steps are undertaken. In an effective process, both technical developers and technical users typically make queries about results, and technical details and these queries should lead to revised models and/or diverse results produced. This iterative process involves close interaction between developers and users, and is essential to quality assurance of models and results.

3.1 ROLE OF PLATFORM IN SUPPORTING DECISION MAKING

Figure 1 shows one way to look at the role of the unified risk/reliability modeling platform in supporting seismic risk decision-making. The steps of this process that are shown in Figure 1 do not necessarily mirror actual temporal orders; rather, they are intended to define the role of unified risk/reliability methods in complex multi-objective decision-making processes. These steps are summarized below.

3.1.1 Step 1. Decision Issues to be Addressed

In Step 1, the decision-maker identifies those issues or questions to be addressed by the unified risk/reliability modeling platform. As a minimum, we have defined these issues or questions as addressing status-quo system performance (before any seismic improvement is implemented). In this step, the decision-maker may also wish to compare the performance of diverse decision alternatives, or may wish to use various investment decision criteria to evaluate the performance of the status-quo system and/or any conceivable alternatives (financial, emergency response and recovery, engineering). The risk/reliability modeling platform to be developed under this project will be amenable to a wide variety of diverse issues that decision-makers may wish to address.

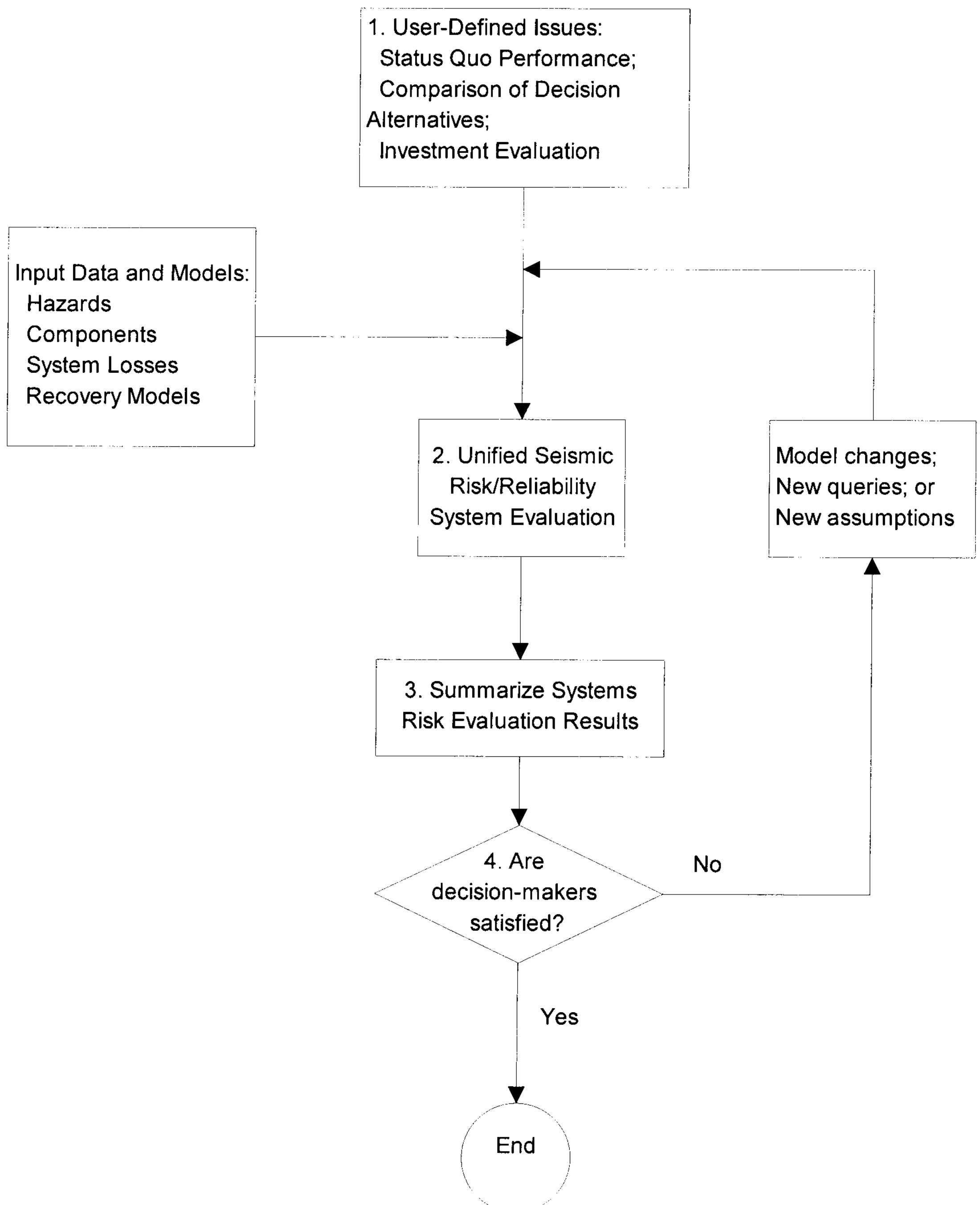

Figure 1. Role of Unified Seismic Risk/Reliability Evaluation in Seismic Risk Decision-Making for Lifelines.

3.1.2 Step 2. Application of Unified Risk/Reliability Modeling Platform

Step 2 consists of the actual application of the unified seismic risk/reliability methodology for lifelines, in order to evaluate the various seismic decision alternatives identified in Step 1 and to also address the other issues raised by the decision-maker in that step. As summarized in Section 3.2, this application of the modeling platform will require appropriate input data and models for hazards, components, and the system, and will lead to various types of loss estimates in a form that meets user needs.

3.1.3 Step 3. Summary of Results

Under Step 3, results from each evaluation of seismic decision alternatives and other issues during Step 2 are summarized.

3.1.4 Step 4. Evaluation of Results by Decision Makers.

Under Step 4, the decision makers evaluate the analysis results so far. Then, they decide whether they are satisfied with the analysis as it stands or, alternatively, whether they wish to carry out new analyses. These additional analyses may result from the perceived need to modify the models used and/or from new queries that have arisen in connection with the results of the prior analyses. If a new analysis or re-analysis is desired, then the unified risk/reliability model will again be applied to address the issues at hand.

3.2 TECHNICAL STEPS IN PLATFORM

Figure 2 shows the basic steps in a unified seismic risk/reliability modeling platform for lifeline systems. These steps are summarized below.

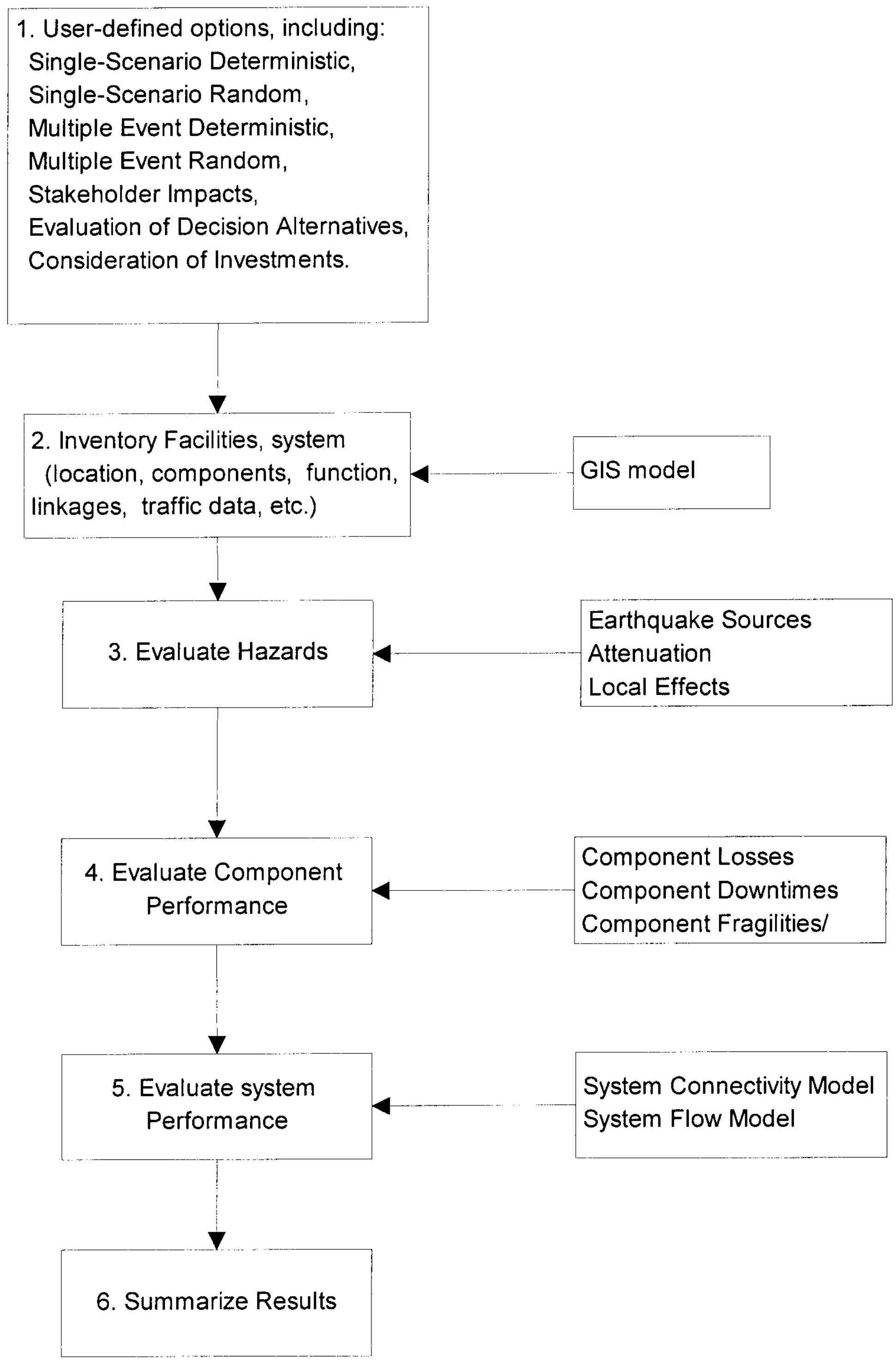

Figure 2. Basic Common Steps in a Seismic Risk/Reliability Evaluation for Lifeline Networks.

3.2.1 Step 1. Initialization

Step 1 enables the user to define the type of evaluation to be made. As a minimum, the user may opt to carry out a single-scenario evaluation. This single-scenario evaluation may be performed deterministically (with median or best estimates) or randomly. One random simulation may suffice, or a set of random simulations may be requested. Alternatively, the user will have the option of using a representative suite of earthquake scenarios. These also may be evaluated deterministically or randomly. In addition, the user must define whether to consider decision alternatives and/or initial prospective investments. This unified seismic risk/reliability platform will include a number of options to be selected by the decision-maker and user.

3.2.2 Step 2. Inventory of Facilities

Step 2 will develop an inventory of the lifeline system to be evaluated, including the components within the system that will impact its seismic vulnerability. This inventory should include the specification of the system's nodes (e.g., bridges, roadway intersections, and substations) and linkages (e.g., roads and transmission lines.) Relevant system information should include the network configuration, service demands and capacities, redundancies, locations of water crossings and co-locations with other lifeline systems, and examples of past major system downtimes including causes and responses. Pertinent information to be provided for the component at each node should include its location within the system, function, functional connectivity to other components, configuration, physical characteristics, site soil conditions, current condition, and past causes of significant downtimes that may have occurred (particularly during past earthquakes.) Depending on user needs and the availability of these data, this may entail a considerable effort. For instance, users evaluating a highway/roadway system may desire considerable traffic data along with data on the physical condition and design of existing bridge structures and other key components.

3.2.3 Step 3. Evaluate Seismic Hazards

Under Step 3, existing models of earthquake sources are used to define individual or multiple scenario earthquake events to be considered in the system evaluation. Then, the seismic hazards at the site of each component in the system are evaluated for each earthquake scenario and simulation. This is accomplished by adapting existing models of ground motion hazards, surface fault rupture hazards, liquefaction, and landslide into a systems model that can potentially cover a number of random effects[3]. Adaptation of models developed through ongoing PEER investigations of seismic hazards will be a central feature of this multi-year PEER program.

3.2.4 Step 4. Evaluate Component Performance

Step 4 evaluates the seismic performance of each component due to the hazards identified in Step 3 for each earthquake. This requires: (a) estimation of the component's damage state (extents, types, and locations of earthquake damage) due to these hazards; and (b) for that damage state, estimation of the costs and duration of the repair or replacement of the component and the functionality (downtime) of the component during repair. For some purposes, component loss models are desirable. For systems evaluation purposes, models of component downtimes and/or fragilities are needed. The development of component vulnerabilities and/or fragilities will be a central feature of this multi-year PEER program.

3.2.5 Step 5. Evaluate System Performance

Under Step 5, each component's loss of functionality and downtime for each earthquake, as estimated under Step 4, are included into a system model for evaluating the ability of the system to perform its intended function after the earthquake. At a minimum, this includes an evaluation of

[3] Site-specific soils data needed as input to data-intensive hazard models are often not available at sites of the large number of components that comprise spatially distributed lifeline systems. For this reason, simplified hazard models that can accommodate input data from readily available sources (e.g., soil maps and geologic maps) are typically used at most component sites within the system. If course, detailed hazard models can be used selectively at sites of critical components within the system, in conjunction with site-specific field exploration and/or laboratory test programs to develop the required input data for these models.

system connectivity -- whether or not sources are connected to distribution points through some linkages or pathways. For transportation system evaluations, "traffic flow" models can be quantified in the context of this unified risk/reliability platform. Results from such models can be used to estimate post-earthquake traffic flows and travel times at specific times (on the order of days, weeks, and months) after the earthquake. From this, first order estimates of economic losses due to repair costs and increases in commute time can also be readily estimated[4].

For electric power systems, it may not be feasible to incorporate standard load/flow models in the context of this unified risk/reliability model. In place of such load/flow models, simple performance algorithms can be developed that are based on pre-determined power flow configurations that represent most likely conditions and acceptable performance. Return-to-service models can be incorporated into the evaluation at this time, to allow the user to gain a perspective on the impact of the seismic event on system function. For example, these models can be used to determine the time line for function restoration, the resources needed to affect the function restoration time line, and dollars lost (e.g., due to repair costs, loss of service, loss of revenue, etc.[4]).

3.2.6 Step 6. Summary of Results

Under this final step, the results from the previous step are summarized and displayed in order to communicate important technical results to decision-makers. The development of such information that addresses the variety of decision making queries, issues, and contexts that can arise for lifelines systems will be one of the main focuses of this multi-year PEER program.

[4] Because such economic loss estimates do not include the effects of earthquake damage to the region's economic activity system, they provide only a limited picture of the difference between pre- and post-earthquake economic activity. Procedures have been developed to estimate effects of earthquake damage to a regional economic activity system. However, input data requirements for such procedures are formidable. Simplification of these procedures to reduce their input data needs so they are practical for incorporation into a lifeline risk/reliability platform is a worthwhile and recommended research effort.

4. PROGRAM PLAN PROJECTS

4.1 OBJECTIVE

This plan identifies projects to be carried out during this two-year research program to enable the program to meet the objectives listed in Section 2.1. These projects will use existing information to:

1. Identify two existing seismic risk/reliability analysis software packages -- one for electric power systems and one for highway transportation systems -- that are either under development or are now used in current practice, and use these packages as the initial basis for building the software platforms for these lifeline systems under this two-year project. .
2. Identify and incorporate appropriate additional features pertaining to program architecture, user interfaces, and input-output features into these software platforms.
3. Compile the latest available geoscience, earthquake engineering, risk analysis, and decision guidance technology, and incorporate it into these software platforms.
4. Use these platforms to carry out a demonstration analysis of an electric power and highway transportation systems in a common region, in order to illustrate their applicability and the types of results that they can provide.
5. Identify research needs associated with merging these two platforms into a common platform and with further developing their technology, and document these needs into a program plan that can be carried out through future PEER research.

This work will feature close interaction and transfer of knowledge with a utility power agency and a highway transportation agency -- Pacific Gas & Electric Company (PG&E) and California Department of Transportation (Caltrans) -- to assure that the platforms being developed will meet the needs of future users. Close interaction with leading consulting engineers and PEER academics will also be featured, to assure that the latest technology from current practice and recent research is being utilized.

4.2 PROGRAM SCOPE AND BUDGET ALLOCATIONS

Table 1 lists the six projects that will be carried out during this two-year program, together with the tasks that comprise each project. All projects listed in Table 1 are viewed as being equally essential for accomplishing the stated objectives.

Table 1
Projects for Two-Year Lifelines Risk/Reliability Platform Development Program

Project (1)	Tasks (2)	Possible Partnering Opportunities (3-6)
1. Lifelines Platform Development and Application (35%)	1.1 Software Development Planning (10%) 1.2 Software Platform for Risk Analysis of Electric Power Systems (20%) 1.3 Software Platform for Risk Analysis of Highway Transportation Systems (20%) 1.4 Integration of Hazards, Electric Power, Highway Transportation, and Decision Guidance Models into Platforms from Tasks 1.2 and 1.3 (10%) 1.5 Metrics and Display Strategies (5%) 1.6 Interaction between Electric Power and Highway Transportation System Performance (5%) 1.7 Demonstration Application (30%)	PG&E, CRIEPI PG&E, CRIEPI MCEER
2. Seismic Hazard Models for Lifelines Platform (5%)	2.1 Scenario Earthquake Modeling (20%) 2.2 Ground Motion Modeling (20%) 2.3 Liquefaction Hazard Modeling (20%) 2.4 Landslide Hazard Modeling (20%) 2.5 Surface Fault Rupture Hazard Modeling (20%)	Caltrans, PG&E Caltrans, PG&E MCEER Caltrans
3. Electric Power Component and System Models for Lifelines Platform (20%)	3.1 Input Database Needs and Development (10%) (7) 3.2 Component Failure Modes (10%) 3.3 Component Performance Algorithms (20%) 3.4 Component Slack Algorithms (20%) 3.5 Substation Damage Characterization (5%) 3.6 Component Repair/Functionality Models 10%) 3.7 System Analysis Procedures (25%)	PG&E PG&E PG&E[3]
4. Highway Transportation Component and System Models for Lifelines Platform (20%)	4.1 Input Database Needs and Development (10%) (7) 4.2 Highway Bridge Damage Characterization (5%) 4.3 Bridge Repair/Functionality Models (20%) 4.4 Retrofitted Bridge Models (20%) 4.5 Non-Bridge Highway Component Models (15%) 4.6 Models of Highway Components subjected to Permanent Ground Displacement (20%) 4.7 System Analysis Procedures (10%)	Caltrans, MCEER MCEER Caltrans, MCEER MCEER MCEER Caltrans, MCEER MCEER
5. Decision Procedures Module for Lifelines Platform (15%)	5.1 Identification of Alternative Decision Procedures (25%) 5.2 Documentation of Procedures for Incorporation into Platform (75%)	MCEER, PG&E MCEER, PG&E
6. Recommendations for Future Research (5%)	6.1 Synthesis of Research Needs from Projects 1 through 5 (33%) 6.2 Research Recommendations and Priorities (67%)	

Note: Above subscripts in each column of above table have following definitions:

(1) Percentage of Total Program Budget for Years 1 and 2 to be Allocated to Each Project (Total for all Projects = 100%).

(2) Percentage of Total Project Budget for Years 1 and 2 to be Allocated to Each Task (Total for all Tasks of Each Project = 100%).

(3) PG&E = Pacific Gas & Electric Company.

(4) CRIEPI = Central Research Institute for Electric Power Industry.

(5) MCEER = Multidisciplinary Center for Earthquake Engineering Research.

(6) Caltrans = California Department of Transportation.

(7) At the discretion of PEER, input database Subtasks 3.1 and 4.1 (as well as other subtasks in this table) may be grouped together into common projects during this two-year program.

Table 1 also includes guidelines for allocation of budget resources to each project and each task, in order to lead to an appropriately balanced effort. These guidelines are provided in the following form: (a) the number in parentheses that is shown for each project in the first column of Table 1 is the suggested percentage of the total two-year program budget that should be allocated to that project; and (b) the number in parentheses that is shown for each task of each project in the second column of Table 1 is the suggested percentage of the total project budget that should be allocated to that task.

Finally, other research centers, electric power utilities, and highway transportation departments are now either actively involved in parallel research, or are sponsoring closely-related engineering development projects. These agencies are PG&E, the Central Research Institute for the Electric Power Industry (CRIEPI), the Multidisciplinary Center for Earthquake Engineering Research (MCEER), and Caltrans. Because they could conceivably be interested in sharing of knowledge and/or funding resources with PEER, these agencies are listed in Table 1 as representing possible partnering opportunities.

We estimate that a total budget on the order of $250,000 will be needed to implement Projects 1 through 6 in accordance with Objectives 1 through 5 of Section 4.1. However, to meet this budget limit, it is essential that arrangements be made among the above possible partnering agencies to work together in sharing relevant research results, research products, and costs for further development of these products. Without such resource sharing, PEER costs to implement the scope of work described in this program plan will be substantially larger than $250,000. This budget also assumes that Caltrans and PG&E will provide in-kind support in the form of: (a) providing component and system input data for the demonstration application; and (b) having knowledgeable staff available and accessible to guide repair cost and functionality modeling, to answer questions regarding decision guidance needs, and to answer other questions on Caltrans and PG&E practices that may arise.

4.3 PROJECT SUMMARIES

The six projects listed in Table 1 are briefly summarized below. Appendix A of this Plan provides more detailed descriptions of each project.

4.3.1 Project 1. Lifelines Platform Development and Application

Project 1 will develop and apply a beta version of two separate risk/reliability platforms -- one for electric power systems and the second for highway transportation systems -- that can eventually be merged into a common platform during future PEER research. These two platforms will be based on existing software packages that are either under development elsewhere or are now used in current practice. This project will include all planning, programming, integration of models from Projects 2 through 5, quality assurance, demonstration application, and documentation activities needed to develop beta software that meets Objectives 1, 2, 4, and 5 listed in Section 4.1. Section A.3 of Appendix A provides further details on this project.

4.3.2 Project 2. Seismic Hazard Models for Lifelines Platform

Project 2 will identify existing earthquake occurrence and seismic hazard models from current practice and/or recently completed research at PEER and elsewhere that will be integrated into the electric power and highway system risk/reliability platforms under Project 1. These existing models will estimate scenario earthquake magnitudes, locations, and frequencies of occurrence, as well as ground motion liquefaction, landslide, and surface fault rupture hazards. Project 2 (together with Projects 3 through 5) will meet Objective 3 from Section 4.1. Section A.4 of Appendix A provides further details on this project.

4.3.3 Project 3. Electric Power Component and System Models for Lifelines Platform

Project 3 will: (a) identify input database needs for implementation of the electric power system risk/reliability platform developed under Project 1; (b) identify existing procedures from current practice and/or recently completed research for modeling of electric power components and systems; (c) select preferred models to be incorporated into the electric power risk/reliability platform; and (d) document and flowchart these models in sufficient detail to facilitate their integration into the electric-power platform under Project 1. These models will address component failure modes, performance algorithms, and slack algorithms, substation damage characterization, component repair and functionality estimation, and system analysis procedures. Existing models from current practice and/or from past and current research will be incorporated where available and feasible; otherwise simple algorithms or procedures will be proposed. Project 3 (together with Projects 2, 4, and 5) will meet Objective 3 from Section 4.1. Section A.5 of Appendix A provides further details on Project 3.

4.3.4 Project 4. Highway Transportation Component and System Modeling for Lifelines

Project 4 will: (a) identify input database needs for implementation of the highway transportation system risk/reliability platform developed under Project 1; (b) identify existing procedures from current practice and/or recently completed research for modeling of highway transportation components and systems; (c) select preferred models to be incorporated into the highway system risk/reliability platform; and (d) document and flowchart these models in sufficient detail to facilitate their integration into the highway system platform under Project 1. These models will address bridge damage characterization, bridge repair and functionality estimation, retrofitted bridges, non-bridge highway components (tunnels, walls, pavements, embankments, and conduits), effects of permanent ground displacement on the seismic performance of highway components, and highway-roadway network analysis. Existing models from current practice and/or from past and current research will be incorporated where available and feasible; otherwise, simple algorithms or procedures will be proposed. Project 4 (together with Projects 2, 3, and 5) will meet Objective 3 from Section 4.1. Section A.6 of Appendix A provides further details on Project 4.

4.3.5 Project 5. Decision Procedures Module for Lifelines Platform

Project 5 will identify existing procedures from current practice and/or recently completed research that can be used to guide seismic risk reduction decision making for electric power and highway transportation systems. The procedures will consist of existing algorithms from decision theory that can be applied to lifeline risk/reliability analysis results for various seismic risk reduction options under consideration, in order to develop and display relative cost and risk information for each option that can facilitate informed decision making. The existing procedures will include a range of deterministic[5] decision methods (e.g., dominance, mini-max, and maxi-min, all of which employ only a few scenarios or system states) and probabilistic[5] reliability and financial evaluation methods (e.g., benefit-cost, least cost, mean-variance, and stochastic dominance) that can be selected for use by decision makers, based on their preferences and needs. No new research will be performed under

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[5] See Section 2.3.4 for the definition of deterministic and probabilistic methods used in this plan.

Project 5. Project 5 (together with Projects 2 through 4) will meet Objective 3 from Section 4.1. Section A.7 of Appendix A provides further details on Project 5.

4.3.6 Project 6. Recommendations for Future Research

Project 6 will prioritize research needs that were identified during this two-year research program,, and will synthesize the higher priority needs into research recommendations and priorities for further developing this unified lifeline risk/reliability platform during future PEER research. Project 6 satisfies Objective 5 from Section 4.1. Section A.8 of Appendix A provides further details on Project 6.

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APPENDIX A: DETAILED PROJECT DESCRIPTIONS

A.1 OBJECTIVE

Chapter 4 of this plan has summarized the following six projects that will be carried out during this two-year research program:

- Project 1: Lifeline Platform Development and Application
- Project 2: Seismic Hazards Models for Lifelines Platform
- Project 3: Electric Power Component and System Models for Lifelines Platform
- Project 4: Highway Transportation Component and System Models for Lifelines Platform
- Project 5: Decision Procedures Module for Lifelines Platform
- Project 6: Recommendations for Future Research

This appendix describes how these projects will be coordinated and staffed, and provides more detailed descriptions of these projects and their various tasks (as listed in Table 4-1 of Chapter 4).

A.2 PROJECT COORDINATION AND STAFFING

The above projects will be staffed by a program manager, one or more principal investigators for each project, and a technical support staff for each project.

A.2.1 Program Manager

This two-year program of projects will be managed by a senior person from consulting practice or PEER with broad technical expertise in all of the technical area encompassed by these projects, and also with experience in management and coordination of multidisciplinary technical programs and software development projects. This Program Manager will report directly to the PEER Lifelines Program Joint Management Committee, and will be responsible for coordinating the various projects and for meeting the program's overall technical, cost, and schedule objectives.

A.2.2 Principal Investigators

Each project will be directed by a Principal Investigator who is a consultant or PEER academic with appropriate expertise and experience in the technical area being addressed by that project. These project investigators will have responsibility for meeting the technical objectives of their project, in accordance with project time and budget constraints. They will also work closely with the Program Manager to assure that overall program objectives are also being met.

A.2.3 Technical Support Staff

The Principal Investigators will direct a team of staff engineers and/or graduate students with the necessary engineering background and computer skills for carrying out the various tasks that comprise each project.

A.2.4 Executive Committee

An Executive Committee will provide periodic review and oversight of the progress and results of the overall program and each project, to assure that end-user needs are being met. This Committee will consist of end users from the California Department of Transportation, the Pacific Gas & Electric Company, and the California Energy Commission, as well as representatives of the PEER Lifelines Program's Joint Management Committee.

A.3 PROJECT 1: LIFELINE PLATFORM DEVELOPMENT AND APPLICATION

A.3.1 Objective

Project 1 will develop beta software platforms for electric power and highway transportation systems that will: (a) contain all hazard, component, and system models needed for risk analysis; (b) carry out the lifeline system risk analysis using these models; and (c) develop and display risk analysis results in a useful form for guiding seismic upgrade decision-making for the lifeline system.

A.3.2 Scope

Two separate but parallel beta software platforms will be developed -- one for highway transportation systems and the other for electric power systems. These platforms will be based on existing software packages that are either under development or are now used in current practice. Their development will be closely coordinated to assure that each platform: (a) meets the technical objectives and contains the technical features described in Chapter 4; (b) has comparable architecture that will facilitate their subsequent enhancement and merging into a single software platform during future PEER research; (c) can be run independently of the original software developers, by outside engineers and academics; and (d) can eventually be merged into a single platform during future PEER research. The following subsections summarize the anticipated features of these two platforms.

A.3.2.1 Analytical Capabilities

The two software platforms will contain existing state-of-practice models (identified under Projects 2 through 5) for estimating seismic hazards, component vulnerabilities and fragilities, and system performance, and for using results from the software to develop information to guide decision making. The software packages will have a modular architecture to facilitate inclusion of new and improved models that are developed during future PEER research.

A.3.2.2 User-Interface and Input-Output Capabilities

These software platforms will each include tabular, graphical, and GIS methods for user interface, input display and checking, and output display and interpretation. The output from these packages shall include GIS displays of electric power system performance on an hourly basis, GIS displays of highway transportation system performance over longer time lines (days, weeks, months), and integrated displays of electric power and highway transportation system performance to facilitate evaluation of system interaction effects. Alternative types of output will be available to meet needs of system managers and decision makers, engineers, and the media. Existing software will be used to provide these capabilities to the extent possible.

A.3.2.3 Documentation

Nominal user manuals will be developed from existing manuals that are sufficient to enable users to run each software package during this two-year project. Further documentation -- including a software manual and a technical manual -- will be developed after further engineering and improvement of the software during future PEER research is in place.

A.3.3 Principal Investigators and Project Staff

The Principal Investigators for Project 1 will consist of a team of senior consultants or PEER academics with expertise and experience in seismic risk analysis of electric power and highway transportation systems, risk analysis, decision analysis, and development of large software platforms. Technical support for each task of Project 1 will be provided by staff engineers and/or graduate students with appropriate skills in computer programming and earthquake engineering.

A.3.4 Task Descriptions

Project 1 will be organized into the following tasks: (1.1) software development planning; (1.2) software platform for risk analysis of electric power systems; (1.3) software platform for risk analysis of highway transportation systems; (1.4) integration of seismic hazard models, electric power components and system models, highway transportation component and system models, and decision models; (1.5) development of metrics and display strategies; (1.6) interaction between electric power and highway transportation system performance; and (1.7) demonstration application; These tasks are further described below.

A.3.4.1 Task 1.1 -- Software Development Planning

- ***Scope.*** Task 1.1 will lay the groundwork for future incorporation of the software for analysis of electric power and highway transportation systems into a common platform. This task will: (a) identify existing software packages that are either under development or are now used in current practice that will be the basis for the software platforms for risk analysis of electric power systems and highway systems to be developed under Tasks 1.2 and 1.3 respectively; (b) identify any additional features pertaining to program architecture, user interfaces, and technical and input-output features that should be incorporated into these software packages under Tasks 1.2

and 1.3 during this two-year research program; and (c) develop a plan for close interfacing of the technical staffs for each software platform during their development.

- ***End Product.*** The end product of Task 1.1 will be a report that contains a detailed plan that meets the objective and scope described above. This plan will be reviewed and approved by the Executive Committee before proceeding with Tasks 1.2 and 1.3.

A.3.4.2 Task 1.2 -- Software Platform for Risk Analysis of Electric Power Systems

- ***Scope.*** Upon approval of the Task 1.1 software plan by the Executive Committee, Task 1.2 will develop a beta software platform for risk analysis of electric power systems in accordance with the plan established in Task 1.1. This software will be modular, to enable the various seismic-hazards, electric-power, and decision-guidance models from Projects 2 through 5 to be programmed into the software under Task 1.4. It will also be coordinated with the software for risk analysis of highway systems from Task 1.3, to assure that the two software packages are sufficiently consistent to enable them to facilitate their inclusion into a common platform during future PEER research.

- ***End Product.*** Task 1.2 will provide: (a) a beta software platform for electric-power systems that will be further developed and tested during future PEER research; and (b) a nominal user manual to guide the implementation of this software. Task 1.2 will also document any unresolved technical issues that were encountered during this platform development, and will discuss how they may be addressed through future PEER research.

A.3.4.3 Task 1.3 -- Software Platform for Risk Analysis of Highway Transportation Systems

- ***Scope.*** Upon approval of the Task 1.1 software plan by the Executive Committee, Task 1.3 will develop a beta software platform for risk analysis of highway transportation systems in accordance with the plan established in Task 1.1. This software will be modular, to: (a) enable the various seismic-hazards, highway-transportation, and decision-guidance models from Projects 2 through 5 to be programmed into the software under Task 1.4. It will also be coordinated with the software for risk analysis of electric power systems from Task 1.2, to assure that the two software packages are sufficiently consistent to facilitate their inclusion into a common platform during future PEER research.

- ***End Product.*** Task 1.3 will provide: (a) a beta software platform for highway-transportation systems that will be further developed and tested during future PEER research; and (b) a nominal user manual to guide the implementation of this software. Task 1.3 will also document any unresolved technical issues that were encountered during this platform development, and will discuss how they may be addressed through future PEER research.

A.3.4.4 Task 1.4 -- Integration of Hazards, Electric-Power, Highway-Transportation, and Decision Guidance Models into Platforms from Tasks 1.2 and `1.3

- ***Scope.*** Task 1.4 will program the various models for estimation of seismic hazards (from Project 2), electric-power component and system performance (from Project 3), highway-transportation component and system performance (from Project 4), and decision guidance (from Project 5), and will then integrate them into the electric-power and highway-transportation software platforms from Tasks 1.2 and 1.3.

- ***End Product.*** Task 1.4 will provide a series of programmed modules for modeling of seismic hazards, electric power and highway transportation components and systems, and decision guidance methods that have been integrated into the software platforms from Tasks 1.2 and 1.3. Task 1.4 will also document any unresolved technical issues that were encountered during this model integration process, and will discuss how they may be addressed through future PEER research.

A.3.4.5 Task 1.5 -- Metrics and Display Strategies

- ***Scope.*** Task 1.5 will develop output modules that enable to electric power and highway transportation platforms from Tasks 1.2 and 1.3 to provide the tabular, graphical, and GIS forms of results identified for these platforms under the Task 1.1 software plan. It will then incorporate these output modules into the software platforms from Tasks 1.2 and 1.3.

- ***End Product.*** Task 1.5 will provide two output software modules -- one for electric power systems and the other for highway transportation systems -- that will be integrated into the platforms from Tasks 1.2 and 1.3. Task 1.5 will also document any unresolved technical issues that were encountered during this output module development, and will discuss how they may be addressed through future PEER research.

A.3.4.6 Task 1.6 -- Interaction between Electric Power and Highway Transportation System Performance

- ***Scope.*** Past experience has shown that the post-earthquake performance and recovery of an electric power and highway transportation system can be mutually dependent. For example, loss of electric power for stop lights, road signs, and transportation emergency response centers could impact the rate of recovery of a highway transportation system. Likewise, electric transmission or distribution lines are often supported within bridges or tunnels at water crossings, and damage to these bridges could also damage these electric lines. Accordingly, Task 1.6 will develop strategies for using the results from the Task 1.2 and 1.3 software platforms in order to assess effects of interaction between the seismic performance of electric power and highway transportation systems. These strategies will be applied during the demonstration application of the two platforms under Task 1.7

- ***End Product.*** Task 1.6 will provide a report that documents procedures for assessing effects of interaction between the seismic performance of electric power and highway transportation systems, and evaluates their future applicability within the software platforms developed under Tasks 1.2 and 1.3. Task 1.6 will also document any unresolved technical issues that were encountered during this work, and will discuss how they may be addressed through future PEER research.

A.3.4.7 Task 1.7 -- Demonstration Application

- ***Scope.*** Task 1.7 will apply the software platforms for electric power and highway transportation systems from Tasks 1.2 and 1.3 to an actual Caltrans highway transportation system in a single northern California region (e.g., the region that surrounds Vallejo, California) and to either an actual PG&E electric power system in this region or, if required because of security constraints, a hypothetical power system. These applications will develop and apply input data needed to implement this demonstration application using the software packages that contain integrated hazard, component, and system models and decision guidance module from Task 1.4, and the output module from Task 1.5 . This demonstration application will illustrate the applicability of these platforms and their integrated models and modules, and the types and ranges of results that can be obtained. The application will also show how the platforms can be used to assess effects of interaction between the seismic performance of electric power and highway transportation systems, based on the procedures developed under Task 1.6.

- ***End Product.*** Task 1.7 will provide a report that documents the procedures used to carry out the demonstration application, and provides a full range of tabular, graphical, and GIS results that can be developed to meet a user's engineering, planning, or decision guidance needs. This report will also document any unresolved technical issues that were encountered during this demonstration application, and will discuss how they may be addressed through future PEER research.

A.4 PROJECT 2: SEISMIC HAZARD MODELS FOR LIFELINE PLATFORM

A.4.1 Objective

Project 2 will establish the existing earthquake occurrence and seismic hazard models that will be integrated into the electric power and highway system risk/reliability platforms under Project 1.

A.4.2 Scope

Existing earthquake occurrence and seismic hazard models from current geoscience or engineering practice and/or from past and recent research at PEER and elsewhere will be identified and documented in sufficient detail to facilitate their programming and integration into the risk/reliability platforms for electric power and highway transportation systems under Task 1.4 of Project 1. No research directed toward modification of existing models or development of improved models will be conducted under Project 2. The existing models to be identified and documented will address:

- *Scenario Earthquakes.* An ensemble of scenario earthquakes must be defined from a recognized model that represents the seismicity and geology of the surrounding region.

- *Site-Specific Ground Shaking.* For each scenario earthquake, ground motions at the site of a particular electric power or highway transportation component will be defined from recognized models that estimate how the seismic waves attenuate with distance from the earthquake, how they are affected by earthquake magnitude, and how they are affected by local soil conditions.

- *Site-Specific Permanent Ground Displacement.* In addition to ground shaking, models will be used to estimate the exposure of an electric power or highway transportation component to ground displacement from earthquake-induced liquefaction or landslide of the surrounding site soil materials or from rupture of a nearby causative fault.

A.4.3 Principal Investigators and Project Staff

The Principal Investigator for Project 2 will be a senior engineer from consulting practice or PEER academia, with recognized expertise and experience in seismic hazard modeling and analysis. Technical support for Project 2 will be provided by staff engineers and/or graduate students with appropriate backgrounds in geotechnical earthquake engineering and the geosciences.

A.4.4 Task Descriptions

Project 2 consists of five tasks that address modeling of scenario earthquakes, and hazards from ground shaking, liquefaction, landslide, and surface fault rupture. The tasks are summarized below.

A.4.4.1 Task 2.1 -- Scenario Earthquake Modeling

- ***Scope.*** Task 2.1 will assess existing procedures from current practice and from recent research at PEER for modeling the occurrence of earthquakes in California. These assessments will consider whether the models are appropriate for integration into the lifeline risk/reliability software platforms from Tasks 1.2 and 1.3. A preferred earthquake occurrence model will be selected, integrated into the platforms, and then used within the platforms to develop an ensemble of scenario earthquakes that will be input to the demonstration applications conducted under Task 1.7. Candidate modeling approaches that will be assessed are documented in Toro and Silva (2001), Schneider et al. (2000), and Taylor et al. (2001).

- ***End Product.*** Task 2.1 will provide a report that identifies a preferred earthquake model, and documents the model in sufficient detail to facilitate its programming and integration into the risk/reliability software platforms as part of Task 1.4. This report will also document any unresolved technical issues encountered with respect to lifelines platform applications, and will discuss how these issues may be addressed through future PEER research.

A.4.4.2 Task 2.2 -- Ground Motion Modeling

- ***Scope.*** Task 2.2 will assess several existing procedures from current practice and from recent research at PEER for estimation of site-specific ground motions. These assessments will consider whether these procedures are suitable for integration into the lifeline risk/reliability software platforms from Tasks 1.2 and 1.3. A preferred ground motion model will be selected, integrated into the platforms, and then used within the platforms to estimate site-specific ground motions for the demonstration applications conducted under Task 1.7. The models to be assessed will estimate how the amplitude and spectral content of ground shaking in California are affected by the earthquake magnitude, source-site distance, local soil conditions, and near-fault ground motion effects. Candidate models that will be assessed are documented in Abrahamson and Silva (1997), Boore et al. (1997), Sadigh et al. (2000), and Spudich et al. (1999).

- ***End Product.*** Task 2.2 will provide a report that documents a preferred earthquake ground motion model in sufficient detail to facilitate its programming and integration into the risk/reliability software platforms as part of Task 1.4. This report will also document any unresolved technical issues encountered with respect to lifelines platform applications, and will discuss how these issues may be addressed through future PEER research.

A.4.4.3 Task 2.3 Liquefaction Hazard Modeling

- ***Scope.*** Task 2.3 will assess several existing procedures from current practice and from recent research at PEER for estimation of site-specific liquefaction hazards. These assessments will consider whether these procedures are suitable for integration into the lifeline risk/reliability software platforms from Tasks 1.2 and 1.3 (e.g., whether the extent and type of soil input data needed to implement the procedure are practical for application to the large numbers of component sites within a lifeline system.) A preferred model will be selected, integrated in the platforms, and then used within the platforms to estimate liquefaction hazards for the demonstration applications conducted under Task 1.7.. The models to be assessed will first estimate the potential for occurrence of liquefaction as a function of the level of ground shaking at sites throughout the lifeline network. Then, if liquefaction is estimated to have occurred at a site, the model will estimate the extent of the resulting permanent ground displacement. Candidate models that will be assessed will include those described in Youd (1998) and Bardet et al. (1999 and 2002), as well as other appropriate models.

- ***End Product.*** Task 2.3 will provide a report that documents a preferred liquefaction hazard model in sufficient detail to facilitate its programming and integration into the risk/reliability software platforms as part of Task 1.4. This report will also document any unresolved technical issues encountered with respect to lifelines platform applications, and will discuss how these issues may be addressed through future PEER research.

A.4.4.4 Task 2.4-- Landslide Hazard Modeling

- ***Scope.*** Task 2.4 will assess several existing procedures from current practice and from recent research at PEER for estimation of site-specific earthquake-induced landslide hazards. These assessments will consider whether these procedures are suitable for integration into the lifeline risk/reliability software platforms from Tasks 1.2 and 1.3 (e.g., whether the extent and type of soil input data needed to implement the procedure are practical for application to the large numbers of component sites within a lifeline system.) A preferred model will be selected, integrated into the platforms, and then used within the platforms to estimate landslide hazards for the demonstration applications that are conducted under Task 1.7. The models to be assessed will first estimate the potential for occurrence of landslides as a function of the level of ground shaking at sites throughout the lifeline network. Then, if landslide is estimated to have occurred at a site, the model will estimate the extent of the resulting ground displacement. Candidate models for this purpose will include those described in Kramer (1996) and Dickenson (1998), as well as other appropriate models.

- ***End Product.*** Task 2.4 will provide a report that documents a preferred earthquake-induced landslide hazard model, in sufficient detail to facilitate its programming and integration into the risk/reliability software platforms as part of Task 1.4. This report will also document any unresolved technical issues encountered with respect to lifelines platform applications, and will discuss how these issues may be addressed through future PEER research.

A.4.4.5 Task 2.5 -- Surface Fault Rupture Hazard Modeling

- ***Scope.*** Task 2.5 will assess several existing procedures from current practice and from recent research at PEER for estimation of surface fault rupture hazards. These assessments will consider whether these procedures are suitable for integration into the lifeline risk/reliability software platforms from Tasks 1.2 and 1.3. A preferred model will be selected, integrated into the platforms, and then used within the platforms to estimate surface fault rupture hazards for the demonstration applications under Task 1.7. The models to be assessed will estimate earthquake-induced surface fault rupture hazards and corresponding permanent ground displacements at sites within the lifeline system that are crossed by active faults. Candidate models for this purpose will include those developed by Wells and Coppersmith (1994), as well as other appropriate models.

- ***End Product.*** Task 2.5 will provide a report that identifies a preferred surface fault rupture model in sufficient detail to facilitate its programming and integration into the risk/reliability software platforms as part of Task 1.4. This report will also document any unresolved technical issues encountered with respect to lifelines platform applications, and will discuss how these issues may be addressed through future PEER research.

A.5 PROJECT 3: ELECTRIC POWER COMPONENT AND SYSTEM MODELS FOR LIFELINES PLATFORM

A.5.1 Objective

Project 3 will establish the component and system modeling procedures to be used in the electric power system risk/reliability software platform developed under Task 1.2. Project 3 will also identify input database needs for these models, will develop and apply strategies for compiling such input, and will use these strategies to compile input to the demonstration application of the platform that will be carried out under Task 1.7.

A.5.2 Scope

The establishment of electric power component and system modeling procedures will be based on review and assessment of existing models from current engineering practice and from recently completed research. In addition, limited research will be carried out to develop or improve those models that are known to be inadequate.

Assessment and development of input databases for these models will be based on experience in performing seismic risk analyses for electric power utilities, together with the following considerations:

- ***Input Database Requirements.*** What input data are needed to apply the risk/reliability platform to electric power systems, and what should be the form of these data?
- ***Current Database Assessment.*** How much of these input data are readily available at the power utility, and what is the current form of these data? How well do these available databases meet the above input requirements for the risk/reliability platform?
- ***Input Database Development Planning.*** If the currently available input data at the power utility do not meet the above requirements, what specifically should be done to enable these agencies to develop the necessary databases? How should these data development efforts be organized, what staff within the agencies should carry them out, and what is a realistic schedule and time expenditure for developing these data?

- ***Development of Input Databases for Demonstration Analyses.*** By applying the above input database development plans to an actual power utility subsystem, what is the practical applicability of these plans? How should the plans be modified to improve their practical applicability to actual electric power systems?

A.5.3 Principal Investigators and Project Staff

The Principal Investigator for Project 3 will be a senior engineer from consulting practice or PEER academia who has recognized expertise and experience in seismic risk analysis and earthquake engineering of electric power equipment and systems, forensics of electric utility systems after earthquakes, and electric utility component testing. Technical support for Project 3 will be provided by staff engineers and/or graduate students with appropriate skills in earthquake engineering of utility power structures, equipment, and systems.

A.5.4 Tasks

Project 3 will be organized into the following seven tasks: (3.1) input database needs and development; (3.2) component failure modes; (3.3) component performance algorithms; (3.4) component slack algorithms; (3.5) component power substation damage characterization; (3.6) component repair/functionality models; and (3.7) system analysis procedure. These tasks are summarized below.

A.5.4.1 Task 3.1 -- Input Database Needs and Development

- ***Scope.*** The ready accessibility of computerized input databases is essential to the future application of this risk/reliability platform to evaluate seismic risks to electric power systems. Therefore, Task 3.1 will develop guidelines for future compilation of databases that contain all information needed to characterize the substations and their components, and will use these guidelines to develop input data for the demonstration application being conducted under Task 1.7. Compilation of these input data will be based on the following considerations.

  - *Overall System.* Data to characterize the overall electric power system includes definition of the voltage to be included in the model and the substations, transmission lines, buildings, communication systems, and generation facilities to be modeled. In most cases, data should be gathered only for 230kV and 500kV equipment, unusual substation details (layout, connectivity), and 230kV and 500kV spare equipment. Data should not be gathered for lower voltage switch-gear, transformers, or control equipment and buildings. In addition, if load flow analyses are being considered within the SRA platform, data on anticipated load demands along with component and line capacities will also need to be gathered. One way around this would be to coordinate the SRA output with the utility's existing load flow analysis and conduct the load flow analysis outside of the SRA platform.

- *Soil Conditions.* Soils data needed to characterize ground shaking, liquefaction, and landslide hazards at the site of each significant component should be compiled. These particular data needs are comparable for electric power and highway transportation components.

- *Equipment and Unusual Substation Details.* Electric equipment data should include equipment types, location, connectivity, anchorage and conductor slack. Unusual substation electric details include raised disconnect switches or transformers, bus configurations (other than double breaker and breaker and a half), rigid conductor, poorly supported transformer radiators, vulnerable and poorly located surge arresters and jack busses, poorly anchored equipment, and equipment components without fragilities.

- *Data Gathering Procedures.* Substation data gathering should include a photo survey, and should be computer friendly and adequate for present and likely future parameterization of component and/or substation performance algorithms.

- ***End Product.*** Task 3.1 will provide a report that contains guidelines for future development of databases that can serve as input to the risk/reliability platform for electric power systems (from Task 1.2). This report will also provide input databases for use in the demonstration application of the platform under Task 1.7. Finally, the report will document any unresolved technical issues encountered during the development of these guidelines and input data, and will discuss how these issues may be addressed through future PEER research. Because of the sensitivity of such data to system security, it is possible the a hypothetical electric power system rather than an actual system will be used for the demonstration application.

A.5.4.2 Task 3.2 -- Component Failure Modes

- ***Scope.*** Task 3.2 will develop and document failure modes and return-to-service resource requirements for electric power components. The sources to be included are fragilities that: (a) are listed in the Inter Utility Working Group meeting minutes Sept 1993; (b) have been investigated during recent PEER projects; and (c) are not included in a) and b) but are contained in the system to be considered in the demonstration application of this platform under Task 1.7 (i.e., have been identified under Task 3.1).

- ***End Product.*** Task 3.2 will provide a report that contains tabulations of failure modes for all of the components that are contained in the above lists and/or have been investigated by PEER. This report will also document any unresolved technical issues encountered during the development of these failure mode results, and will discuss how these issues may be addressed through future PEER research.

A.5.4.3 Task 3.3 -- Component Performance Algorithms

- ***Scope.*** Task 3.3 will document the most current seismic performance algorithms for electric power components that: (a) are listed in the California Water and Power Earthquake Engineering Forum; and (b) have been investigated during recent PEER projects. Task 3.3 will also develop procedures for creating performance algorithms from qualification tests. Finally, Task 3.3 will develop new performance algorithms for components that are not included in a) and b) but are contained in the system to be considered in the demonstration application of this platform (i.e., have been identified under Task 3.1).

- ***End Product.*** Task 3.3 will provide a report that describes performance algorithms for all of the above components, in sufficient detail to facilitate their programming and integration into the Task 1.2 risk/reliability platform as part of Task 1.4. This report will also document any unresolved technical issues encountered during the development of these failure mode results, and will discuss how these issues may be addressed through future PEER research.

A.5.4.4 Task 3.4 -- Component Slack Algorithms

- ***Scope.*** Task 3.4 will use results from recent PEER research to develop a component slack algorithm that estimates earthquake-induced damage to a given component, as a function of the level of conductor slack that connects that component to adjacent components.

- ***End Product.*** Task 3.4 will provide a report that documents a computer-ready slack algorithm for estimating the seismic performance of components that are interconnected by conductors. This documentation will be in sufficient detail to facilitate the programming and integration of the algorithm into the electric power system risk/reliability platform, as part of Task 1.4. This report will also document any unresolved technical issues that were encountered during the development of this algorithm, and will discuss how these issues may be addressed through future PEER research.

A.5.4.5 Task 3.5 -- Substation Damage Characterization

- ***Scope.*** Task 3.5 will develop an approach to assess the seismic performance and post-earthquake functionality of a substation, as a function of the level of damage and functionality of the individual components within the substation. This approach will be based on load flow, local performance macros, and/or expert opinion. These substation performance estimates will be provided in a form to facilitate their subsequent use in evaluating overall system functionality after an earthquake. It is noted that this task is only necessary if system load flow calculations will not be used to determine system functionality.

- ***End Product.*** Task 3.5 will provide a report that documents the above substation assessment approach in sufficient detail to facilitate its programming and integration into the electric power system risk/reliability platform as part of Task 1.4. This report will also document any unresolved technical issues encountered during the development of these substation damage characterizations, an d will discuss how these issues may be addressed through future PEER research.

A.5.4.6 Task 3.6 -- Component Repair/Functionality Models

- ***Scope.*** Task 3.6 will develop a database and models of repair costs and downtimes for those electrical equipment components contained in the power system that is being analyzed under the demonstration evaluation from Task 1.7.. Repair cost and downtime models will be based on expert judgment and/or past experience in California. Downtimes that are forecast by a system risk analysis will depend on the equipment's estimated damage state due to the seismic hazards estimated using procedures identified under Tasks 3.2 to 3.5.

- ***End Product.*** Task 3.6 will provide a report that documents models for estimating electric power component repair costs and downtimes as a function of their damage states. These models will be documented in sufficient detail to facilitate their programming and integration into the electric power system risk/reliability platform as part of Task 1.4. This report will also document any unresolved technical issues encountered during the development of these repair/functionality models, and will discuss how these issues may be addressed through future PEER research.

A.5.4.7 Task 3.7 -- System Analysis Procedures

- ***Scope.*** Task 3.7 will identify existing approaches for estimation of the seismic performance of electric power systems, and will select appropriate approaches for use with the electric power system risk/reliability platform being developed under Task 1.2. In this, the first step in the evaluation of electric power system performance is to evaluate the connectivity of the system (which is highly dependent on the performance of the substation), and to develop post-earthquake system (function) states for the power network. Then, load-flow solutions can be obtained for source and load sets. However, it is more likely that experienced system operators who are intimately familiar with the power system will either: (a) directly estimate how the system will perform after viewing the damage sets; or (b) will develop simple substation function algorithms that deal with minimum permissible transformation and substation/system connectivity. From either of these approaches, forecasts of the system's performance can be obtained and used to estimate return-to-service levels, strategies, and times can be estimated. Time dimensions for electric power system restoration are often expressed in terms of hours.

- ***End Product.*** Task 3.7 will provide a report that documents an existing load-flow approach for evaluation of the seismic performance of an electric power system, recognizing that alternative system evaluation procedures based on operator experience or simple algorithms are more often used. This approach will be documented in sufficient detail to facilitate its programming and integration into the electric power system risk/reliability platform, as part of Task 1.4. This report will also document any unresolved technical issues encountered during the development of these system evaluation approaches, and will discuss how these issues may be addressed through future PEER research.

A.6 PROJECT 4: HIGHWAY TRANSPORTATION COMPONENT AND SYSTEM MODELS FOR LIFELINES PLATFORM

A.6.1 Objective

Project 4 will establish the component and system modeling procedures to be used in the highway transportation system risk/reliability software platform developed under Task 1.3. This project will also identify input database needs for these models, will develop and apply strategies for compiling such input, and will use these strategies to compile input to the demonstration application of the platform that will be carried out under Task 1.7.

A.6.2 Scope

This establishment of highway transportation component and system modeling procedures will be based on review and assessment of existing models from current engineering practice and from recently completed research. In addition, limited research will be carried out to develop or improve those models that are known to be inadequate.

Assessment and development of input databases for these models will be based on experience in performing seismic risk analyses for highway transportation systems, together with the following considerations (which are very similar to those considerations previously noted for electric power systems in Section A.5.2):

- ***Input Database Requirements.*** What input data are needed to apply the risk/reliability platform to highway transportation systems, and what should be the form of these data?

- ***Current Database Assessment.*** How much of these input data are readily available at the highway transportation agency, and what is the current form of these data? How well do these available databases meet the above input requirements for the risk/reliability platform?

- ***Input Database Development Planning.*** If the currently available input data at the highway transportation agency do not meet the above requirements, what specifically should be done to enable these agencies to develop the necessary databases? How should these data development efforts be organized, what staff within the agency should carry them out, and what is a realistic schedule and time expenditure for developing these data?

- ***Development of Input Databases for Demonstration Analyses.*** By applying the above input database development plans to a highway transportation system, what is the practical applicability of these plans? How should the plans be modified to improve their practical applicability to actual highway transportation systems?

A.6.3 Principal Investigators and Project Staff

The Principal Investigators for Project 4 will be a team of senior engineers from consulting practice or PEER academia with recognized expertise and experience in seismic risk analysis and earthquake engineering of highway transportation components and systems, forensics of such components and systems after earthquakes, and transportation network analysis. Technical support for Project 4 will be provided by staff engineers and/or graduate students with appropriate skills in earthquake engineering and seismic risk analysis of highway transportation components and systems.

A.6.4 Task Descriptions

Project 4 will be organized into the following seven tasks: (4.1) input database needs and development; (4.2) highway bridge damage characterization; (4.3) bridge repair/functionality models; (4.4) retrofitted bridge models; (4.5) non-bridge highway component models; (4.6) models of highway components subjected to permanent ground displacement; and (4.7) system analysis procedure. These tasks are summarized below.

A.6.4.1 Task 4.1 -- Input Database Needs and Development

- ***Scope.*** The ready accessibility of computerized input databases is essential to the future application of this risk/reliability platform to evaluate seismic risks to highway transportation systems. Therefore, Task 3.1 will develop guidelines for future compilation of databases that contain all information needed to characterize the bridges and other highway system components, and will use these guidelines to develop input data for the demonstration application to be conducted under Task 1.7. Compilation of these input data will be based on the following considerations:

  - *System Configuration.* Input data to define the highway system includes the links and nodes that comprise the system model, locations of end nodes for each link and for the bridges and other key components in the system, link classifications or facility type (e.g., freeway, major arterial), and the number of lanes and the directionality of traffic flows for each link.

  - *Traffic Flow Data.* Pre-earthquake traffic flow data for each link includes passenger-car-units per hour, percentage of flows that are not automobiles, free-flow travel speed, current and projected traffic flow characteristics, observed speed or travel time, and speed class.

- *Pre-Earthquake Trip Demands.* Data to characterize pre-earthquake trip demands will usually include a GIS map showing locations and shapes of all origin-destination zones within the region, trip tables that define the number of trips to and from all zones in the system, and current and projected demographic data for the zones.

- *Soil Conditions.* Soils data needed to characterize ground shaking, liquefaction, and landslide hazards at the site of each significant component in the highway system should be compiled. These particular data needs are comparable to those for electric power components.

- *Bridge Data.* For conventional bridges that can be modeled by available simplified methods (e.g., Mander et al., 1998), input data will usually include attributes contained in the FHWA National Bridge Inventory database. For more complex bridges requiring user-specified models, the data would need to include additional information that defines bridge geometry, materials of construction, member sizes, reinforcement and details, joint details (bearings and seat widths), foundation conditions, and abutments.

- *Other Highway Components.* Input data to characterize non-bridge roadway pavements generally include pavement material type and characteristics of the underlying soils and any embankments along the lengths of these roadways. If other components are also to be modeled (e.g., tunnels), input data describing the characteristics of these components in accordance with the models integrated into the software under Task 1.4 are also required.

- ***End Product.*** Task 4.1 will provide a report that contains guidelines for future development of input databases needed to evaluate highway transportation systems using the risk/reliability platform developed under Task 1.3. This report will also provide input databases that will be used in the demonstration application of the platform under Task 1.7. Finally, the report will document any unresolved technical issues encountered during the development of these guidelines, and how these issues may be addressed through future PEER research.

A.6.4.2 Task 4.2 -- Highway Bridge Damage Characterization

- ***Scope.*** There is a need to develop damage state descriptors that facilitate improved modeling of repair costs and downtimes for a given damage state. This need arises because most current vulnerability and fragility models use qualitative damage-state descriptors (e.g., slight, moderate, major, extensive, and collapse). However, these descriptors are very subjective; e.g., different engineers viewing the same damaged bridge may assign different descriptors of this type to the bridge. This, in turn, could affect the development of models that estimate repair cost and downtime for various damage states, as a function of ground shaking level. Therefore, Task 4.2 will investigate alternative ways to characterize the damage of the bridges contained in the system being evaluated under the demonstration analysis from Task 1.7. One candidate approach from the University of California at San Diego uses an experimentally-based database of bridge performance to characterize bridge damage (Hose and Seible, 1999). Other candidate approaches are based on analysis of bridge performance data from past earthquakes. (e.g., Shinozuka, 2001; Basoz and Kiremidjian, 1997).

- ***End Product.*** Task 4.2 will provide a report that documents this assessment of candidate procedures for characterizing bridge damage states. If it is determined that improved bridge damage characterizations can be developed, the report will also document strategies for developing updated bridge damage-state fragility models during Years 3 to 5 that use these improved characterizations. Finally, the report will document any unresolved technical issues that are encountered during the development of these damage state descriptors, and how these issues may be addressed through future PEER research.

A.6.4.3 Task 4.3 -- Bridge Repair/Functionality Models

- ***Scope.*** There is a need to develop improved data for characterizing bridge repair procedures and corresponding costs, durations, and loss of functionality during repair, as a function of the bridge damage state (as well as the bridge type and accessibility.) The best available source of such information is from Caltrans' bridge repair data from past earthquakes. However, these data are not yet available as a computerized database for possible use in developing bridge repair/functionality models for this risk/reliability platform. Therefore, Task 4.3 will develop a database and models of repair costs and downtimes for bridges contained in the highway system being evaluated in the demonstration analysis from Task 1.7. These repair cost and downtime estimates will be based on expert judgment and past experience in California, and will depend on the bridge's estimated damage state due to the seismic hazards estimated under Project 2. A similar project for electric power components is included in this program plan (under Task 3.6).

- ***End Product.*** Task 4.3 will provide a report that documents improved models for estimating bridge repair costs, repair times, and functionalities during repair, as a function of the bridge's damage state, type, and accessibility. These models will be documented in sufficient detail to facilitate their programming and integration into the highway system risk/reliability platform, as part of Task 1.4. This report will also document any unresolved technical issues that are encountered during the development of these models, and how these issues may be addressed through future PEER research.

A.6.4.4 Task 4.4 -- Retrofitted Bridge Models

- ***Scope.*** Current bridge fragility models are applicable to new or existing bridges that have not been seismically retrofitted. This will be a problem when applying the risk/reliability platform throughout much of California, in view of the large number of bridges throughout the state that have been retrofitted, and the probable beneficial effects of the retrofit on the seismic performance of a bridge. Therefore, Task 4.4 will: (a) review available analytical, experimental, and empirical data for retrofitted bridges; and (b) use these data to develop first-order models of how seismically retrofitted bridges in California perform during an earthquake. These models will estimate a retrofitted bridge's damage state, repair costs, repair times, and functionality during repairs, as a function of its seismic hazard levels.

- ***End Product.*** Task 4.4 will provide a report that documents new first-order models for assessing retrofitted bridge damage states and associated repair costs, durations, and functionalities, as a function of seismic hazard level. These models will documented in sufficient detail to facilitate their programming and integration into the highway system risk/reliability evaluation platform, as part of Task 1.4. This report will also document any unresolved technical issues that are encountered during the development of these models, and how these issues may be addressed through future PEER research.

A.6.4.5 Task 4.5 -- Non-Bridge Highway Component Models

- ***Scope.*** The ability of a highway-roadway system to accommodate post-earthquake traffic demands will depend on the seismic performance of other types of components besides bridges, such as pavements, tunnels, retaining walls, embankments, and culverts. Therefore, Task 4.5 will: (a) review available analytical, experimental, and empirical data for these components; and (b) use these data to develop first-order models of how the components perform during an earthquake. These models will estimate the component's damage state, repair costs, repair times, and functionality during repairs, as a function of its seismic hazard levels.

- ***End Product.*** Task 4.5 will provide a report that documents new first-order models for assessing damage states and associated repair costs, repair times, and functionalities during repairs of pavements, tunnels, retaining walls, embankments, and culverts, as a function of seismic hazard level. These models will be documented in sufficient detail to facilitate their programming and integration into the highway system risk/reliability platform, as part of Task 1.4.. This report will also document any unresolved technical issues encountered during the development of these models, and how these issues may be addressed through future PEER research.

A.6.4.6 Task 4.6 -- Models of Highway Components subjected to Permanent Ground Displacement

- ***Scope.*** In addition to ground shaking hazards, the seismic performance of highway transportation components will, of course, also be affected by permanent ground displacements (PGD) due to earthquake-induced liquefaction, landslide, or surface fault rupture. However, the vast majority of the past studies of PGD effects have consisted of analytical and experimental investigations of their effects on bridge foundations only. There has been only very limited use of these to results to develop models of how PGD hazards can affect the seismic performance of an overall bridge structure-foundation system. In addition, relatively little work has been done to develop general models of the performance of other non-bridge highway components subjected to PGD. Finally, for use in SRA of highway transportation systems, there is a need to compile data on repair costs, repair times, and functionalities during repairs of highway components subjected to PGD. Therefore, Task 4.6 will provide information to help fill this research gap by: (a) evaluating the limited models of this type that are currently available (e.g., from HAZUS99 as described in FEMA, 1999); (b) compiling available data on the performance of bridges and other highway components subjected to PGD, together with repair cost, time, and functionality data; and (c) developing and implementing a strategy for using the data from b) to improve the existing models for bridges and other highway components from a).

- ***End Product.*** Task 4.6 will provide a report that documents first-order models of damage states and associated repair costs, durations, and functionality during repairs of bridges and other highway components subjected to earthquake-induced PGD. These models will be documented in sufficient detail to facilitate their programming and integration into the highway system risk/reliability platform, as part of Task 1.4. In addition, any unresolved technical issues encountered during the development of these models will be identified, and strategies for addressing these issues through future PEER research.

A.6.4.7 Task 4.7 -- System Analysis Procedures

- ***Scope.*** Task 4.7 will evaluate existing approaches for estimating the seismic performance of highway transportation networks, and will select a preferred approach for integration into the highway system risk/reliability platform being developed under Task 1.3. In this, the first step in the evaluation of highway system performance is to evaluate the connectivity of the system, and to develop post-earthquake system (function) states of the power network. Then, network analysis procedures are applied to these system states (which will vary with time after the earthquake, to reflect the estimated rate at which repairs to the system can be made.) These network analyses will estimate post-earthquake traffic flows, travel times, and travel paths throughout the system for trip demands on the system that are anticipated to occur after the earthquake. From this, alternative repair strategies and priorities can be selected that are shown to most effectively reduce the effects of earthquake damage on the system-wide traffic flows. Although many rapid rerouting and other activities occur immediately after earthquakes, time dimensions for highway transportation system recovery are often measured in terms of days, weeks, and months.

- ***End Product.*** Task 4.7 will provide a report that documents the existing procedure selected under this task for evaluating the post-earthquake performance of highway systems. This model will be documented in sufficient detail to facilitate its programming and integration into the Task 1.3 risk/reliability platform, as part of Task 1.4. This report will also document any unresolved technical issues encountered during this network model assessment, and will discuss how these issues may be addressed through future PEER research.

A.7 PROJECT 5: DECISION PROCEDURES MODULE FOR LIFELINES PLATFORM

A.7.1 Objective

Project 5 will provide a range of procedures that are appropriate for application in electric power or highway system risk/reliability analyses, in order to provide results in forms that can be used to guide decision makers during their use of these results to select a preferred seismic risk reduction option in accordance with their financial and acceptable risk constraints.

A.7.2 Scope

Project 5 will identify and select simplified quantitative deterministic and probabilistic procedures for application to lifeline system risk/reliability analysis results, in order to provide additional information to guide decision making. Idiosyncratic methods such as those requiring elaborate construction of subjective utility functions will not be considered in this project.

One or more simplified decision guidance procedures may be selected for use by a particular decision maker, based on his/her background and cost and risk constraints. To accommodate this range of possible decision-maker backgrounds and constraints, Project 5, will document a range of alternative procedures in sufficient detail to facilitate their integration into the electric power and highway transportation system risk/reliability platforms being developed under Tasks 1.2 and 1.3.

A.7.3 Principal Investigators and Project Staff

The Principal Investigator for Project 5 will be a senior engineer from consulting practice or PEER academia with recognized expertise and experience in seismic risk analysis of lifeline systems and in decision analysis. Technical support for Project 5 will be provided by staff engineers and/or graduate students with appropriate skills in software development.

A.7.4 Task Descriptions

Project 5 will be organized into the following two tasks: (5.1) identification of alternative decision procedures; and (5.2) documentation of procedures for incorporation into platform. These tasks are summarized below.

A.7.4.1 Task 5.1 -- Identification of Alternative Decision Procedures

- ***Scope.*** Based on existing algorithms and heuristics from decision theory, Task 5.1 will identify simplified quantitative procedures that can be applied to lifeline system risk analysis results that enable decision-makers to: (a) carry out more informed evaluations of costs and risks associated with alternative seismic risk reduction options under consideration; and (b) organize their assessments and decisions into familiar decision analysis frameworks. These frameworks may be deterministic or probabilistic; deterministic decision procedures include dominance, mini-max, and maxi-min, and probabilistic procedures include reliability evaluation and various financial evaluation methods (e.g., benefit-cost, least cost, mean-variance, and stochastic dominance). Inputs to all but selected reliability evaluations will typically include initial marginal costs (their present value) of seismic risk reduction alternatives.

- ***End Product.*** Task 5.1 will develop a list of simplified decision methods that can be readily used by decision-makers to determine how various seismic decision alternatives fare in view of various available decision models.

A.7.4.2 Task 5.2 -- Documentation of Procedures for Incorporation into Platform

- ***Scope.*** Task 5.2 will provide detailed documentation of the decision methods identified under Task 5.1. This documentation will be in sufficient detail to facilitate programming of the decision methods, and integrating them into a post-processor for the risk/reliability platforms being developed under Tasks 1.2 and 1.3. Caveats for these decision models will be included among supporting materials for this post-processor.

- ***End Product.*** Task 5.2 will provide a report that documents the decision methods in sufficient detail to facilitate their programming and integration into the electric-power and highway system risk/reliability platforms, as part of Task 1.4. This report will also document any unresolved technical issues encountered while implementing Tasks 5.1 and 5.2, and how these issues may be resolved through future PEER research.

A.8 PROJECT 6: RECOMMENDATIONS FOR FUTURE RESEARCH

A.8.1 Objective

Project 6 will develop recommendations and priorities for future research that builds on the progress and results from Projects 1 through 5 in order to further develop the risk/reliability platforms and its models.

A.8.2 Scope

As part of the implementation of each task from each project carried out during this two-year project, unresolved technical issues and methods for addressing these issues through future PEER research will be documented. Project 6 will prioritize these research issues, and synthesize them into a set of recommendations and priorities for future PEER research.

A.8.3 Principal Investigators and Project Staff

Project 6 will be carried out by a team comprised of the Program Manager plus the Principal Investigators for Projects 1 through 5.

A.8.4 Task Descriptions

Table 4-1 shows that Project 6 will be organized into the following two tasks: (6.1) synthesis of research needs for Projects 1 through 5; and (6.2) program plan documentation. These tasks are summarized below.

A.8.4.1 Task 6.1 -- Synthesis of Research Needs from Projects 1 through 5

- ***Scope.*** Task 6.1 will synthesize, assess, and prioritize the list of research needs identified from each task of this two-year research project, and will develop objectives and approximate scopes and budgets for projects to meet the highest priority needs.

- ***End Product.*** Based on the above prioritizations and also from consideration of PEER Lifeline Program research budget constraints (as provided by PEER Lifeline Program managers), Task 6.1 will develop a list of recommended projects and priorities for future PEER research, and will develop approximate scopes and budgets for the highest priority projects.

A.8.4.2 Task 6.2 – Documentation of Recommended Projects

- ***Scope.*** Task 6.2 will prepare a planning document that identifies objectives and approximate scopes and budgets for each high priority project identified under Task 6.1.

- ***End Product.*** The end product from Task 6.2 will be the above research planning document that will be submitted to the PEER Joint Management Committee for their consideration.