The Owner's Role in Project Risk Management

DETAILS

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U.S. Department of Energy Project Management

Board on Infrastructure and the Constructed Environment

Division on Engineering and Physical Sciences

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Acronyms and Abbreviations

BICE	Board on Infrastructure and the Constructed Environment
CD-0	critical decision 0, approval of mission need
CD-1	critical decision 1, approval of system requirements and alternatives
CD-2	critical decision 2, approval of project baseline
CD-3	critical decision 3, authorization to complete implementation
CD-4	critical decision 4, approval of project completion and transition to operations
DOE	U.S. Department of Energy
EIA	Electronic Industries Alliance
EIR	external independent review
ES&H	environment, safety, and health
FMEA	failure modes and effects analysis
IPRA	International Project Risk Analysis
IPT	integrated project team
PDRI	Project Definition Rating Index
PERT	program evaluation and review technique
SOW	statement of work
WBS	work breakdown structure

Executive Summary

This report was prepared at the request of the U.S. Department of Energy (DOE) as a summary of the most effective risk management practices used by leading owner organizations in project management in the public and private sectors. The methods described here are appropriate for public- and private-sector project owners' representatives, including senior managers, program managers, project directors, and project managers. The primary objective of this report is to provide DOE project directors with a basic understanding of both the risk management role of an owner's representative member of a project management team and the knowledge needed for effective oversight of risk management activities that are delegated to contractors. The report also discusses the roles and responsibilities of senior managers and program managers in developing risk consciousness among all owner, contractor, and supplier personnel by educating them about the importance of explicit consideration of risks and the implementation of an effective risk management process. This document is not intended as a rigid process to be followed for all projects but as a guide for all project stakeholders to ensure that project risks are adequately addressed.

Identification and analysis of project risks are required for effective risk management. One cannot manage risks if one does not characterize them to know what they are, how likely they are, and what their impact might be. But project risk management is not limited to the identification and aggregation of risks, and it cannot be repeated too often that the point of risk assessment is to be better able to mitigate and manage the project risks. Additional effort is needed to develop and apply risk management strategies: Project risk management tools and methods, discussed in this report, can facilitate this effort.

The major steps in a risk management process discussed in this report are the following:

- Project risk identification,
- Qualitative risk assessment,
- Quantitative risk analysis,
- Risk mitigation,
- Setting contingency, and
- Portfolio risk management.

The discussion of the project risk management process in this report is based on the tenets of a proactive approach in which owners take the following basic actions:

- Establish and maintain management commitment to performing risk management on all capital projects.
- Start the risk management process early in the project life cycle, prior to critical decision 0, approval of mission need (CD-0) for all projects.
- Include key stakeholders in the process, with the DOE project director as the lead and the integrated project team intimately involved in the process.
- Evaluate project risks and risk responses periodically during the project life cycle (CD-0 through approval of the start of operations [CD-4]).
- Develop risk mitigation plans and update them as the project progresses.
- Follow through with mitigation actions until risks are acceptable.
- Tie a project's level of risk to cost and schedule contingencies.
- Effectively communicate to all key stakeholders the progress and changes to project risks and mitigation plans.

It should be noted that successful risk management needs to be performed by qualified personnel working within a project management process that includes review and approval by senior management. Critical decision points, such as those defined in DOE O 413.3, are essential for senior managers to ensure the quality of the risk management process and that the risks inherent in a project are necessary and acceptable. Reliance only on team experience, without critical decision reviews, can lead to gaps in analysis and lack of consistency.

In general, the owner is initially responsible for all of the project risks, as it is usually the owner's decision to execute the project or not. In some cases, of course, there may be no completely risk-free strategy, because not executing the project may entail risks to the successful implementation of the owner's mission or business plan. Therefore, the owner has the ultimate responsibility for identifying, analyzing, mitigating, and controlling project risks, including acceptance of the project risks, or modification, or termination of the project—all of which are project risk management activties. Owners who successfully manage projects develop expertise and excellence in actively managing project risks and ensure that this excellence is carried through by their contractors. Tools and methods are available that can form the basis for the development of risk management excellence by owners and contractors. However, traditional project management tools, methods, and practices that are satisfactory for typical, conventional projects may be inadequate for project success on unusual or first-of-a-kind projects. In addition to fundamental practices such as development of a risk management plan, repeated risk assessments, statistical analysis, setting contingencies, and mitigation planning, this report describes the following risk management tools and techniques:

- Database of the events on past projects
- Brainstorming sessions by the project team
- Root cause and essential function analysis
- Repeated risk assessments as new information becomes available
- Impact and probability analysis
- Pareto diagrams
- Failure modes and effects analysis
- Project Definition Rating Index
- Multivariate statistical analysis
- Event trees
- System dynamics
- Sensitivity analysis
- Project simulation
- Stochastic simulation
- Additive models
- Risk mitigation plan
- Risk transfer
- Risk buffering
- Risk avoidance
- Risk control
- Organizational flexibility
- Options

- Risk assumption
- Precise and consistent contingency-setting process
- Risk management plan
- Waterfall diagram
- Risk register

Owners with ongoing programs of multiple projects also develop project portfolio risk management expertise and excellence. The intellectual, theoretical, computational, and other resources necessary to produce excellence in project risk management are available to DOE, but they need to be actively sought out and applied.

1

Introduction

In response to a directive from the Committee of the Conference on Energy and Water Development of the 105th Congress (U.S. Congress, 1997), the Department of Energy (DOE) requested that the National Research Council (NRC) appoint a committee to review and assess the progress made by the department in improving its project management practices. The NRC appointed a committee under the auspices of the Board on Infrastructure and the Constructed Environment to undertake the review and assessment of DOE project management (known as the Phase III review). The committee is composed of 10 professionals with diverse experience in academic, government, and industrial settings and extensive knowledge of project management and process improvement.[1] (See Appendix A for biographies of the committee members.)

The principal task of the committee has been to review and comment on DOE's recent efforts to improve its project management. (See Appendix B for the statement of task.) This committee's efforts are the third phase of evaluative activities that began in 1997. The first phase was an assessment of the need for independent project reviews in the Department of Energy (Phase I) (NRC, 1998), followed in 1998 by a comprehensive assessment of DOE project management practices (Phase II) (NRC, 1999). The current third phase was planned as a 3-year effort beginning in July

[1]Three members of the committee also participated in the Phase II review and assessment (NRC, 1999) and one member participated in both the Phase I (NRC, 1998) and Phase II efforts.

2000 and has produced three annual assessment reports (NRC, 2001, 2003, 2004).

The committee has noted in each of its annual assessment reports that risk management is probably the most difficult aspect of project management, and for many DOE projects it is also the most critical. During the 3 years of the Phase III assessment, the committee observed examples of improvement in DOE's risk management efforts, but also found evidence of persistent deficiencies. In its final annual assessment (NRC, 2004) the committee found that "risk management is an integral requirement of Order O 413.3 but has not been adequately addressed in Manual M 413.3-1 and in *Project Management Principles"* (NRC, 2004, p. 29) and that "a consistent approach to risk identification, assessment, and mitigation would be a first step toward making risk management more useful and usable across the department" (NRC, 2004, p. 29). The committee has recommended that DOE develop guidance for effective risk management beginning prior to approval of mission need (CD-0) and continuing through project execution, and require its implementation for all projects.

This report is provided, at the request of DOE, as a summary of the risk management practices of leading owner organizations in project management in both the public and private sectors. This report therefore simply attempts to summarize what the committee believes constitutes excellence in project risk management. The methods described here are appropriate for public- and private-sector project owners' representatives, including senior managers, program managers, project directors, and project managers. The objective of this report is to summarize the knowledge of project risk management needed by an owner's representative to understand both issues that require active owner participation and issues that require oversight of activities that are delegated to contractors. For DOE this representative is primarily the project director; however, program directors and senior managers also have responsibilities for effective project risk management and therefore need a thorough understanding of the owner's role in project risk management.

This report is based on the expertise and experience of the committee members as noted in their biographies. The report is presented as a resource for DOE and all project owners who are concerned with risks in their projects. Chapter 2, "Owners' Roles and Responsibilities," provides an overview of project teams and the overall enterprise direction deemed necessary for successful project risk management. Chapter 3, "Properties of Project Risks," defines project risks and describes activities to manage them. Chapter 4, "Risk Identification and Analysis," covers risk analysis techniques and the managerial skills needed to interpret risk assessments. Chapter 5, "Risk Mitigation," describes actions that owners' representatives can take to reduce the impact of identified risks if they occur. Chapter 6, “Contingency,” defines contingency and discusses the implications of various approaches to setting cost and schedule contingencies for projects. Chapter 7, “Active Risk Management,” discusses how owners can use risk identification, analysis, and mitigation to increase project success. Chapter 8, “Portfolio Risk Management,” identifies the challenges and opportunities for owners of multiproject programs for managing and reducing overall risks. Chapter 9, “Conclusions,” is an overview of the actions owners can take to achieve excellence in risk management.

2

Owners' Roles and Responsibilities

INTRODUCTION

Managing risk is one of an owner's most important functions in making any major project successful. In general, the owner is initially responsible for all of the project risks, as it is usually the owner's decision to execute the project or not. (Of course, the owner may not have a completely risk-free strategy, because not executing the project may entail risks to the successful implementation of the owner's mission or business plan.) The owner has the ultimate responsibility for identifying, analyzing, mitigating, and controlling project risks, including acceptance of the project risks, or modification, or termination of the project—all of which are project risk management activities. This is true whether the project execution is managed directly by the owner or by contractors under the owner's supervision.

Effective risk management begins with risk assessment. There are two primary purposes for a preproject risk assessment: (1) to decide whether to execute the project and accept the risks, or terminate it as unacceptably risky and (2) to identify the highest-priority risk factors that should receive the most attention by management.

One form of risk mitigation for the owner is to transfer some of the project risks by contract to others, presumably at a mutually acceptable price. For example, under a cost-plus-fee contract, the owner retains the cost risk; however, under a fixed-price contract, the owner seeks to transfer the cost risk to the contractor. Whether the fixed-price or cost-plus-fee approach is more beneficial to the owner depends on circumstances, such as whether the owner or the contractor is better able to manage the risks.

If the owner is going to have a cooperative, integrated project team, the entire team has to share the objective of risk reduction for every member of the project, rather than delegating the responsibility to one participant who may have incentives to impose risks on the other project members. Contractors and consultants may play major roles in identifying, analyzing, mitigating, and controlling project risks, but project risk management is not a function that the owner can completely delegate to contractors or to consultants with impunity. There are no paradigms for assigning responsibility for specific risk management activities to the members of the project team. The optimal delegation of responsibilities needs to be determined by the owner, then tracked and managed using the tools described in Chapter 7. There remains an essential role for the owner that cannot be delegated—the responsibility for the management of the owner's interests and the owner's risks.

OWNER'S ROLE

Senior Executives

The Department of Energy's (DOE's) senior management has the responsibility for developing risk consciousness among all owner, contractor, and supplier personnel by educating them about the importance of explicit consideration of risks. Risk consciousness is the development of a viewpoint that continually examines how risks may occur and what their impact might be. It is analogous to the mindset of an experienced safety professional entering a construction work site; such a person would have developed a trained eye for risky situations and could automatically assess what could go wrong. In former years, some people opposed the introduction of integrated safety management on the basis that it would stop construction projects in their tracks or make them prohibitively expensive. These objections turned out to be false, and the value of safety programs is now unquestioned. Similarly, project risk management can be effectively carried out without stopping projects dead in their tracks or even slowing them down. Risk consciousness, like safety consciousness, has to flow from the top throughout the enterprise; in order to develop it in an organization, senior management must have it and they must constantly communicate the need for it to all program managers and project teams.

Program Managers

DOE program managers oversee the management of risks for multiple projects and should have the authority to ensure that the policies and procedures established by senior owner executives are followed. They have the responsibility to transfer the risk consciousness established by senior executives to line project directors and managers. They also have the opportunity to manage risks across projects and to transfer lessons learned from one project to another. (See Chapter 8 regarding management of project portfolio risks.)

Project Directors

DOE project directors are the owner's representatives responsible for implementing risk management policies and procedures. They have direct involvement and oversight of efforts to identify, analyze, mitigate, and control project risks from inception through completion. Project directors should have a thorough knowledge of project risks as well as of risk management tools and their implementation. They are responsible for leadership of the project management team, oversight of contractors and consultants, notification of senior management when significant risks arise, and management of risks during project execution.

Integrated Project Team

Risk identification is one of the most important functions of the project management team, and is one major reason the team should be formed early in the project (or even before) and should meet face-to-face as soon as possible. Members of the project management team should be selected on the basis of their breadth of experience and diverse viewpoints to make sure that all significant project risks are identified. Even if contractors execute the project, the owner's project representative should be informed and actively involved in risk management.

Contractors and Consultants

In an environment where ongoing program and project management is delegated to contractors, the owner nonetheless retains the responsibility to ensure that the contractors employ qualified personnel and apply appropriate risk management practices. Because the owner maintains the burden of many irreducible project risks, it is essential that the owner's representatives take an active role in all phases of risk management, including knowledgeable oversight and review of tasks undertaken by contractors and consultants.

Successful project execution begins with selection of the right contractor. Contractor proposals should demonstrate successful experience in employing risk management methods in past performance on comparable projects. The weight given to risk management as a factor in contractor selection is one way for the owner to show a commitment to improving project performance through effective risk management.

As DOE relies more and more on performance-based approaches for acquiring services, in keeping with the President's management objectives, it becomes critical that both contractor and government work in partnership to achieve the outcomes sought. With effective acquisition planning and a well-defined risk mitigation plan developed at the front end of the project, DOE and the contractor together are well positioned to deal with problems in execution as they arise. However, for these plans to be effective there has to be continuing communication between the department and the contractor once the work is under way. Both parties must be willing to adjust approaches as necessary to keep the project on track. Success depends on a flexible, coordinated approach for managing risks well before they have a significant negative impact on the project.

One way for owners to augment their ability to manage risk is to seek consulting support and technical assistance from firms that specialize in project risk management. This approach enables the owner to take advantage of the expertise of individuals who regularly deal with these types of problems and can help ensure that risk management concerns are fully addressed in the development of acquisition plans and work plans.

Reviewers

Objective and impartial external consultants and advisors can provide essential input on risk management. Evaluation of risk management functions, responsibilities, and plans should be specified as one of the major components of external independent reviews (EIRs) (NRC, 1999, 2001, 2003) and is a major reason why EIRs should be implemented. EIRs are typically performed prior to approval of the performance baseline (CD-2) and in some cases prior to approval of alternative selection and cost range (CD-1). Outside independent reviewers may identify potential risks that project personnel miss, so it is entirely in the owner's interest to obtain these independent opinions for the reassurance they can provide. DOE managers should determine when EIRs should be used, the depth and breadth of coverage of the reviews, specific risks to be examined, and other issues relevant to the owner's interests. Project management should be required to address all risks identified in EIRs in the same way as risks identified by the project team.

DEVELOPMENT OF RISK MANAGEMENT EXCELLENCE

All projects experience some degree of uncertainty, and some uncertainties can create risks to achieving the project objectives. The successful management of these risks is therefore critical to project success. Furthermore, traditional project management tools, methods, and practices that are satisfactory for typical, conventional projects may be inadequate for project success on unusual or first-of-a-kind projects.

Risk management that follows typical industry good practices that have been developed on conventional projects, and that may be perceived as low-risk simply because they have been done many times, is not enough for projects that have more than the usual level of risk. Improved risk management abilities are needed if future projects are to be managed more successfully than those in the past. It is not sufficient to apply business-as-usual risk management techniques and expect to get good results. Even supposedly low-risk projects may be susceptible to unanticipated risks, just as many conventional projects were recently surprised by the run-up in steel prices, perhaps indicating that the lessons of the mid-1970s have been forgotten.

Improved risk management tools and methods are being actively developed by a number of organizations and can form the basis for the development of risk management excellence by DOE and contractors. Thus the intellectual, theoretical, computational, and other resources necessary to produce significant improvements in project risk management are available, but they need to be actively sought out and applied by managers at all levels. Owners' representatives need to draw on these resources to develop expertise and excellence in actively managing project risks, and they need to ensure that this excellence is carried through by their contractors. Knowledgeable owners ensure that both their own personnel and their contractors are using the most appropriate risk management methods and that risk analysis is neither excessive nor too little. Owners with ongoing programs of multiple projects especially need to develop their own risk management expertise and excellence and should not expect contractors to look out for the owner's risks unless they are specifically and properly directed to do so.

Project managers are inherently motivated to achieve the intended project goals and are therefore motivated to manage project risks effectively. Although this is generally the case, Flyvbjerg (2002) has argued that there are times, especially in large projects, when project managers are motivated to obscure or hide the risks inherent in a project. It is the responsibility of senior managers to ensure that project teams thoroughly identify, analyze, mitigate, and manage all project risks. Because the outcome of projects is influenced by many factors beyond the control of risk management, the quality of project risk management is difficult to assess. Senior managers need to establish policies and procedures as well as a thorough understanding of risk management to ensure that all risks have been considered and properly addressed before allowing projects to proceed past critical decision points.

MANAGERIAL ATTITUDES TOWARD RISK AND UNCERTAINTY

Project risk may be defined simply as the possibility of an unintended future event with potential undesirable consequences. For precisely this reason, project risks are difficult to manage, because they relate to events that may or may not occur. Risk is a concept that encompasses things, forces, or circumstances that pose a threat to people or what they value (NRC, 1996). In the context of project management, risk has several dimensions, such as mission-related risk, cost or schedule risk, or risks to the environment, safety, or health. The development of effective and efficient project-specific risk management strategies requires the use of risk assessment, a decision technique that systematically incorporates consideration of adverse events, event probabilities, event consequences, and vulnerabilities.

Uncertainty, as it relates to project performance, cost, quality, and duration, comes from a lack of knowledge about the future. It is neither objective nor measurable but rather based on subjective assessments, which can differ between observers. Managers must therefore make decisions in an uncertain world and, in the absence of good historical databases, subjective probability estimates are the only available measures of uncertainty.

Decision Theory and Managerial Perspective

Projects continually face new risks, which must be identified, analyzed, and understood in order to develop a framework both for selecting the right projects to execute and for successfully executing them. Thus project owners, sponsors, and managers are increasingly concerned with ways to analyze risks and to mitigate them.

However, the term "risk" has different meanings to different people. In decision theory, risk is defined as variation in the distribution of possible outcomes, a definition that allows the risks of alternatives to be quantified, calculated, expressed numerically, and compared. But most project managers do not use the decision-theory definition of risk. That is, they do not evaluate it on the basis of uncertainty or probability distributions, as used in decision theory, but rather, as March and Shapira (1987) observed, on the basis of the following general characteristics:

- Managers typically define risk as their exposure to loss.
- Managers aren't necessarily interested in reducing project risks to a single number. Instead, risks are considered multidimensional, with the maximum exposure considered for each risk dimension.
- Managers are more likely to take risky actions when their jobs are threatened than when they feel safe. The risks taken on a project are relative to the alternative options and opportunities available. For example, contractors will take more risks (such as submitting very low bids to buy jobs) when business is bad and their survival is under threat than they are willing to take when they have ample backlogs.

Managers do not act as if risks were immutable properties of the physical world. Successful managers believe that they can control risks through their expertise; that is, they act as if risks are manageable. And the more successful managers have developed proven methods by which they can in fact more predictably control risks. Conversely, project managers may be unwilling to accept risks if they have not had experience successfully managing projects under similar conditions of technological challenges, public scrutiny, regulatory constraints, outside stakeholder influence, tight budgets, tight schedules, unusual quality requirements, fixed-price contracts, adversarial relations with contractors, and other factors that add risks to projects. But even successful project managers may not always be correct in their assumption that they can control risks, and making mistakes in this regard can have serious consequences. Therefore, even successful project managers need to know about risk management methodology in order to support the self-confidence they need to control risks.

In summary, the empirical, managerial approach to risk is as follows:

- Break down the total risk into its components.
- Analyze the risk for each component, in terms of its maximum exposure for loss.
- If any risk is unacceptable, take steps to reduce it, mitigate it, or otherwise manage it.
- Revise the project until the risks are acceptable or a plan is in place to actively reduce the risks to acceptable levels.

The decision-theory and managerial approaches to risk are compared in Table 2-1.

TABLE 2-1 Two Complementary Approaches to Risk Management

Decision Theory	Managerial
Sees risks as probability distributions	Sees risks as maximum exposures
Synthesizes individual risks into one risk factor	Breaks out risks into individual components
Quantifies risks numerically	Characterizes risks verbally and qualitatively
Looks at probability distributions over all conceivable outcomes	Looks at relatively few critical outcomes
Sees risks as uncontrollable random events	Sees risks as avoidable and controllable

Integrating Two Approaches to Risk

Although decision-theory and managerial viewpoints on risk are different, they are not mutually exclusive. Managers are better equipped to take risks when they have both effective tools to assess the nature of the risks involved and the information necessary to control and manage these risks. Experience shows that many projects have not been successful in containing risks because project managers used inappropriate methods and did not see the need to apply risk management methodologies. Learning risk management on the job can be an educational experience that is very expensive for the project's owner.

A better solution lies in integrating the two approaches to risk described above. By identifying, objectifying, quantifying, and estimating risks, and by assessing individual risks through simulation, scenario analysis, decision analysis, and other techniques, project managers can do what engineers do—that is, compensate for lack of direct experimental evidence by means of thorough analysis and appropriate safety factors. By synthesizing the managerial approach to risk with analytical methods, project managers are better able to manage risks, because the analytical approach requires the risks to be quantified and allows the systematic evaluation of the best methods to control them.

3

Properties of Project Risks

INTRODUCTION

Identification and analysis of project risks are required for effective risk management. One cannot manage risks if one does not characterize them to know what they are, how likely they are, and what their impact might be. This chapter focuses on the general attributes of project risks. But project risk management is not limited to the identification and aggregation of risks, and it cannot be repeated too often that the point of risk assessment is to be better able to mitigate and manage the project risks. Additional effort is needed to develop and apply risk management strategies: Project risk management tools and methods, discussed later, can facilitate this effort.

Inadequate or untimely characterization of risks has a number of consequences, all of them detrimental to the project:

- Time and money may be spent needlessly to prepare for risks that are actually negligible.
- The need for contingency allowances may be overstated, tying up the owner's funds, preventing other vital projects from being funded (opportunity costs) (Mak and Picken, 2000), and resulting in increased project costs, as excess contingencies are typically expended rather than returned to the project sponsor.
- Contingency allowances may be understated, leading to budget or schedule overruns and often performance and quality shortfalls as well, as quality and scope are reduced in an attempt to keep costs within the budget.

- Actual significant risks may be missed and result in unwelcome surprises for the project manager and owner—cost overruns, completion delays, loss of functions to be provided by the project, and even cancellation.

GENERAL PROJECT RISK CHARACTERIZATION

The types of project risks addressed in this report include these:

- *Performance, scope, quality, or technological risks.* These include the risks that the project when complete fails to perform as intended or fails to meet the mission or business requirements that generated the justification for the project. Performance risks can also lead to schedule and cost risks if technological problems increase the duration and cost of the project.
- *Environment, safety, and health risks.* These include the risks that the project may have a detrimental effect on the environment or that hidden hazards may be uncovered during project execution. Serious incidents can have a severe impact on schedule and costs.
- *Schedule risk.* This is the risk that the project takes longer than scheduled. Schedule risk may also lead to cost risks, as longer projects always cost more, and to performance risk, if the project is completed too late to perform its intended mission fully. Even if cost increases are not severe, delays in project completion reduce the value of the project to the owner.
- *Cost risk.* This is the risk that the project costs more than budgeted. Cost risk may lead to performance risk if cost overruns lead to reductions in scope or quality to try to stay within the baseline budget. Cost risk may also lead to schedule risk if the schedule is extended because not enough funds are available to accomplish the project on time.
- *Loss of support.* Loss of public or stakeholder support for the project's goals and objectives may ultimately lead to a reduction of scope and to funding cuts, and thus contribute to poor project performance.

Although the above types of risks may be encountered in an almost infinite variety of forms and intensity, it is most useful to consider two varieties:

- *Incremental risks.* These include risks that are not significant in themselves but that can accumulate to constitute a major risk. For example, a cost overrun in one subcontract may not in itself constitute a risk to the project budget, but if a number of subcontracts overrun due to random causes or a common cause (i.e., a common mode failure) affecting them all, then there may be a serious risk to the project budget. While individually such risks may not be serious, the problem lies in the combination of a number of them and in the lack of recognition that the cumulative effect is a significant project risk. An obvious example of an incremental risk in construction is weather-related delays, which are not usually major problems in themselves, but a long run of inclement weather that impedes progress on the project may create a serious challenge to the schedule and budget.

An example of a common mode failure in the nuclear area is the 1975 fire at the Brown's Ferry nuclear plant. The fire started in the cable trays, caused by a workman using a candle to detect leaks. Three independent safety trains were designed to inject cooling water into the core of the reactor. However, the power cables for all three trains were routed through the same cable trays. Therefore, the risk of all three safety injection pumps failing to operate was just the risk that a fire occurred in the cable tray—the three safety trains were correlated, not independent. This incident led directly to the development of the methodology of probabilistic risk assessment and its required implementation at all nuclear power plants. The lesson learned from this is that independence of risk events is something that must be demonstrated, not merely assumed.

- *Catastrophic risks.* These include risks that are individually major threats to the project performance, ES&H, cost, or schedule. Their likelihood can be very low but their impact can be very large. Examples of such risks are dependence on critical technologies that might or might not prove to work, scale-up of bench-level technologies to full-scale operations, discovery of waste products or contamination that are not expected or not adequately characterized, and dependence on single suppliers or sources of critical equipment.

CONSEQUENCES OF INCREASED PROJECT UNCERTAINTY

Studies of projects with low and high degrees of uncertainty (see, e.g., Shenhar, 2001) show that as uncertainty increases there is also an increased likelihood of the following:

- Increased project budgets,
- Increased project duration,
- Increased planning effort,
- Increased number of activities in the planning network,
- Increased number of design cycles,
- Increased number of design reviews,

- Delayed final design,
- Increased need for exchange of information outside of formal meetings and documentation,
- Increased management attention and effort (probabilistic risk assessment, risk mitigation),
- Increased systems engineering effort, and
- Increased quality management effort.

The use of techniques and skills that are appropriate to low-uncertainty projects may give poor results when applied to high-uncertainty projects, for which a flexible decision-making approach focused on risk management may be more successful. The owner can determine whether a project is very low risk or has significant risks by performing a risk assessment, which starts with risk characterization.

RISK MANAGEMENT STRATEGIES

The effectiveness of risk management strategies varies for different project risk profiles. Following are two examples of the applicability of different strategies:

- For relatively certain projects, fast decision making can minimize uncertainties from delays caused by regulatory changes, political changes, or economic changes.
- For projects with a high level of uncertainties, purposeful postponement of some decisions or commitments can reduce risks through acquisition of more or better information that will lead to better decisions. This includes keeping options open as long as possible but explicitly does not include managerial procrastination in the hope that some miracle will happen.

Thus risk management strategies are not one-size-fits-all but need to be matched to the risk profiles and objectives of the project and of the owner's total project portfolio. Project directors need to be knowledgeable about project risk management tools in order to develop comprehensive risk management plans prior to project approval for design or construction funding.

The major steps in determining the appropriate risk management strategies include the following:

- Development of risk awareness,
- Project risk identification,
- Qualitative risk assessment,

- Quantitative risk assessment,
- Risk prioritization,
- Risk mitigation, and
- Active, ongoing risk management.

Project risk management starts with the development of risk awareness on the part of all project personnel, suppliers, and contractors. The development of risk consciousness is similar to the development of safety consciousness on construction sites, which requires unremitting attention by the owner's management and demonstration of the management's commitment to this issue at every opportunity. One might argue that, considering the constant barrage of safety messages, nothing more remains to be said; the object, however, is not to say something new but to keep repeating the same message over and over until it becomes part of the culture. People on construction sites may initially assume that safety is the responsibility of the safety engineer, but the consistent message has to be that it is everyone's responsibility. Safety consciousness is achieved when all personnel understand that they cannot ignore any unsafe condition. Similarly, risk consciousness is achieved when everyone on the project knows that he or she cannot ignore any potentially risky condition in the belief that risk management is someone else's responsibility.

That said, certain aspects of project risk management are the responsibility of particular personnel. Qualified personnel with in-depth understanding of the project should perform risk identification and analyses. Technological risk assessments may be performed by outside consultants with specialized knowledge. Regardless of who prepares the risk assessments, they should be separately evaluated by independent qualified personnel and reviewed by management for a "reality check" of the reasonableness of the assumptions, results, quality, and completeness of the process. If deficiencies are identified, corrective action plans should be prepared and implemented.

Owners and contractors need to jointly develop and implement a coordinated risk mitigation planning process. This point implies that owners and contractors have a common purpose—not an adversarial situation in which each entity tries to shift its risks to another. Adversarial relationships on a project are an indication that risk management is nonexistent or has failed.

Project risks and risk management responses need to be reassessed and revised throughout the project's life cycle. Risk assessments and risk management plans should be part of the documentation for every critical decision point—especially the early ones required by the DOE policies defined in O 413.3. Risk mitigation plans should be documented, independently reviewed, critiqued, and reworked as needed so that management may permit the project to proceed to the next phase with confidence that the project risks are acceptable and are being adequately managed.

4

Risk Identification and Analysis

INTRODUCTION

Ensuring that adequate and timely risk identification is performed is the responsibility of the owner, as the owner is the first participant in the project. The sooner risks are identified, the sooner plans can be made to mitigate or manage them. Assigning the risk identification process to a contractor or an individual member of the project staff is rarely successful and may be considered a way to achieve the appearance of risk identification without actually doing it.

It is important, however, that all project management personnel receive specific training in risk management methodology. This training should cover not only risk analysis techniques but also the managerial skills needed to interpret risk assessments. Because the owner may lack the specific expertise and experience to identify all the risks of a project without assistance, it is the responsibility of DOE's project directors to ensure that all significant risks are identified by the integrated project team (IPT). The actual identification of risks may be carried out by the owner's representatives, by contractors, and by internal and external consultants or advisors. The risk identification function should not be left to chance but should be explicitly covered in a number of project documents:

- Statement of work (SOW),
- Work breakdown structure (WBS),
- Budget,
- Schedule,

- Acquisition plan, and
- Execution plan.

METHODS OF RISK IDENTIFICATION

There are a number of methods in use for risk identification. Comprehensive databases of the events on past projects are very helpful; however, this knowledge frequently lies buried in people's minds, and access to it involves brainstorming sessions by the project team or a significant subset of it. In addition to technical expertise and experience, personal contacts and group dynamics are keys to successful risk identification.

Project team participation and face-to-face interaction are needed to encourage open communication and trust, which are essential to effective risk identification; without them, team members will be reluctant to raise their risk concerns in an open forum. While smaller, specialized groups can perform risk assessment and risk analysis, effective, ongoing risk identification requires input from the entire project team and from others outside it. Risk identification is one reason early activation of the IPT is essential to project success.

The risk identification process on a project is typically one of brainstorming, and the usual rules of brainstorming apply:

- The full project team should be actively involved.
- Potential risks should be identified by all members of the project team.
- No criticism of any suggestion is permitted.
- Any potential risk identified by anyone should be recorded, regardless of whether other members of the group consider it to be significant.
- All potential risks identified by brainstorming should be documented and followed up by the IPT.

The objective of risk identification is to identify all possible risks, not to eliminate risks from consideration or to develop solutions for mitigating risks—those functions are carried out during the risk assessment and risk mitigation steps. Some of the documentation and materials that should be used in risk identification as they become available include these:

- Sponsor mission, objectives, and strategy; and project goals to achieve this strategy,
- SOW,

- Project justification and cost-effectiveness (project benefits, present worth, rate of return, etc.),
- WBS,
- Project performance specifications and technical specifications,
- Project schedule and milestones,
- Project financing plan,
- Project procurement plan,
- Project execution plan,
- Project benefits projection,
- Project cost estimate,
- Project environmental impact statement,
- Regulations and congressional reports that may affect the project,
- News articles about how the project is viewed by regulators, politicians, and the public, and
- Historical safety performance.

The risk identification process needs to be repeated as these sources of information change and new information becomes available.

There are many ways to approach risk identification. Two possible approaches are (1) to identify the root causes of risks—that is, identify the undesirable events or things that can go wrong and then identify the potential impacts on the project of each such event—and (2) to identify all the essential functions that the project must perform or goals that it must reach to be considered successful and then identify all the possible modes by which these functions might fail to perform. Both approaches can work, but the project team may find it easier to identify all the factors that are critical to success, and then work backward to identify the things that can go wrong with each one.

Risk identification should be performed early in the project (starting with preproject planning, even before the preliminary concept is approved) and should continue until the project is completed. Risk identification is not an exact science and therefore should be an ongoing process throughout the project, especially as it enters a new phase and as new personnel and contractors bring different experiences and viewpoints to risk identification. For this reason, the DOE project director should ensure that the project risk management plan provides for periodic updates.

METHODS OF QUALITATIVE RISK ASSESSMENT

The goal of risk identification is not only to avoid omissions but also to avoid the opposite pitfall—of being distracted by factors that are not root causes but only symptoms. Treating the symptoms, rather than the root causes, will give the appearance of activity but will not solve the problem. Unfortunately, identification of symptoms is far easier than identification of root causes. Project owners should ensure that the risk identification process goes beyond the symptoms. While outside, disinterested reviewers can sometimes help perform this function, the following sections describe methods that can be used by project personnel to identify risks and their causes.

Risk Screening

Following the initial risk identification phase, the project director should have a working list of risks that have been identified as potentially affecting the project. From this list, the project director should differentiate those that seem minor and do not require further attention from those that require follow-up, qualitative analysis, quantitative analysis, and active mitigation and management. This process requires some qualitative assessment of the magnitude and seriousness of each identified risk. Various methods that have been developed to assess failures in physical equipment and systems have also been applied in one form or another to project risks.

The commonly used risk tool shown in Table 4-1 is a two by two matrix that allows assigning a risk to one of four quadrants based on a qualitative assessment of its relative impact (high or low) and the likelihood of its occurrence (high or low). Risks in the upper right quadrant

TABLE 4-1 Risk Screening Based on Impact and Probability

Likelihood of Occurrence	High		
	Low		
		Low	High
		Relative Impact	

need the most attention. Finer gradations of impact and likelihood—for example, very high, high, medium, low, and very low (a five by five matrix)—would allow a more nuanced consideration of the attention needed.

Low Impact, Low Probability

Risks that can be characterized as both low impact and low likelihood of occurrence are essentially negligible and can usually be eliminated from active consideration. The main concern of the owner's project director is to monitor these factors sufficiently to determine that the impact or likelihood does not increase.

High Impact, High Probability

Risks that are characterized as both high impact and high likelihood of occurrence often cause a project to be terminated, or to fail if it is continued in spite of the risks. In this situation, the owner's management must determine if the project should be terminated or if the project is so mission critical or the potential benefits are so great that taking the risks is justified. Risk management does not imply that no risks are taken; it means that the risks taken should be calculated risks. For example, an owner may decide to proceed if there is a reasonable expectation that enough engineering or management effort can reduce either the impact or the likelihood of the events, such that the risk can become either low impact, high probability or low probability, high impact. Often such a decision is contingent on achieving the necessary risk reductions by some deadline.

Low Impact, High Probability

Low-impact, high-probability risks are those largely due to uncertainties about a number of elements that may be individually minor risks but that in the aggregate could amount to a significant risk. These include uncertainties concerning the actual costs of labor and materials (such as steel), the actual durations of activities, deliveries of equipment, productivity of the workforce, changes due to design development or the owner's preferences, and other uncertainties that are typically considered to lie within the natural variability of project planning, design, construction, and start-up (they do not include catastrophic events or radical design changes). Each of these uncertainties, taken alone, would have little impact on the project. However, taken together, there is the possibility that many of the estimates of these factors would prove to be too optimistic, leading to cumulative effects such as performance shortfalls, schedule overruns, and cost overruns. Methods for dealing with such risks include

- Provision for adequate contingencies (safety factors) for budget and schedule (contingencies are discussed in Chapter 6).
- Improvement in the work processes in order to reduce the uncertainties. Prefabrication of major components to avoid the uncertainties of construction at a job site is one example of changing the normal process to reduce risks (although in this example the change may also introduce new risks, such as transportation of the components to the job site; thus the resolution of one risk may give rise to another).

High Impact, Low Probability

By definition, high-impact, low-probability events are rare occurrences, and therefore it is very difficult to assign probabilities to them based on historical records. Data do not exist and so subjective estimates of probabilities are necessary. However, the objective is not the scientific determination of accurate probabilities of rare events but the determination of what management actions should be taken to monitor, mitigate, and manage the risks. For example, if a certain risk is identified and management determines that some specific mitigation actions should be taken if the risk has a likelihood of more than 1 in 100 of occurring, then a precise characterization of the probability is unnecessary; the only issue is whether it is assessed to be more than 1 in 100 or less than 1 in 100.

Pareto Diagrams

One of the important uses of a good risk analysis is to determine where to apply management resources and what to leave alone, as management resources are not unlimited. One approach is to break down the uncertainties into manageable parts. Pareto diagrams are one way to show the sources of uncertainty or impact in descending order. This form of presentation makes explicit those activities that have the greatest effect on the project completion date or cost and that therefore require the greatest management attention. The project director or manager must then determine whether the high-ranking events are (1) truly root causes or (2) simply work packages or activities that may reflect underlying causes but are themselves symptoms. The resulting analysis can provide guidance for managers to reduce, mitigate, buffer, or otherwise manage these sources of uncertainty.

As a simple illustration, suppose we are interested in determining which work packages have the greatest effects on the uncertainty in the total cost. First, we estimate the uncertainty, or variance, in the cost of each individual work package. Second, we estimate the correlations or associations between each pair of work packages. Then, by elementary second-moment theory (Benjamin and Cornell, 1970),[1] the sensitivity of the uncertainty in the total project cost with respect to each work package is proportional to the combination of the activity uncertainties and the correlations between activities. That is, the uncertainty in the total cost is affected not only by the uncertainty in each work package but also by how much each work package affects, and is affected by, the others. As an elementary example, the uncertainty in the cost of a construction project may be more sensitive to outdoor activities than to indoor activities because unusually bad weather can cause a number of outdoor activities to run over budget and over schedule simultaneously, whereas indoor activities are typically not linked so tightly to the weather. By tabulating these values for all work packages, and sorting them from largest to smallest, we can identify those work packages with the largest sensitivities, which are those to which the project manager should give the highest priority. If we do this for a project of, say, 20 work packages and sort them according to the largest values of the sensitivities, we can then plot a Pareto diagram, as shown in Figure 4-1. (The absolute values of the sensitivities have no importance; the only concern is the relative values.)

Failure Modes and Effects Analysis

In project risk assessment, a failure can be any significant event that the sponsor does not want to happen—a budget overrun, a schedule overrun, or a failure to meet scope, quality, or mission performance objectives. While risks may arise from specific causes, they may also be the result of general environmental conditions that are not limited to specific times and places but are pervasive throughout the project. The objective of failure modes and effects analysis is the identification of root or common causes, which may affect the project as a whole. Often this identification is facilitated by methodically considering the project function by function,

[1]All probability distributions may be characterized by their moments. Second-moment theory is the use of the second moments of probability distributions—that is, means, variances, and covariances (or correlation coefficients), instead of full probability distribution functions. As probability distributions are subjective and therefore not capable of precise definition, this approximate method can greatly simplify many calculations and, more importantly, provide the risk analyst with insight into the effects of uncertainty on project outcomes.

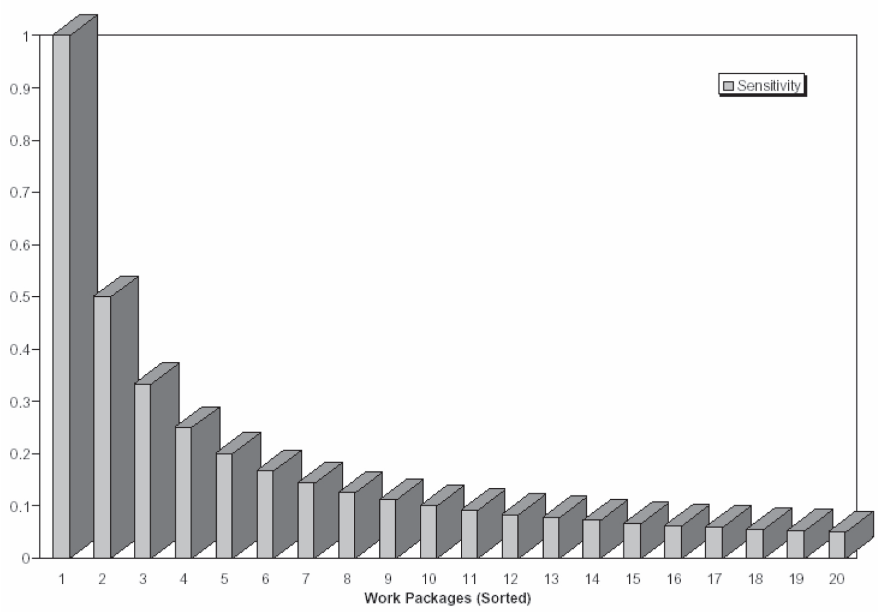

FIGURE 4-1 Pareto diagram.

to try to avoid omissions. Identification of potential risks that turn out, upon further assessment, to be negligible is a waste of time; however, failure to identify potential risks that turn out to be serious is a threat to the project. Therefore, the project director should err on the side of caution when identifying possible risks.

Failure modes and effects analysis (FMEA) is a discipline or methodology to assist in identifying and assessing risks qualitatively. It is a method for ranking risks for further investigation; however, it is not a method for quantifying risks on a probabilistic basis (Breyfogle, 1999). FMEA is typically based on a subjective assessment of the relative magnitudes of the impacts of the risk events on the project (often on a scale from 1 to 10), multiplied by the relative likelihood that the risk event will occur (also on a scale from 1 to 10). In addition, a third parameter may be included to assess the degree of warning that the project will have regarding the actual occurrence of the risk event (again on a scale from 1 to 10). This third parameter may give some management support by establishing early warning indicators for specific serious risks, which might not otherwise have been established.

The purpose of assigning these values for all significant risks is only to rank the risks and to set priorities for subsequent quantitative analysis of the significant risks. In the absence of more quantitative factors, such as sensitivity analysis, the failure modes, or better, all root causes, can be used to rank the risks. One can prepare a Pareto chart that shows the risks ordered by possible impact or by the combination of impact and likelihood of occurrence. Then risk mitigation efforts can first address the failure mode or root cause with the highest impact and work from there.

The three factors—severity, likelihood, and leading indicators—interact. For example, if the project is the construction of a facility in a flood plain or an area with poor drainage, then a failure mode could be flooding of the work site. Project management cannot affect the frequency of floods, so risk management must focus on trying to reduce the severity of the impact of a flood. If the control method is to buy flood insurance and then evacuate personnel and abandon the site if the water rises, then measuring the height of the water (the "Nilometer" method) may be a sufficient indicator. If the control method is to reduce the severity of loss by placing sandbags around the perimeter and renting pumps, then measuring the water height may have little impact on the mitigation effort; but measuring the rainfall across the watershed may be more appropriate because it allows time to implement the control. If the control method is to build a cofferdam around the site before constructing anything else, then the choice of leading indicator may be irrelevant.

Efforts to mitigate the risks will focus on the impact, likelihood, and detectability of the most serious risk or its root causes and will try to reduce these factors until this risk becomes as low as or lower than the next higher risk. As this process continues, the most important risks will be reduced until there are a number of risks essentially the same and a number of other risks all lower than the first group. The first group will require specific management actions and may require constant monitoring and attention throughout the project. The second group will be monitored, but with lower priority or frequency. The first group is considered the critical group, much like the critical-path activities in a network schedule; the second group is the noncritical group, which must be watched primarily to see that none of the risks from this group become critical.

It should be emphasized that this form of risk assessment is qualitative and relative, not quantitative and absolute. It is primarily for distinguishing between risks that require follow-up and management, because of high impact or high likelihood (or both), and risks that do not appear to require follow-up, because of both low impact and low likelihood. It should be clearly understood that there is no quantitative assessment of the overall risk to the total project: The severity factors are not estimated in terms of loss of dollars, the likelihoods of occurrence are not probabilities, and there is no cost-benefit analysis of the risks versus the control methods. The analysis only identifies risk priorities in a methodical way to help direct further risk management activities. It is left to the judgment of the project engineers, designers, and managers to determine the appropriate risk mitigation and control measures to achieve an acceptable level of risk. Note especially that risks with a low likelihood of occurrence but very high severities may require follow-up and management action.

Due to changes in project conditions or perceptions, even risks that appear to have low impact and high likelihood at one time may appear differently at another. Therefore, the owner's representatives have the responsibility to reevaluate all failure modes and effects periodically to ensure that a risk previously considered negligible has not increased in either impact or likelihood to a level requiring management attention.

Project Definition Rating Index

The Project Definition Rating Index (PDRI) is an example of an additive qualitative risk assessment tool (CII, 1996, 1999). The PDRI is used in front-end project planning to help the project team assess project scope definition, identify risk elements, and subsequently develop mitigation plans. It includes detailed descriptions of issues and a weighted checklist of project scope definition elements to jog the memory of project team participants. It provides the means to assess risk at various stages during the front-end project planning process and to focus efforts on high-risk areas that need additional definition. The PDRI facilitates the project team's assessment of risks in the project scope, cost, and schedule. Each risk element in the PDRI has a series of five predetermined weights. Once the weights for each element are determined they are added to obtain a score for the entire project. This score is statistically correlated with project performance to estimate the level of certainty in the project baseline.

METHODS OF QUANTITATIVE RISK ANALYSIS

After risk factors are assessed qualitatively, it is desirable to quantify those determined by screening activities to be the most significant. It cannot be repeated too often that the purpose of risk assessment is to be better able to mitigate and manage the project risks—not just to compute project risk values. The assessment of risks attributed to elements completely out of project management control—such as force majeure, acts of God, political instability, or actions of competitors—may be necessary to reach an understanding of total project risk, but the risk assessment should be viewed as a step toward identifying active measures to manage all risks, even those considered outside the control of project managers, not to support a passive attitude toward risks as inevitable.

It is often desirable to combine the various identified and characterized risk elements into a single quantitative project risk estimate. Owners may also be interested in knowing the total risk level of their projects, in order to compare different projects and to determine the risks in their project portfolios. (See the discussion of program risk and project portfolios in Chapter 8.) This estimate of overall project risk may be used as input for a decision about whether or not to execute a project, as a rational basis for setting a contingency, and to set priorities for risk mitigation.

While probabilistic risk assessment methods are certainly useful in determining contingency amounts to cover various process uncertainties, simple computation methods are often as good as, or even better than, complex methods for the applications discussed here. Owner's representatives should be proficient in simple statistical approaches for computing risk probabilities, in order to be able to check the numbers given to them by consultants and contractors. When addressing probabilistic risk assessment, project directors should keep in mind that the objective is to mitigate and manage project risks and that quantitative risk assessment is only a part of the process to help achieve that objective.

There are many available methods and tools for quantitatively combining and assessing risks. Some of the most frequently used methods are discussed briefly below.

Multivariate Statistical Models

Multivariate statistical models for project costs or durations are derived from historical data. Also known as regression analysis, statistical models are one of two methods of analysis explicitly cited in OMB Circular No. A-94 (OMB, 1992). The models are typically either top-down or parametric and do not contain enough detail to validate bottom-up engineering estimates or project networks.

These methods are objective in that they do not rely on subjective probability distributions elicited from (possibly biased) project advocates. Analysts build linear or nonlinear statistical models based on data from multiple past projects and then compare the project in question to the models. The use of such statistical models is desirable as an independent benchmark for evaluating cost, schedule, and other factors for a specific project, but statistically based methods require a large database of projects, and many owners do not perform enough projects or expend the effort to create such databases. Owners who have performed many projects but have not developed usable historical project databases have an opportunity to improve their competence in project and program management by organizing their own data. Computational methods such as resampling and bootstrapping are also used when data are insufficient for direct statistical methods.

The bootstrap method is a widely used computer-based statistical process originally developed by Efron and Tibshirani (1993) to create a proxy universe through replications of sampling with replacement of the original sample. Bootstrapping is used to estimate confidence levels from limited samples but is not applicable for developing point estimates.

Event Trees

Event trees, also known as fault trees or probability trees, are commonly used in reliability studies, probabilistic risk assessments (for example, for nuclear power plants and NASA space probes), and failure modes and effects analyses. The results of the evaluations are the probabilities of various outcomes from given faults or failures. Each event tree shows a particular event at the top and the conditions causing that event, leading to the determination of the likelihood of these events. These methods can be adapted to project cost, schedule, and performance risk assessments.

System Dynamics Models

Projects with tightly coupled activities are not well described by conventional project network models (which prohibit iteration and feedback). Efforts to apply conventional methods to these projects can lead to incorrect conclusions, counterproductive decisions, and project failures. In contrast, system dynamics models (Forrester, 1969) describe and explain how project behavior and performance are driven by the feedback loops, delays, and nonlinear relationships in processes, resources, and management. System dynamics models can be used to clarify and test project participants' assumptions as well as to design and test proposed project improvements and managerial policies. Because system dynamics models are based on dynamic feedback the models can also be used to evaluate the impacts of various failure modes or root causes, particularly in cases where the root causes can be identified but the ripple effect of their impacts is difficult to estimate with any confidence.

System dynamics models have been effectively used for project evaluation, planning, and risk assessment (Cooper, 1980; Lyneis, Cooper, and Els, 2001; Ford and Sterman, 2003). Although the use of these models is not standard practice for project planning and risk management, they can significantly help owners to improve their understanding of project risks.

Sensitivity Analysis

Sensitivity analysis of the results of any quantitative risk analysis is highly desirable. A sensitivity coefficient is a derivative: the change in some outcome with respect to a change in some input. Even if the probability of a particular risk cannot be determined precisely, sensitivity analysis can be used to determine which variables have the greatest influence on the risk. Because a primary function of risk analysis is to break down the problem into essential elements that can be addressed by management, sensitivity analysis can be very useful in determining what decisions the manager should make to get the desired results—or to avoid undesired results. In the absence of hard data, sensitivity analysis can be very useful in assessing the validity of risk models.

Project Simulations

Project simulations are group enactments or simulations of operations, in which managers and other project participants perform the project activities in a virtual environment before undertaking them on the project. This type of simulation may or may not be supported by computers; the emphasis is not on the computer models but rather on the interactions of the participants and the effects of these interactions on project outcomes. For this reason, project simulations are very good for team building before a project actually starts up. They are not inexpensive, but the cost is generally comparable to the costs of the other techniques cited here, and they can be very cost-effective in the long run, compared to the typical approach of jumping into major projects with little or no preparation of the personnel and their working relationships. Engineering and construction contractors have developed project simulation methods (Halpin and Martinez, 1999), and owners can develop their own or specify that their contractors should perform such simulations before a project starts, in conjunction with the other preproject planning efforts.

Stochastic Simulation Models

Stochastic simulation models are computerized probabilistic simulations that, for computational solution, typically use random number generators to draw variates from probability distributions. Because the computer simulation is performed with random numbers, these methods are also called Monte Carlo simulations. The objective of the simulation is to find the uncertainties (empirical probability distributions) of some *dependent* variables based on the assumed uncertainties (subjective probability distributions) of a set of *independent* variables, when the relationships between the dependent and independent variables are too complex for an analytical solution. Thus each iteration (random simulation) may be considered an experiment, and a large number of these experiments gives insights into the probabilities of various outcomes. Monte Carlo simulation is typically used to combine the risks from multiple risk factors and as such is useful to determine whether the total risk of a project is too great to allow it to proceed or to determine the appropriate amount of contingency. This technique is the second of the two methods explicitly cited in OMB Circular No. A-94 (OMB, 1992).

Stochastic simulations differ from multivariate statistical models because they are typically not based on hard data. They can be useful in the absence of real data in that they are based on subjective assessments of the probability distributions that do not require large databases of previous project information. An often-cited weakness of this method is that subjective assessments of probability distributions often lack credibility, because they may be influenced by bias. This can be overcome to some degree by a carefully structured application of expert judgment (Keemey and von Winterfeldt, 1991).

As is the case with all the other computer methods for quantitative risk analysis discussed here, the validity of the method lies entirely in the validity of the probabilistic models. Monte Carlo simulation is very versatile because it can be applied to virtually any probabilistic model. However, the validity of the results may sometimes be suspect, due to the following factors:

- The independent variables may not actually be independent;
- The number of iterations in the simulation may be insufficient to produce statistically valid results; or
- The probability distributions assumed for the independent variables are subjective and may be biased if they are provided by project proponents.

It is certainly possible to develop project-specific cost models, for example, by using causal parameters that are totally independent. However, many risk analyses are not based on project-specific models but simply adopt the standard engineering additive cost models, in which the total cost is the sum of work package costs. The simulations simply add up the uncertainties associated with work packages, but they may be inaccurate because these work packages are not necessarily independent. It is computationally much easier to perform Monte Carlo simulation if the analyst avoids the need to consider interactions between variables by simply assuming that all variables are independent; however, an analysis without consideration of common mode failure can lead to an underestimation of total project risk. In project risk assessment, a common mode could be an event or environmental condition that would cause many cost variables to tend to increase (or decrease) simultaneously. It is widely recognized that a single event can cause effects on a number of systems (i.e., the ripple effect). If the event occurs, the costs of these systems will all increase, whereas if it does not occur, they will remain within the budget. Thus these affected costs are definitely not statistically independent.

Collaboration between people who are very conversant with the specific risks of the project and those who are familiar with probabilistic methods is typically required to reduce bias and to produce realistic quantification of project risks. Project owners should ensure that the probabilistic inputs are as objective and unbiased as possible and that the reasons for choosing specific probability distributions are adequately documented.

As with any method, the use of stochastic simulation requires quality control. The owner's policies and procedures on Monte Carlo simulation should include cautions to project directors and managers about the limitations of this method as it is commonly applied. The project director is generally not a specialist in Monte Carlo simulation, and does not need to be, but should understand the advantages and limitations of this approach. This is particularly true now that Monte Carlo simulation is readily available through common spreadsheet software and so can be used by people with little knowledge of statistics. A project director should know enough to be able to critically evaluate the stochastic simulation results for plausibility and should not accept the results just because they come from a computer.

It is common for Monte Carlo simulations to use far fewer iterations than the minimum normally required to get statistically valid answers. But simulations with insufficient iterations may underestimate the probability in the tails of the distributions, which is where the risks are. (See, for example, Alder, Feldman, and Taggo, 1998.) Therefore, a simulation with fewer random samples may indicate more or less risk than one with more iterations. There are mathematical formulas (Breyfogle, 1999) that can be used to compute the minimum number of iterations for acceptable confidence limits on the means or the values in the tails of the distribution. If a consultant or contractor is performing Monte Carlo simulations for risk assessments, it would be prudent for the owner's project director to review the confidence limits on all values computed using Monte Carlo simulation, to ensure that a sufficient number of iterations has been performed.

The use of Monte Carlo and other techniques for mathematically combining the risks of individual work packages into a single project risk number should not obscure the fact that the objective is to manage the risks.

As typically used, Monte Carlo simulations tend to be focused on total risk probabilities, not on sensitivity analysis, risk prioritization, or assessing possible outcomes from different proposed risk management policies.

Additive Models

Additive models, as the name implies, are those in which the combination of risk factors is based on simple addition. An example is the summation of cost elements to generate the total project cost, or the summation of activity durations to generate the total project duration. These models are relatively simple programs based on the summation of moments, derived from probability theory, to combine risks for dependent as well as independent variables. If the objective is simply to find the probability distribution of the project cost estimate as the sum of a number of work packages or activities, stochastic simulation is unnecessary. One advantage of simple additive models is that they are easily understood, and it is usually obvious which activities contribute the most to the total project uncertainty and which do not. This method is the basis for the program evaluation and review technique (PERT) for determining uncertainty in project completion times.

In bottom-up project cost estimating, the total cost is simply the sum of the costs in the WBS work packages. This is a purely linear relationship. Therefore, estimating the uncertainty in the total cost requires only summing the uncertainties in the individual cost accounts, modified by the dependencies between them. Probability theory tells us that we can compute the moments of the probability distribution of the total project cost by summing the moments of the uncertainties in all the individual cost accounts (Burlington and May, 1953; Hald, 1952). The number of moments can be approximated to some finite number. (This is a very common method of approximation in engineering—for example, the truncation of a Taylor Series after one term in order to gain a linear equation.) The second-moment approach (Benjamin and Cornell, 1970) uses the first two moments, i.e., the mean and the variance, and neglects the third (skewness) and higher. The second-moment approach does not deal with full probability distributions but uses only the means, variances, and covariances (the first two moments) to characterize uncertainties.

This approximation is justified because it is very difficult or even impossible to estimate higher moments (skewness, kurtosis, etc.) with any accuracy, even if one were in possession of large historical databases. In most cases of risk assessment, the probability distributions are largely subjective and based on judgment and experience rather than hard data. There is little point in making highly precise computer calculations on numbers that cannot be estimated accurately anyway.

There are some additional advantages of the second-moment approach:

- Priorities for risk mitigation can be obtained from a Pareto analysis using just the uncertainty in each individual risk factor and the correlations between risk factors.
- Sensitivity analyses are easily performed.
- As a project progresses, the estimates of the uncertainties in future cost accounts or activities can readily be revised, based on the past performance of the project itself. This is one of this method's most useful properties. By comparing the actual performance on completed work packages, activities, or milestones with the prior estimated uncertainties, one obtains revised estimates of the work packages, activities, or milestones yet to come.

Through second-moment analysis, project directors can use the information and experience on the actual project to revise the estimates of the work to go. This approach can be a valuable tool for program managers, if each project director is required to report the updated, revised cost at completion, including the confidence bounds on this estimate, for every reporting period. Because this method looks forward instead of backward, as most other project management methods do (including earned value analysis), unfavorable revisions to either the expected cost at completion or the uncertainty in the cost at completion should trigger management action. Conversely, favorable revisions to either the expected cost at completion or the uncertainty in the cost could allow management reserves to be reallocated to other projects with greater needs. (See Chapter 8 for a discussion of managing risks of project portfolios.)

The second-moment method provides a simple, convenient method for the adjustment of risks, and hence the adjustment of the required contingencies, as a project proceeds and data are obtained on how well or badly it is performing. The objective of this approach is to react as soon as possible to information on recent project performance that tends to confirm or to refute the current estimates. The key control parameter is the estimated cost (or time) at completion. For example, if the best estimate of the cost at completion, updated with the most recent progress information, is higher than the original estimate, then, assuming no scope changes, either the risk of overrunning the budget is greater than originally estimated, or program management corrective action may be needed to bring the project back on target. Conversely, if the updated best estimate of the cost at completion is the same as or lower than the original estimate, then the required contingency can be decreased. In this approach, the estimates of all future work packages are updated as the actual costs for each completed work package become available through the cost reporting system.

TABLE 4-2 Summary of Risk Analysis Tools

Tool	Characteristics
Two-dimensional impact/ probability	Qualitative, simple to use and most frequently used, can be expanded to three or more dimensions, and can be combined with FMEA
Pareto diagram	Simple qualitative method for prioritizing risk elements
Failure modes and effects analysis (FMEA)	Qualitative, used for initial screening only, effective in a team environment
Project Definition Rating Index	Qualitative, used in front-end project planning, effective in a team environment
Multivariate statistical model	Quantitative, requires historical database
Event tree	Quantitative, rarely used for risk analysis
System dynamics model	Both qualitative and quantitative, rarely used but effective, requires skilled modelers
Sensitivity analysis	Quantitative, useful regardless of which other process used, useful in absence of hard data
Project simulation	Both qualitative and quantitative, useful for team building, expensive to implement
Stochastic simulation	Quantitative, frequently used, often misused, so limitations must be made clear
Additive model	Quantitative, can be adjusted as project progresses

Table 4-2 provides a summary of the qualitative and quantitative methods of risk analysis reviewed in this section.

CONCLUSION

Although additive, second-moment models lack the computational complexity of stochastic risk assessment techniques, for most practical applications they are more than adequate. From the standpoint of the owner, the purpose of project risk assessment is to minimize the impact of uncertainty on the project. How this is best accomplished will vary with circumstances, but, in general, simple direct methods have proven themselves in practice. This does not discount the value of stochastic models, but their application needs to be considered in terms of their contribution to risk management. Probabilistic simulations are of particular value when data are sparse and the full range of possible adverse events cannot be easily inferred. Provided that a sufficient number of simulations are performed, boundaries for total project risk can be established. However, for the vast majority of projects, it is the committee's collective experience that the simpler models are more useful for generating risk estimates that can be used in day-to-day project management.

5

Risk Mitigation

INTRODUCTION

The ultimate purpose of risk identification and analysis is to prepare for risk mitigation. Mitigation includes reduction of the likelihood that a risk event will occur and/or reduction of the effect of a risk event if it does occur. This chapter discusses the importance of risk mitigation planning and describes approaches to reducing or mitigating project risks.

RISK MITIGATION PLANNING

Risk management planning needs to be an ongoing effort that cannot stop after a qualitative risk assessment, or a Monte Carlo simulation, or the setting of contingency levels. Risk management includes front-end planning of how major risks will be mitigated and managed once identified. Therefore, risk mitigation strategies and specific action plans should be incorporated in the project execution plan, or risk analyses are just so much wallpaper. Risk mitigation plans should

- Characterize the root causes of risks that have been identified and quantified in earlier phases of the risk management process.
- Evaluate risk interactions and common causes.
- Identify alternative mitigation strategies, methods, and tools for each major risk.
- Assess and prioritize mitigation alternatives.
- Select and commit the resources required for specific risk mitigation alternatives.

- Communicate planning results to all project participants for implementation.

Although risk mitigation plans may be developed in detail and executed by contractors, the owner's program and project management should develop standards for a consistent risk mitigation planning process. Owners should have independent, unbiased outside experts review the project's risk mitigation plans before final approval. This should be done prior to completing the project design or allocating funds for construction. Risk mitigation planning should continue beyond the end of the project by capturing data and lessons learned that can benefit future projects.

RISK RESPONSE AND MITIGATION TOOLS

Some risks, once identified, can readily be eliminated or reduced. However, most risks are much more difficult to mitigate, particularly high-impact, low-probability risks. Therefore, risk mitigation and management need to be long-term efforts by project directors throughout the project.

Responding to the Level of Uncertainty

If a project is determined to have a low level of uncertainty, then the optimal policy is to proceed expediently in order to increase the present value of the project by completing it as soon as possible and thereby obtaining its benefits sooner. Fixed-price contracts, perhaps with schedule performance incentives, are appropriate for this type of project. Everything else being equal, projects that take longer generally cost more and deliver less value to the owner. Many projects take longer than they should, in part due to dilatory decision-making processes and the lack of a sense of urgency.

However, when a project has some uncertainty, a full-speed-ahead approach may not be optimal. In such projects, scope changes and iterative recycling of the design are the norm, not the exception. Regulatory issues also provide a fertile source of uncertainty that can cause conceptual project planning and design to recycle many times. For projects with a high degree of uncertainty, fixed-price contracts may be inappropriate, but performance-based incentive contracts can be used.

Failure to recognize and anticipate changes, uncertainty, and iteration in preparing schedules and budgets can lead to unfortunate results. The techniques and skills that are appropriate to conventional projects often give poor results when applied to projects with great potential for changes and high sensitivity to correct decisions. For these projects, a flexible decision-making approach may be more successful. Often this approach may seem contrary to experience with conventional projects. The use of unconventional methods to manage uncertainty requires the active support of senior managers.

Dealing With High-Impact, Low-Probability Risks

High-impact, low-probability events in general cannot be covered by contingencies. In these cases, the computation of the expected loss for an event as the product of the loss if the event occurs times the probability of the event is largely meaningless. As an extreme example, suppose a certain project is expected to cost $1,000,000 if a certain event does not occur and $50,000,000 if it does. One would certainly not assign a contingency of $49,000,000 to a $1,000,000 project. If the probability of the event is estimated as 0.02, the expected loss due to the risk event is $1,000,000. One would not assign this number as a contingency either, because the estimated cost with contingency would rise 100 percent to $2,000,000. If the event occurs, the contingency of $1,000,000 will be completely inadequate to cover it, with a shortfall of $49,000,000. If the event never occurs, the additional $1,000,000 is likely to be spent anyway, so that the net effect is simply to double the cost of the project.

High-impact, low-probability events must be mitigated by reducing the impact or the likelihood, or both. But risk mitigation and management certainly are not cost-free. In the simple illustration above, it might be worth it to the owner to expend as much as $1,000,000 more to mitigate the $50,000,000 risk, and perhaps more than $1,000,000 if the owner is very risk averse. In determining the budget allocation needed to mitigate high-impact, low-likelihood risks, it is necessary to identify specific risk mitigation activities. These activities should then be included in the project budget and schedule, and tracked and managed just as other critical project activities are managed. However, risk mitigation activities may differ from other project activities in that there may be some uncertainty about whether the selected risk mitigation strategies will work—that is, the activities may be contingent on whether the risk mitigation strategies are effective. This has led to the development of a special kind of network diagram for risk mitigation activities, known as the waterfall diagram, which is described in Chapter 7.

Risk Transfer and Contracting

There is a common adage about risk management—namely, that the owner should allocate risks to the parties best able to manage them.

Although this sounds good, it is far easier said than done. It is impossible, for example, to assign risks when there is no quantitative measurement of them. Risk allocation without quantitative risk assessment can lead to attempts by all project participants to shift the responsibility for risks to others, instead of searching for an optimal allocation based on mutually recognized risks. Contractors generally agree to take risks only in exchange for adequate rewards. To determine a fair and equitable price that the owner should pay a contractor to bear the risks associated with specific uncertainties, it is necessary to quantify the risks.

Owners' project representatives should explicitly identify all project risks to be allocated to the contractors and to the owner, and these risks should be made known to prospective bidders. In order to use a market-based approach to allocate risks, and to avoid unpleasant surprises and subsequent litigation, it is necessary that all parties to the agreements have full knowledge of the magnitude of the risks and who is to bear them.

Risk transfer can be entirely appropriate when both sides fully understand the risks compared to the rewards. This strategy may be applied to contractors, sureties, or insurance firms. The party that assumes the risk does so because it has knowledge, skills, or other attributes that will reduce the risk. It is then equitable and economically efficient to transfer the risks, as each party believes itself to be better off after the exchange than before and the net project value is increased by the risk transfer.

Risk Buffering

Risk buffering (or risk hedging) is the establishment of some reserve or buffer that can absorb the effects of many risks without jeopardizing the project. A contingency is one example of a buffer; a large contingency reduces the risk of the project running out of money before the project is complete. Buffering can also include the allocation of additional time, manpower, machines, or other resources used by the project. It can mean oversizing equipment or buildings to allow for uncertainties in future requirements.

Risk buffering is often applied by project contractors as well as by owners. Overestimating project quantities, man-hours, or other costs is a form of buffering used by many project participants. If jobs are awarded on the basis of lump-sum, fixed-price bids, then too much cost buffering can be detrimental to contractors' ability to compete. Contractors and subcontractors may compensate by overestimating project or activity durations. Schedule buffers allow contractors to adjust their workforce and resource allocations within projects and across multiple projects.

Buffering in the forms of cost or schedule overestimates and other factors can accumulate across a project and can be to the owner's detriment because they can easily result in a general upward trend in the expected project costs and durations. In private projects, this trend is controlled by competitive factors and by the owners' knowledge of what costs and schedules should be. If the bidding pool is small, or if the owner is not knowledgeable, there may be inadequate controls on scope creep, cost creep, and schedule creep.

Risk Avoidance

Risk avoidance is the elimination or avoidance of some risk, or class of risks, by changing the parameters of the project. It seeks to reconfigure the project such that the risk in question disappears or is reduced to an acceptable value. The nature of the solution may be engineering, technical, financial, political, or whatever else addresses the cause of the risk. However, care should be taken so that avoiding one known risk does not lead to taking on unknown risks of even greater consequence.

Risk avoidance is an area in which quantitative, even if approximate, risk assessments are needed. For example, the project designers may have chosen solution A over alternative B because the cost of A is estimated to be less than the cost of B on a deterministic, single-point basis. However, quantitative risk analysis might show that A is much riskier than the alternative approach B. The function of quantitative risk assessment is to determine if the predicted reduction in risk by changing from alternative A to alternative B is worth the cost differential.

Risk avoidance is probably underutilized as a strategy for risk mitigation, whereas risk transfer is overutilized—owners are more likely to think first of how they can pass the risk to someone else rather than how they can restructure the project to avoid the risk. Nevertheless, risk avoidance is a strategy that can be employed by knowledgeable owners to their advantage.

Risk Control

Risk control refers to assuming a risk but taking steps to reduce, mitigate, or otherwise manage its impact or likelihood. Risk control can take the form of installing data-gathering or early warning systems that provide information to assess more accurately the impact, likelihood, or timing of a risk. If warning of a risk can be obtained early enough to take action against it, then information gathering may be preferable to more tangible and possibly more expensive actions.

Risk control, like risk avoidance, is not necessarily inexpensive. If the project is about developing a new product, and competition presents a risk, then one solution might be to accelerate the project, even at some considerable cost, to reduce market risk by beating the competition to market; this is a typical strategy in high-technology industries. An example of a risk control method is to monitor technological development on highly technical one-of-a-kind projects. The risk is that the promised scientific development will not occur, requiring use of a less desirable backup technology or cancellation of the project.

Organizational Flexibility

Many projects experience high levels of uncertainty in many critical components. Some of these important risks cannot be adequately characterized, so optimal risk mitigation actions cannot be determined during project planning. This is common when uncertainties will be reduced only over time or through the execution of particular project tasks. For example, the uncertainty about the presence of specific chemical pollutants in a water supply may be reduced only after project initiation and partial completion. Under these circumstances commitment to specific risk management actions during planning makes project success a gamble that the uncertainty will be resolved as assumed in planning.

The following are examples of flexible decision making that can help mitigate risks under conditions of uncertainty:

- *Defer some decisions* until more data are obtained in order to make better decisions based on better information. Good decisions later may be preferable to bad decisions sooner, particularly if these decisions constrain future options. It may be argued that deferring decisions is never desirable because to do so might delay the project, but this is a fallacy of deterministic thinking. When uncertainty is high, poor decisions made too early will delay the project much more, or even cause it to be canceled due to resulting budget and schedule overruns. In these circumstances, deliberately deferring decisions may be good management practice, but it is essential that the project be scheduled such that deferred decisions reduce rather than increase the risks of delays.

  A flexible policy of delaying decisions should not be equated with simple procrastination or wishful thinking. Decisions should be delayed only when, based on analysis, there are solid reasons to believe that new information will be forthcoming that will affect the decision one way or another. If there is no such expectation, then the project manager should consider whether it might be cost-effective to acquire more information even at additional cost. For example, an expanded boring program to identify subsurface conditions, an expanded testing program to characterize wastes, or pilot plant tests of new technology are just a few examples in which it may be very cost-effective to buy more information before making a decision.

- *Restructure the project* such that the impact of early decisions on downstream conditions is minimized. Decisions that constrain future decisions and eliminate options should be reconsidered. Safety factors may be added to buffer the effect of decisions. For example, something may be oversized to provide a safety factor against high uncertainty in requirements, just as safety factors are used in engineering design to provide a margin against uncertainty in loads; the higher the uncertainty, the greater the contingency in the load factor. If a building must be built before the contents are known precisely, then oversizing the building may well be prudent. These safety factors typically increase project costs, but they may increase them far less than the alternative strategies for mitigating risk or the consequences of an undersized building.
- *Stage the project* such that it is reviewed for go or no-go decisions at identifiable, discrete points. These decision points should be built into the front-end plan. Based on updated information available at these future times, the project may be modified, continued, or terminated. Termination of the project at a future time will be costly, but it may be far less costly than continuing it in the hope that something good will happen.
- *Change the scope* of the project, either up or down, at some future decision points. Changing scope is generally a bad practice in conventional projects, but in high-uncertainty projects midcourse corrections may be necessary responses to changed conditions or improved information, if the scope change is made in accordance with a preplanned review and decision process defined in the front-end plan (i.e., not scope creep or the unplanned use of scope as contingency).
- *Analyze and simulate* the effects of strategic decisions before making them. These issues typically cannot be decided only on the basis of prior experience, especially when that experience may have been obtained on conventional projects.

A flexible decision-making approach requires that project directors be active and show initiative. If project directors are constrained by organizational culture, bureaucratic restrictions, fear, or self-interest, they will not exhibit initiative or flexibility and are likely to apply rigid management principles to situations that require flexible decision making. The value of management flexibility increases in direct proportion to the uncertainty in the project. As stated by General Dwight D. Eisenhower, "In preparing for battle, I have always found that plans are useless, but planning is indispensable." The same thought can be applied to risk management.

Options

An option provides the opportunity to take an action without the obligation to take that action. Options may cost money, but they also add value by allowing managers to shift risk or capture added value, depending on the outcome of one or more uncertain parameters. For example, a contract clause permitting termination of a contract if a critical technology is not developed provides an opportunity (but not an obligation) to terminate. An options approach also improves strategic thinking and project planning by helping to recognize, design, and use flexible alternatives to manage uncertainty.

Increasing options and decision points is a valid risk mitigation strategy for project owners. For example, the option to terminate a contract can be of value to owners. Conversely, contractors often want to reduce owners' options to terminate a project once it gets started. Obviously, the owner's option is not cost-free as there are costs involved in terminating a project; nevertheless, owners should always provide off-ramps or exit strategies in case projects become nonviable.

Delaying commitment to a single strategy or solution by carrying alternative optional strategies until sufficient information becomes available to resolve the uncertainty is an example of the use of options as a form of managerial flexibility. Another example of an options approach was that used by the Manhattan Engineer District in World War II, in which both an enriched uranium and a plutonium device were developed so that there would be an available alternative; information gained from one was used in making a decision about the other (i.e., which to use), so that the managers had an option to switch between alternatives and select the more attractive one. This is similar to power plants that can run on gas or oil and switch between the fuels based on their relative price. In the case of the Manhattan Project we can safely assume that the progress and relative effectiveness of the alternative efforts were compared in order to make informed choices, including (ultimately) the choice that was used in the war. Both worked, but the additional cost to buy the option was considered justifiable.

There are many places in which options can be inserted to deal with virtually any project's technical, market, financing, or other risks. The use of these options may, however, require some imagination and changes from the usual methods and practices. Because risk is uncertainty and information reduces uncertainty, many options involve the creation or purchase of information. It should be stressed that creating options to generate new information is not the same as simply postponing decisions in the hope that some new data will materialize to save the situation.

The use of options is premised on specific rules for implementation that define the conditions that would trigger a change in strategy. The process includes continuing to monitor the uncertain parameters, evaluating their status and impact, and changing strategies if alternative options are warranted. This should be a proactive not a reactive process.

As an illustration of a risk assessment applied to both downside risk and upside opportunity, consider the case of a risk associated with two alternate technologies or processes. Process 1 is newer, and the cost estimates for this process are highly uncertain, compared to Process 2, which is more established and for which the cost estimates are much less uncertain than those of Process 1. If the estimated construction cost of using either of the two processes is the same, then there is a substantially greater risk of obtaining a high project cost with Process 1 than with Process 2.

It is assumed that the probable costs of these two processes are statistically independent—that is, there is no correlation between the cost of one and the other. Figure 5-1, which plots the probability that the project

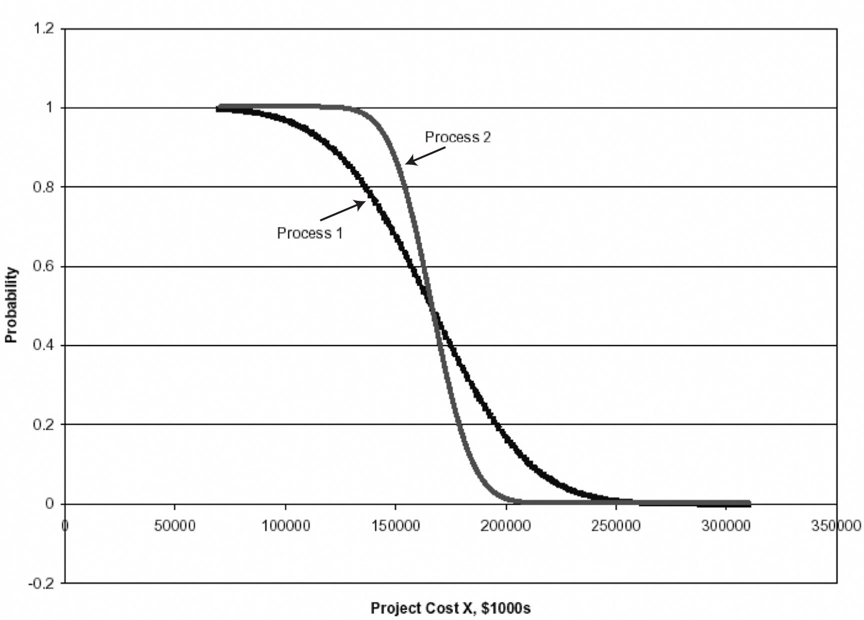

FIGURE 5-1 Probable cost of independent projects.

cost will overrun any specified budget, shows the relationship between the use of either process and the likelihood of project cost overruns.

Figure 5-2 shows these two options plus a third, which is to pursue both Process 1 and Process 2. Note that in this third approach, the expected cost is less than for either of the two processes individually, and the probability of a cost overrun is less than with either of the others for any budget. Obviously, one does not construct two facilities just to find out which process is cheaper. However, this elementary illustration indicates that the best approach may be to pursue the engineering of both options until, using a series of decision points, enough additional information is obtained to refine the cost estimates and thus determine which process should be chosen.

If project directors seek to manage the risks, not simply to compute them, then they should recognize that project engineering and design can be conducted in a series of steps, such that after each step—e.g., conceptual design, process engineering, plant general arrangements, production design, detailed design, and procurement—the engineering process will produce new information and a new cost estimate for the technologies being considered. Thus at discrete breakpoints—for example, at the quarterly project reviews—the project's engineering team will produce its

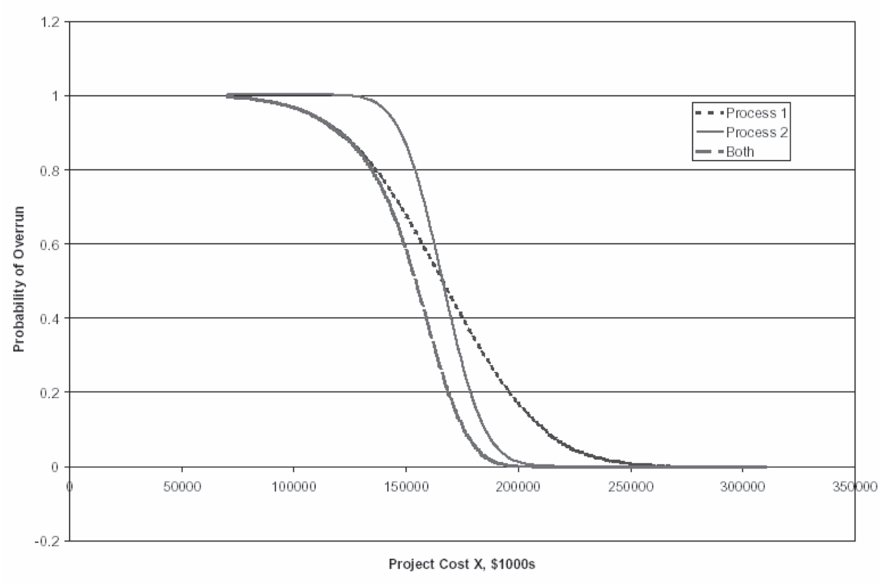

FIGURE 5-2 Effect of using design option.

current best estimate of the final cost of the facility. Based on the new information generated by the engineering, design, and procurement process, the estimates at each quarter will provide better guidance about the economics of the final facility. Then the sponsor can make a decision to continue the project or to terminate it.

The principal benefit of the options approach is that by reliance on sequential decisions made as more and better information is available, rather than on a single decision made at the beginning of a project, and using the high uncertainty as an opportunity not simply a risk, the net value of a project can be increased. Thus a project that might have been canceled can instead be turned into a highly beneficial one. Although this example is simple, the fundamental point it illustrates is that the purpose of risk analysis is to support decisions. The objective of risk management should be to decide whether or not to build a project, and which of alternative process technologies to use, not merely to compute risks or probability distributions. The example also shows that adding management decision points increases the value of the project to the owner.

Risk Assumption

Risk assumption is the last resort. It means that if risks remain that cannot be avoided, transferred, insured, eliminated, controlled, or otherwise mitigated, then they must simply be accepted so that the project can proceed. Presumably, this implies that the risks associated with going ahead are less than, or more acceptable than, the risks of not going forward. If risk assumption is the appropriate approach, it needs to be clearly defined, understood, and communicated to all project participants.

6

Contingency

INTRODUCTION

In discussions of risk, the term “contingency” is often understood to be a number added to an estimate for project costs or durations to cover some element of risk or uncertainty. Owners establish contingency levels for each project based on acceptable risk, degree of uncertainty, and the desired confidence levels for meeting baseline requirements. When used to absorb the impacts of project uncertainty, the contingency is a form of risk mitigation, and so in evaluating potential project contingency funding, owners should apply risk assessment and probabilistic estimating techniques. However, contingency should not be a first alternative and should be used only as part of a complete risk mitigation effort.

DEFINITION

The dictionary definition of contingency is as follows:

> **Contingency (1)**: the condition that something may or may not occur: the condition of being subject to chance **(2)**: the happening of anything by chance: fortuitousness . . .
> **a**: something that is contingent: an event or condition occurring by chance and without intent, viewed as possible or eventually probable, or depending on uncertain occurrences or coincidences . . . **b**: a possible future event or condition or an unforeseen occurrence that may necessitate special measures <a reserve fund for *contingencies*> . . . **c**: something liable to

> happen as a chance feature or accompaniment of something else. (Webster's Third New International Dictionary)

From this dictionary definition it might be supposed that the purpose of a contingency is to cover "the happening of anything by chance . . . uncertain occurrences or coincidences . . . [or] an unforeseen occurrence," and therefore that the contingency would be expended only if the "unforeseen occurrence" actually occurred. In that case, the actual expenditure of the contingency would itself be "an event occurring by chance," and one would therefore not expect the contingency to be used up in the normal course of activities. However, the term "contingency" is not understood in this way by many project personnel; rather, it is often taken to refer to funds that will be completely expended in the course of the project, no matter what happens.

Accounting for Random Error Versus Systematic Error

An example may help in illustrating the point. Suppose that someone tabulates the number of valves used on a substantial set of previous similar projects and finds that, in every case, the number of valves actually installed was always 1.17 times the number of valves counted on the engineering drawings by the quantity surveyor. Then a rule might be to purchase 17 percent more valves than the number of valves counted on the engineering drawings. This 17 percent factor is not a contingency in the sense of the dictionary definition, because there is nothing about it due to chance. Rather, it is an empirical fact that the valves are consistently undercounted, and the 17 percent factor is to offset this inherent bias or systematic error. Therefore, the additional 17 percent for the valves not counted would always be spent. (Note that the rule does not say to add 17 percent to the preliminary cost estimate, because this estimate might already have some adjustment factor in it.)

Suppose now that the above example is slightly different: The investigator determines from the historical data that the factor relating actual valves used to valves counted on drawings is a random number, with average or mean 1.17 and standard deviation 0.10. While the systematic error or bias is still 17 percent, there is now a random component as well, which depends on chance events and hence is contingent. To account for both the systematic error and the random error, we have to add 17 percent to the number of valves actually counted, and then add another contingency to account for chance.

When talking about chance, or contingency by the above definition, we must make probabilistic statements. If we want to be sure that we order enough valves 95 percent of the time, then in this instance we need

TABLE 6-1 Contingency Factors for Systematic and Random Errors

Valves counted on drawings	1,000
Valves added to correct for undercount (systematic error)	170
Valves added to reduce the probability of running out of valves to 5% or less	164
Total number of valves to be ordered	1,334
Number of valves expected to be used	1,170
Number of valves expected to be left over	164

to add 33 percent to the number counted (17 percent for the systematic bias and 1.645 times the standard deviation for the chance variation). Note that we would expect to have 16 percent of the counted valves left over, as these were for protection against running out and were expected to be used only for extraordinary circumstances. The results are shown in Table 6-1.

The problem is that the term "contingency" is often used for both the amount needed to cover the systematic error and the amount needed to buffer against the risk attributable to chance. This usage can cause confusion: Some project personnel, assuming the contingency addresses systematic error or bias, expect that they are entitled to use it all up, whereas others, who believe it is allocated to cover random error or chance, expect that contingency funds will be left over and ought to be returned to the project sponsor. Not surprisingly, those who expect to expend all contingency funds tend to be project managers, and those who expect to see at least some of the contingency allowance returned tend to be owners.

In practice, relatively few projects return leftover contingency funds to the sponsor. In general, project directors regard contingency funds as theirs to use; if the risks fail to materialize, the funds are expended on something else, such as project improvements. Thus there is no agreement either on (1) how large a contingency should be or (2) the basic point of whether the contingency is an unassigned cost that is intended to be spent or a reserve that is intended not to be spent.

Management Reserve

The term "management reserve" is used sometimes as a synonym of contingency and sometimes in distinction to it. The Electronic Industries Alliance (EIA) standard *Earned Value Management Systems*, EIA-748 (EIA, 1998) does not use the term contingency, but does define "budget" and "management reserve" as follows:

> BUDGET AT COMPLETION: The total authorized budget for accomplishing the program scope of work. It is equal to the sum of all allocated budgets plus any undistributed budget. *(Management reserve is not included.)* (Emphasis added.)
>
> MANAGEMENT RESERVE: An amount of the total budget withheld for management control purposes rather than being designated for the accomplishment of a specific task or set of tasks. (EIA, 1998, p. 6)

Presumably, by these definitions, contingency, if there is any, would be included in either the "allocated budgets" or the "undistributed budget," both of which are included in the budget at completion and hence constitute something that is expected or intended to be spent. Management reserve, by contrast, is not included in the budget and therefore presumably is not expected or intended to be expended.

SETTING THE CONTINGENCY

Setting the contingency is a matter of some tension between the project director, who generally wants the contingency allowance set high to permit greater flexibility and protection from uncertainty, and the owner, who wants the contingency set low to maintain greater control over the project. Although the proper amount of contingency is debatable, if the contingency is set too low upper management will be in the position of micromanaging the project, and if it is set too high management may not be sufficiently involved. This point will vary with different organizations and different types of projects. However, if upper management takes the view that there are always uncertainties associated with estimating and executing projects and that competent people are hired to manage these activities, contingency can be set at a level that keeps upper management informed and involved but does not require repeated approvals for additional funding.

A probabilistic view of risk can help to guide this approach. If a probability distribution that represents uncertainty in the cost or duration of an activity is assumed, contingency can then be viewed as an amount of money (or time, in the case of project schedules) added to the mean (or expected value) of the cost (or duration) of that activity. The risk of overrun is thus the probability that the actual cost or duration would be greater than the mean plus the contingency. If the project cost is considered a random variable with an associated mean value, the deterministic or single-point value that is typically quoted as the project or activity estimate may not bear any relationship to the mean or expected value of its probability distribution. The point estimate might be the mode of the distribution, or the median, but most commonly will not be based on the probability distribution because it may already include an allowance for contingency inserted at some lower level. See Box 6-1 for a discussion of the fallacy of point estimates.

If the cost estimates for all the work packages in a project are known to be the mean values of their individual distributions, then the mean value of the total project would be the sum of these values and the contingency could be added to it. However, individual work package estimates are seldom the mean values of their distributions. As a result, the sum of these estimates is not the mean value of the total cost or duration but a

BOX 6-1
The Fallacy of Point Estimates

The fallacy of point estimates has been immortalized by the legendary statistician who drowned while fording a river that was on average 3 feet deep.

The fallacy of point estimates provides some insight on why projects are frequently late. Consider a project consisting of 10 parallel tasks, each of average duration 2 weeks. Many project managers are under the misconception that the average completion time of the project is therefore also 2 weeks. However, the project will finish in 2 weeks only if each of the 10 tasks finishes in average or below average time. Assuming independent symmetric distributions for each task, the chance of this is less than 1 in 1,000. The average of the maximum of 10 durations is greater than the maximum of the average of the 10 durations.

This concept also provides insight on why projects are frequently over budget. Consider the example of a laboratory that must inventory cases of a perishable chemical, demand for which is uncertain but averages five cases per month. Accordingly, the lab plans to stock five cases. The cost of maintaining the inventory has two components: (1) If at the end of the month the demand has been less than the number stocked, the use-by date of the excess cases will have expired and they must be destroyed, for a loss of $50 per unit, and (2) if the demand is greater than the number stocked, the lacking units must be air freighted at an additional cost of $150 per unit. The additive cost associated with the average demand of five is zero, so most managers think this is the average cost. But the cost of five is the minimum cost. The actual cost is greater than the cost of the average demand.

SOURCE: Adapted from Savage (2002).

value that includes some degree of uncertainty (i.e., some multiple of the standard deviation or variance). Therefore, summing the estimates for all work packages without the discipline of using their mean values will result in a total cost estimate that includes unknown uncertainty.

For these reasons, work package estimates, even at the lowest level, often contain some contingency factor. First, there is built-in bias from the estimator, who may expect to be criticized more severely for an underestimate than for an overestimate. Second, there is a need to cover errors in estimating, which are usually errors of omission; for example, in taking quantities off drawings, a quantity estimator is more likely to undercount than to overcount. Even if a computer does the quantity estimates, some items may be missing from the drawings and others may be added later, all contributing to a bias toward undercounting. The addition of a contingency offsets this bias. Finally, the field construction operation will certainly take the position that having material left over due to overestimation is preferable to running out before the job is finished due to underestimation. For these and other reasons, estimators tend to add some contingency or safety factor to each work package estimate. For similar reasons, the next level upward typically also adds a contingency. Each person or organizational level that adds a contingency does so to provide protection from uncertainty, the consequences of which are generally considered to be more dire if the number is underestimated rather than overestimated.

If each management level wishes to set the risk-adjusted cost estimate (estimate plus contingency) at some desired point on the underlying probability distribution, each manager must have some idea of the amount of contingency already incorporated in the estimates. For example, if a manager wishes to set the risk-adjusted cost estimate at approximately the 80th percentile and believes that the estimate is at the 50th percentile, then the difference in dollars (or time) between the 50th and the 80th percentiles must be added. However, if the manager believes the estimate is already at the 70th percentile, less will need to be added. This process does not require exact knowledge of what the lower level contingency or risk is, only that the manager is familiar with the basis for the estimation.

Conversely, if a manager believes that the estimates have already been adjusted up to the 90th percentile, then the estimate can be reduced. This may also occur if the manager's knowledge of the business results in a better (or different) view of the underlying uncertainties than others have. The manager may desire a risk-adjusted cost estimate at the 80th percentile and the estimates provided may have been developed at that level. However, the subjective probability distributions used by the estimators and manager may not agree as to where the 80th percentile is. Or a contractor may feel that regardless of the desirable level of contingency or safety factor, competitive conditions do not permit it—that is, although there is a definite risk in setting contingencies too low, there is a greater risk in setting them too high if one has to bid for a fixed-price contract or receive financial authorization from the owner.

In general, as estimates flow upward through different levels of organizations, higher management levels will have better knowledge of strategic business or political conditions and so may make different decisions about contingencies than their subordinates. It is likely that knowledgeable owners can make better decisions about contingencies than owners who are inexperienced or who do not make the effort to become knowledgeable about the costs and duration of the projects they typically undertake.

PROJECT POLICIES AND PROCEDURES

Project policies and procedures documents should address the different kinds of contingencies, the need for contingency allowances, who controls them, and what should happen to them if they are not expended. They should also include precise and consistent definitions for terminology. The term "contingency" in particular needs a consistent definition, as it means different things to different people. Equally important are discussions and examples of approaches to setting budget and schedule contingencies. Contingency is not like value engineering, change control, or other cost control methods: It is an allowance for error or a safety margin on budget overruns that does not reduce costs or risks but increases the budget. Thus, by itself, contingency is not a cost control method, as its purpose is to ensure adequate funds to pay for uncontrolled costs.

The definition of contingency as a percentage of the estimated cost to complete a project, instead of a percentage of the original estimate, is an improvement, but it is a change from past practices in many cases. Project contingencies should be reported and reviewed in a consistent way that should be defined and emphasized in policy documents in order to achieve consistency across all projects.

Consistency does not, however, mean the establishment of recommended or standard values or ranges for overall contingency allowances. The use of established values is a questionable practice as it encourages project managers to use these values instead of performing project-specific risk assessments. For example, a contingency percentage that might be adequate for some conventional infrastructure projects will be totally inappropriate for big science projects, waste remediation projects, and one-of-a-kind or first-of-a-kind projects, for which the technology may be new and unproven or the volume and characterization of the wastes uncertain, and which may need to retain much larger contingencies even at the final design stage.

There are at least two distinct policy issues in setting a contingency. First, one purpose of a contingency is to provide an allowance for unknowns in making estimates. Because these errors are predominantly errors of omission, some allowance must be added to cover them. Instead of counting all the valves, for example, one estimates them, and adds an allowance as a contingency. This type of contingency is bottom-up, i.e., it is estimated at the work package or activity level. Adding all these work package contingencies is not, however, supported by statistical analysis and can easily result in a very large number, which then becomes the project budget. Second, another purpose of contingency is risk mitigation, which is required not because of omissions in making estimates or any other uncertainty at the activity level but rather to allow for unknowns at the overall project level. For example, a capital acquisition project that is really a research and development project may depend on new technology, which requires more project-level contingency; or a waste remediation project may need a contingency to cover the possibility that the in situ waste may differ from the original characterization. These are not activity-level contingencies. This distinction is not merely semantic; there is an important difference in how such risks are estimated, and project policies and procedures should make this distinction clear.

Moreover, there is a difference in how these different contingency factors are managed. If the project's baseline budget includes those costs that are known and countable, with a separate allowance for the unknowns in estimating these costs, then one expects that over the life of the project all or most of this allowance will be transferred to the budget, as these actual quantities and costs are identified. But a project contingency or management reserve may cover risk factors that would have a very high impact if they occurred but that are highly unlikely to occur. Thus, for example, if the contingency allowance for a possible flood is not used because no flood occurs, then this contingency allowance should not be automatically transferred to the base budget to cover overruns in other areas.

Who owns the contingency and what should happen to it if it is not expended are important issues that should be addressed in the policies and procedures documents. It can be argued that management reserves for high-impact, low-probability events should be held at the program level, not at the project level. At a minimum, these program-level contingencies alert management that there are large risks inherent in projects. Contingencies are known as risk funds in some organizations and are separated from all other budget funds unless needed for a specific project event.

If a contract is for a fixed price, the contractor owns the contingency within the bid price and is entitled to it if there is any left at the end. But this is not the case with cost-plus contracts. Even with a fixed-price contract, the owner needs to hold some contingency to cover potential change orders. Contingency policies need to distinguish between fixed-price, cost-plus, cost plus incentive fee, and other common types of contracts in the discussion of risk and contingency and should state whether contingency is controlled at the project director level or at the owner's program level.

7

Active Risk Management

INTRODUCTION

Some projects appear to have a passive and ad hoc approach to the management of risk, without the benefits of either tracking the root causes of identified risks or making proactive decisions and actions to mitigate the risks. In a passive and ad hoc approach, risks may be identified but they are largely ignored in the planning and execution process until undesired events occur, at which time solutions are sought. This approach often includes an assumption that additional resources will be made available to solve the problems that arise, precludes the prevention of some undesirable events, and increases the costs of addressing others. An inexperienced project team, inadequate front-end risk management planning, and a tradition of budget increases may be the primary motivation for passive risk management and deterrents to implementing proactive risk management.

It is the owner's responsibility to ensure that project risks are rigorously and aggressively managed and reviewed by senior managers in each of the project phases (CD-0 through approval to start operations [CD-4]). The previously discussed risk identification, analysis, and mitigation planning are important, but they are not sufficient. Active risk management includes the assignment of mitigation responsibilities to appropriate project participants and the oversight of follow-through regarding every risk factor. This chapter reviews some tools and methods that can form the basis for the development of risk management excellence by owners.

RISK MANAGEMENT PLAN

The risk management plan ties together all the components of risk management—i.e., risk identification, analysis, and mitigation—into a functional whole. The plan is an integral part of the project plan that informs all members of the project team and their supervisors of the risks to the project, how they will be managed, and who will manage them throughout the life of the project. It should be part of the initial project approval package, and an updated plan should be part of all subsequent project planning and performance reviews. Risk management plans are dynamic documents that are used to guide day-to-day decisions by the project team.

The sample table of contents shown in Box 7-1 provides an outline of the issues that should be covered in a risk management plan. The level of detail in the plan may be adjusted for small, relatively simple projects, but the basics of risk identification, analysis, and mitigation need to be covered. The risk register (described later in this chapter) is often the core of risk management plans for smaller projects.

WATERFALL DIAGRAMS

A risk mitigation effort is a project activity and thus should have assigned resources, assigned personnel, and an estimated cost and duration. Similarly, a risk mitigation activity should be included in the project network and tracked, reported, and managed along with other project activities. The assigned objective of a risk mitigation activity is to reduce the impact or likelihood of a specific risk factor. If a risk is high, it is unacceptable to the project, its mitigation is critical to project success, and it must therefore be closely monitored by project management. A risk mitigation activity may thus be on the project's critical path, making the activity especially important. Even if actual execution of a risk mitigation activity is assigned to a contractor, the owner's project director should follow its progress, because failure to mitigate the risk may require other efforts to avoid project failure.

Waterfall diagrams are used to incorporate risk mitigation activities in the standard project management procedures. They differ in this way from a risk register, which tracks and monitors risks separately from other project activities. Figure 7-1 shows a hypothetical waterfall diagram, extracted from the context of a project network diagram, with the project risks qualitatively tracked over time and divided into three color-coded zones of severity. The red zone corresponds to high or unacceptable risks; the yellow zone corresponds to moderate but unacceptable risks; and the green zone corresponds to low, acceptable risks. Using this simple scale, a

BOX 7-1
Typical Table of Contents for a Risk Management Plan

1.0 Introduction and background
- 1.1 Statement of project philosophy, goals, and objectives relative to risk management
- 1.2 Risk management process and procedures

2.0 Risk management team
- 2.1 Team functions and responsibilities
- 2.2 Team members

3.0 Risk management process
- 3.1 Identification of risks
- 3.2 Assessment of risks
- 3.3 Analysis of risks
  - 3.3.1 Qualitative
  - 3.3.2 Quantitative
  - 3.3.3 Methodology
- 3.4 Setting priorities on risks to be managed
  - 3.4.1 Critical risks
  - 3.4.2 Significant risks
  - 3.4.3 Other (nonsignificant or de minimis) risks
- 3.5 Risk management
  - 3.5.1 Risk avoidance
  - 3.5.2 Risk transfer
  - 3.5.3 Insurance
  - 3.5.4 Risk control
  - 3.5.5 Options
  - 3.5.6 Organizational structures
  - 3.5.7 Risk assumption

4.0 Risk management action plan
- 4.1 Risk register
- 4.2 Actions
- 4.3 Responsibilities
- 4.4 Commitments
- 4.5 Deadlines

5.0 Risk monitoring and updating
- 5.1 Waterfall diagrams
- 5.2 Leading indicators and other warnings
- 5.3 Decision points

6.0 Conclusion

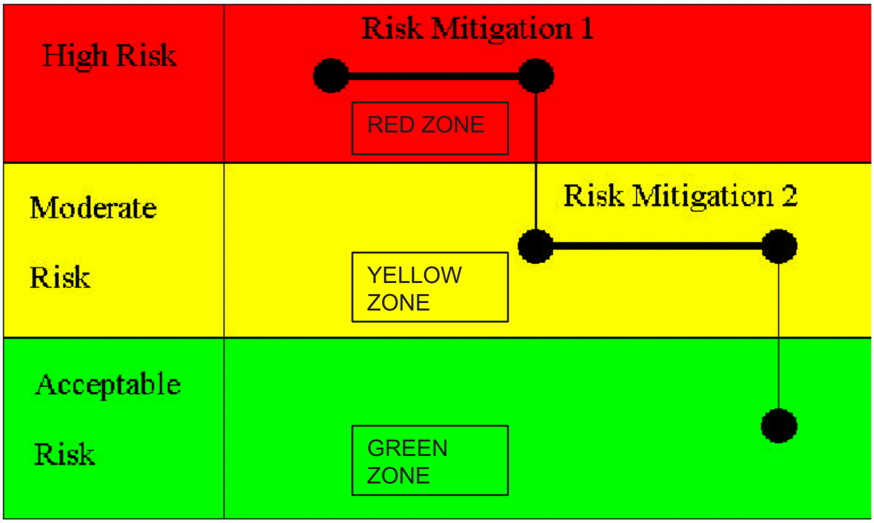

FIGURE 7-1 Waterfall diagram.

project as a whole is characterized as high risk if any project risk is in the red zone; the project is reported as moderate risk if any risk is in the yellow zone and no risks are in the red zone; and the project may be reported as acceptable risk only if there are no risks in the red or yellow zones.

Figure 7-1 shows the progression of a risk as mitigation actions are applied over time. A risk mitigation activity is initiated and tracked because a risk assessment has shown that there is a high risk. This risk could be related to technology, scope, performance, quality, schedule, or any other factor that could expose the project to risks. Because the risk is high, a mitigation activity should be defined and established to reduce it. This mitigation activity is resource loaded, budgeted, and scheduled like any other project activity. At the conclusion of the risk mitigation activity, a new risk assessment is performed. While the mitigation activity might reduce the risk from high to acceptable, in this example the risk has only fallen to moderate—an improvement, but not enough. The project director then initiates a second risk mitigation activity, to try again to get the risk down into the acceptable zone. If this does not succeed, additional risk mitigation steps might be required.

Two risk mitigation steps are shown in Figure 7-1; however, in practice, the risk reduction might be done in one step or in several steps, depending on the risk and the success of the risk mitigation methods.

Thus, the initiation of some risk mitigation activities may be contingent on the outcomes of others. Of course, the longer it takes to reduce a risk to acceptable, the more the project will cost and the longer it will take, especially if these activities are on the critical path. If time is critical, one might undertake two or more risk mitigation activities simultaneously, which, if the risk reduction activities are independent of each other, might cost more but hasten success. Determining which risk mitigation activities to undertake should be based on a cost-effectiveness analysis of the costs, durations, and probabilities of success for each.

Regardless of the actual risk reduction strategies used, the waterfall diagram is a useful way to track specific risks, to be sure that risk reduction activities are scheduled and executed, and to communicate the status of risk reduction efforts to the project team and owner. This method, which highlights the activities related to risk reduction, avoids the common situation in which the project director reports that everything is 99 percent on target and that therefore the whole project is low-risk, despite the fact that the remaining 1 percent related to risk could kill the project. If the owner's representative is not engaged in the actual risk reduction process, the owner should require that contractors present their progress in a similar way, so that the owner is aware of the status of all significant risks and the progress being made to mitigate them.

PROJECT RISK REGISTER

A risk register is a risk tracking system. Like other project activity or commitment tracking systems, it tracks the progress of various critical activities that require management visibility and attention. Because risk management is particularly critical to project success, risks require particular management attention, and the risk register is used to follow the actions and risk management efforts for all of the project's identified risks.

Unlike waterfall diagrams, project risk registers treat risk management activities as separate and distinct entities rather than integral project activities. Such a register identifies what actions are to be taken and when they are to be implemented, thus documenting how a project is going to control its risks. It tracks risks in the way that a project commitment tracking system tracks letters and commitments. It is also somewhat like a quality assurance plan, which documents how a project is going to achieve its quality goals.

The risk register emphasizes that risk assessment should not be a static, one-time operation, as it unfortunately sometimes is, but a continuous operation throughout the life of the project, starting with initial preproject planning. Risk management requires the development of risk mitigation and reduction plans and management of the project in accordance with these plans. The risk register documents these plans and, more importantly, provides a mechanism for project directors to track the plans against project execution to ensure that the project is in conformance with these plans.

The risk register can be a manual system but is most commonly implemented in a computer database system or run in a computer spreadsheet. It may contain the following data elements for every risk that is identified in the risk identification and assessment processes and considered to be of significant interest:

- Name and description of the risk
- Tracking number for computerization
- Name of the party responsible for managing the risk (the risk owner)
- Rank or priority of the risk compared to others
- Severity of the impact if the risk materializes
- Impact on project quality, scope, performance, or ultimate success
- Impact on project cost
- Impact on project duration
- Likelihood that the risk will materialize, given current management controls
- Leading indicators for the risk and when they must be evaluated
- Risk reduction and mitigation plans now in effect
- Risk reduction and mitigation plans contingent on leading indicators
- Tracks of the leading indicators or priority of the risk over past time
- Forecasts of the leading indicators over future time
- Tickler file on actions to be taken in the future

Of course, any information that a manager wishes to track can be included in the risk register. The most important reason for having a computerized system is to maintain a tickler file that reminds managers of what they are supposed to do and when it must be done. These action reminders are either preset, according to project milestones, or based on forecasts of the leading project control indicators. The leading indicators are tracked over time and projected into the future. This projection may be based either on extrapolation, such as by regression analysis or trend analysis, or on statistical control charts, which specify that no action need be taken as long as the indicator tracks inside the prearranged control limits, but that action is required if the indicator falls outside the control limits. The actions themselves may be predetermined, in the form of contingency plans set in motion when triggered by the indicators, or the indicators may simply alert management to develop a response to the relevant risk.

The primary purpose of the risk register should be to support management decisions and actions and to avoid delay. Delay is a serious problem in risk management, whether it is due to procrastination, over-optimism, or simple ignorance that some action needs to be taken. Table 7-1 is an example of a project risk register.

As in all database systems, a potential problem lies in keeping the data in the system current. Therefore, when possible, the risk register should be interfaced to other project management control systems. For example, if one leading indicator is the project schedule performance index, then these values should be input to the risk register every reporting period. Other indicators may be external to the project and some may be qualitative or judgmental. In any case, most of the relevant data will have to be entered manually, and project management must ensure that this is regularly and conscientiously done if the risk register is to have value.

A project risk register is initially constructed during front-end project planning through the identification and analysis of risks that could affect project performance (e.g., scope, schedule, technology, permits, site conditions, environmental impact). The likelihood of occurrence and the nature and magnitude of risks are used for prioritizing risk mitigation actions. The risk register is a tool for allocating managerial responsibility for specific risks and for reporting and monitoring the status of these risks. For example, if fewer funds are appropriated than requested, the risk register provides a basis to redesign the project to remain consistent with the allocated funding level. The effective use of this tool includes regular and frequent progress reporting on each risk until the risk or the project passes the point where the risk is no longer an issue and is closed out.

Project risk registers have been used successfully on many projects, including DOE projects, but they can easily become a merely bureaucratic paper exercise. DOE project directors need to ensure that they are actually managing risks and not simply contributing to a bloated data system that has detailed data on many risks that no one is bothering to manage. Again, the point is not to document risks for the project postmortem, but to take managerial actions in a timely way to mitigate the risks.

TABLE 7-1 Risk Register with Sample Entry

Risk Element ID (1)	Risk Event Description (2)	Likelihood (1 to 5) (3)	Relative Impact (A to E) (4)	Specific Impact to the Project (Cost/Schedule/Scope/Quality) (5)
II.B.2.	Political stability—new socialist parliament, governor, and mayor	4	D	Potential new requirements—policies/laws/etc. to increase percentage of local contractors
				Taxes expected to rise
				More local government interest in all aspects of the project (permits, labor, etc.)

NOTE:
Columns 1 and 2 are identifying features that come directly from the IPRA's assessment sheet. The risk event description in Column 2 should include specific risk event details.
Columns 3 and 4 are the results from the IPRA evaluation.
Column 5 refers to the specific potential impact to the project (cost/schedule/scope/quality).
Once the event or issue is identified as critical owing to its likelihood of occurrence and/or its relative potential impact on the project, a mitigation strategy and/or action must be identified and followed up (Column 6) to mitigate the specific impact in Column 5. Several actions or strategies may be identified, studied, and documented for each item in columns 2 and/or 5.

Mitigation Strategy/ Action (6)	Relative Cost (7)	Probability of Successful Mitigation (8)	Person Responsible for Action (9)	Action Due Date (10)	Status/ Comments (11)
CONTROL— Contact U.S. embassy representative	L	H	John Jones	10/17/XX	
TRANSFER— OPIC political risk insurance	M	H	Paul Smith	12/5/XX	
ACCEPT— Assess tax implications and potential increase	L	M	Rick Reyes	11/1/XX	
CONTROL— Assess local capabilities and requirements in detail	M	M	John Jones	10/18/XX	

Column 7 refers to the cost of the action relative to the total installed cost of the project (high (H)/medium (M)/low (L)) or an estimated amount of money if available.
Column 8 is an estimated probability of success if said mitigation action is implemented.
Columns 9 and 10 refer to the person responsible for the action and the date of the next update or resolution.
Column 11 is for comments and status of the action.

SOURCE: CII (2003).

8

Portfolio Risk Management

INTRODUCTION

Most of the discussions of risk assessment and management in this report have been concerned with risks at the individual project level and have focused on the IPT and project director. However, DOE has numerous projects, and program managers and senior managers should be concerned with the management of risks at the overall enterprise level, or *project portfolio management*. While the portfolio is composed of projects rather than stocks and bonds, the analogy with stock portfolios is intentional. For the investor, high-yield, high-risk stocks and bonds can be balanced by low-yield, low-risk stocks and bonds to achieve the desired level of portfolio risk. The knowledgeable owner, whether of stocks and bonds or of active projects, balances the portfolio to achieve an acceptable overall risk level.

Portfolio risk management does not imply that an owner should not perform risky projects but rather that the knowledgeable owner is aware of an optimum overall level for risk and adjusts project risks accordingly. Project owners do not have the flexibility of investors to trade stocks and bonds on the market and therefore cannot manage project portfolios in the same way that investment portfolios are managed, by buying and selling them. Some of the projects that an organization undertakes may not be freely chosen but rather determined by external forces. For example, an industrial owner may be required by environmental regulations to install scrubbers to reduce air pollution or to clean up contaminated ground water; these are not the owner's choices and cannot be avoided.

However, how these projects are performed may be controlled by the owner. The fact that some projects may not be completely controllable only reinforces the point that the owner should understand the risks. Building a new plant, developing a new product, and cleaning up a contaminated site all affect the total risk in the owner's project portfolio.

The primary difference between investment portfolios and project portfolios is that an investor has historical information about the volatility of the stocks (for example, the beta factors computed for stock prices) and, importantly, the correlation between them, with which to make informed decisions. However, there is no available database of volatility factors and correlation coefficients for first-time or one-of-a-kind projects. Therefore other means must be used to assess project risks. A knowledgeable owner who performs a large number of projects can make valid statistical judgments if a database of past projects is maintained and a consistent methodology for assessing risks is implemented across all projects.

PROGRAM-LEVEL RISK ANALYSIS

A knowledgeable owner maintains a program-level risk analysis of all ongoing significant projects in order to monitor the risks and vulnerabilities of project portfolios with respect to schedule, cost, scope, and performance and to control the total organizational risk. A fundamental maxim of modern management is: "If you don't know it, you can't measure it; if you can't measure it, you can't control it." Therefore, controlling risk has to start with knowing the risks—that is, measuring them or estimating them by the methods discussed in this report.

The program-level risk analysis should assess the risk status of current projects based on each project's original baselines and current project schedules and budgets, compared to performance on completed projects. The assessment should evaluate the risks of future scope shortfalls and budget and schedule overruns and should identify ongoing deficiencies in risk management that undermine the owner's ability to avoid surprises. Managing projects through risk assessment and risk management means looking forward, to anticipate future risks, instead of looking backward at past mistakes. The knowledgeable owner applies this process to all active projects in the portfolio, to minimize surprises.

An inadequate contingency at the program level may lead to project scope reductions, schedule delays, and even terminations. But at the program level, cost underruns could be attributable to an excessive contingency, which ties up the owner's capital or borrowing capacity unnecessarily in management reserves that are not needed and might have been used to support other desirable projects (Mak and Picken, 2000). Overestimation of contingencies leads to opportunity costs (i.e., some valuable projects at the margin will not be undertaken) as well as to excessive project costs if contingencies are routinely used up no matter what happens. The knowledgeable owner uses the best available method to set appropriate contingencies consistently across the project portfolio that are neither too large nor too small for the risks involved.

The knowledgeable owner also undertakes the risk assessments necessary to avoid baseline breaches by predicting the actual cost and time at completion of all ongoing projects. Projects that are the most vulnerable to risks need the most management attention. Consistency is necessary for programwide, cross-project comparisons, so the knowledgeable owner needs consistent procedures for assessing risks across all projects, and these procedures need to be insulated from project biases.

To get started with program-level risk management, an owner needs to have a current risk assessment of all ongoing projects in the portfolio and to establish, on a consistent basis, the vulnerabilities of projects with respect to schedule, cost, and performance risks. This assessment then becomes the baseline for program risk management, and should be updated as:

- Projects are completed and removed from the active project portfolio.
- Projects make progress and the estimated costs to complete, times to complete, and risks are reevaluated periodically (see the discussion on learning from project progress in Chapter 4).
- New projects are authorized, or proposed for authorization, to be added to the active project portfolio.

For proposed new projects, portfolio risk assessment should be used to determine whether the authorization of a particular project would raise the overall portfolio risk to a level unacceptable to enterprise management. If it would, then program managers may wish to terminate the proposed project, modify it, postpone it (until, for example, some active high-risk projects have been completed), or accept the risk of undertaking it. Program management concerns not only doing projects right, but also doing the right projects, and a project that appears to raise the portfolio risk to an unacceptable level may require restructuring before it can proceed.

A very important factor in portfolio risk assessment, as mentioned earlier, is the determination of correlations between projects. In investment portfolio management, for example, the investor needs to understand the correlations between stocks, as the whole point of portfolio management is to ensure that the assets in the portfolio are independent of each other so they do not all lose value at once. Similarly, the program manager needs to know if projects are correlated such that, if one project goes over budget, others might be more likely to go over budget. Correlations may be due to elementary factors such as material cost: If the price of steel goes up, then the costs of all projects that use steel will go up. Or the dependency between projects may be more subtle; for example, if multiple plants or processes are built to the same design, any design flaw would be likely to occur in all of them, potentially affecting the performance of the entire enterprise. The knowledgeable owner may not be able to avoid such dependencies but must certainly know what they are. Owners also need to understand dependencies among projects and their combined effect on the success of the enterprise. For example, if one project is to build a chemical processing plant and another is to build a waste treatment facility to support the former, then the risks for these projects should be managed as one.

Knowledgeable owners set project contingencies to meet risk management criteria at all levels of the enterprise. Portfolio contingency is difficult to control if the project contingencies are not explicitly stated but rather are buried in the project estimates. Consequently, periodic project reviews (known as *scrubbing the estimates*) become necessary as a means to uncover and consolidate the buried contingencies.

It is possible to set contingencies to meet defined risks on a consistent basis across all levels of an enterprise, from work packages at the lowest level up through the work breakdown structure to the total project level and then to the program or enterprise level. When this is done on a consistent basis, the budgets at all levels can be set in accordance with acceptable risks of overrunning at these levels, which need not be the same for all levels and all projects. For example, program management might accept a relatively high risk of overrunning at the detailed work package level, less risk of overrunning the project budget, and still less risk of overrunning the program budget at the enterprise level. However, the budget risks cannot be controlled unless the contingencies are explicitly set to match the risks. Knowledgeable owners should have a consistent and explicit policy on the use of contingencies, what level of risk they should reflect, and, of particular importance, who controls them.

PROJECT AND PORTFOLIO BUDGETS

Project portfolio management needs to address the following question: Why do relatively few projects seem to underrun budgets, and why do so few return the unused contingency? There are at least two possible explanations for this: (1) underestimated costs and (2) project budget entitlement.

Underestimated Costs

One hypothesis is that costs are in fact consistently underestimated, such that the actual project budgets are less than the expected values. Under what circumstances might project budgets be generally biased on the low side (less than the expected values)? Some possible explanations include the following:

- Projects are intentionally underestimated and pushed through the process by their advocates, who recognize that the likelihood of getting funded decreases with increasing project cost estimates. Project proponents also recognize that if a project is underfunded, the funding may not be enough to complete the project, but will be enough to get it started. They expect to go back to the sponsor to authorize a budget increase once the project is under way, and expect that the sponsor will not terminate it with so much money sunk into it. Project proponents are motivated to lowball the cost estimates and discouraged from providing unbiased estimation. Even a small lowball bias at the work package level leads to a virtual certainty that budgets will be overrun at the project level.
- Project estimates are in fact originally accurate at the project level but are arbitrarily reduced at a higher (political) level, in the belief that they are too large or contain too much fat. Or, trying to do more projects than the funds available can support, higher-level managers simply divide their fixed resources among their projects regardless of project estimates. This behavior is also self-reinforcing.

Project Budget Entitlement

Another possible explanation for the apparent fact that more projects seem to overrun than underrun is an asymmetry in how funds are handled. It is typically assumed that cost overruns in some projects are (statistically) offset by underruns in others, and that reserve margins can therefore be proportionally lower when spread over many projects. To take a different view, suppose that every project that overruns its budget and appeals for additional funding receives it, while projects that underrun budgets hold onto all or part of the contingency and use it to enhance the project instead of passing it back to the program.

- This result may be rationalized by a sense of entitlement. Project personnel may feel that their work is highly justified—e.g., essential to the national defense, vital to the advancement of science, necessary to cleaning up the environment—and that if, through their efforts, they have some money left over they deserve it. They can also easily justify spending it on increasing the project scope and quality, improving performance and reliability, getting more and better instruments, upgrading the office space, and the like. Any or all of these options may be much more attractive to the project personnel than giving the money back to the program, especially if they feel they are entitled to it by the value of their work or their suffering through past budget cuts. In fact, many people believe that all contingency funds belong to the project and ought to be spent by the project, whether or not the events on which they were contingent ever occurred.

- No underruns may in fact be observed. This happens because more management attention and efforts are typically directed to projects (or work packages) that are underperforming and overrunning than to those that are outperforming estimates. In typical project monthly reports, projects are classified as red (underperforming and overrunning), yellow (trending toward underperforming and overrunning), or green (outperforming estimates), based on cost and schedule performance, and attention immediately turns to those classified as red, not to those classified as green. Because badly performing projects get more upper management attention than problem-free projects, it is not unusual that the good performers get worse in the absence of careful supervision. In addition, a common solution to the problems on one project is to transfer the project manager from another project that is within budget and on schedule, leaving that project under less competent management. Underruns may thus disappear naturally, and no one can say if they ever existed, much less where they went.

These effects would be very hard to observe in the cost records. In the second case, no one ever observes an underrun, even the personnel on the projects. In the first case, underruns might become known if project personnel admit that they could have come in under budget but spent the full budget anyway because it was there. But this admission is unlikely to occur. Thus an outside observer can never observe the probability distribution of costs as they might have been; one can only observe the actual costs after they have been reported and therefore after any potential underruns have been spent.

The costs of one project may influence the budgets for following projects. If contingencies are expended, the whole cost structure will inexorably creep upward. Thus, as overruns are reported accurately but underruns are spent, costs will get higher and higher, even for programs with cost databases from prior experience. This project-to-project cost creep will doubtless be attributed to construction cost inflation or other uncontrollable factors.

These considerations lead to the conclusion that, not only should contingencies be set objectively based on probability considerations, but also control of these contingent funds should be retained at the enterprise level. Management reserves should be controlled high up the management chain, in order to take advantage of the benefits of larger numbers of projects, and they should be controlled by people who are not proponents of any particular projects to ensure that the reserves are allocated based on actual needs and priorities, not personal bias.

The nature of management reserves and contingencies—how large they are and why—should be made open, rational, and explicit rather than hidden or implicit, at all organizational levels. Rules for the rational setting of management reserves should be published in organizational policies and procedures, along with statistical justifications. Responsible managers should actively manage the reserves. Efforts should be made to reduce costs by controlling the release of contingency funds to projects or activities, by rewarding managers who come in under budget, by sharing any remaining contingency funds between the project and the program, and by giving management attention to prospective risks, whether projects are under budget or over budget. Bringing in a project $1 million under budget should have just the same value and recognition as preventing one from going $1 million over budget.

Some sense of common purpose is required to reinforce cooperation and minimize competition so that project estimates are not manipulated up or down, and surpluses are returned to the higher management level. The likelihood of defensive irrational decisions can be reduced by meeting budget cuts or shortfalls by delaying or canceling the lowest-priority projects and fully funding the rest rather than underfunding, and thus delaying, them all.

9

Conclusions

Department of Energy project directors, program managers, and senior managers have the responsibility to assess and manage risks on their projects and project portfolios. Project risks can be managed to successful conclusions through the following basic actions:

- Establish and maintain management commitment to performing risk management on all capital projects.
- Start the risk management process early in the project life cycle—prior to approval of mission need (CD-0).
- Include key stakeholders in the process, with the DOE project director as the lead and the integrated project team (IPT) intimately involved in the process.
- Evaluate project risks and risk responses periodically during the project life cycle (CD-0 through approval of the start of operations [CD-4]).
- Develop risk mitigation plans and update them as the project progresses.
- Follow through with mitigation actions until risks are acceptable.
- Tie a project's level of risk to cost and schedule estimates and contingencies.
- Effectively communicate to all key stakeholders the progress and changes to project risks and mitigation plans.

An example of a risk assessment tool that uses some of the risk assessment methods discussed in this report is the Construction Industry

Institute's International Project Risk Assessment (IPRA) tool. It provides a systematic method to identify, qualitatively assess, and determine the relative importance of specific risks across a project's life cycle. IPRA consists of 82 pre-identified risk elements that can be assessed according to the likelihood of occurrence and relative impact based on data from a large sample of projects.

Program managers and DOE senior management can contribute to effective risk management by ensuring that project directors and IPTs effectively carry out the actions listed above and by requiring projects to report on the status of all risks and risk management activities in every project status report and at every project review meeting.

Conventional project management is reactive: Senior owner management becomes involved when the project is already over budget, over schedule, and—possibly—underperforming, when it is too late to correct the situation by improving project management.

Active risk management, by contrast, is proactive, directing management attention to uncertainties and risks before the events have happened, when there are still opportunities to do something to avoid, mitigate, or manage them or to stop the project if they cannot be managed. Active risk management is an approach that allows managers to manage rather than just assign blame for failure. Active risk management is the synthesis of the theoretical approach for identifying, assessing, and quantifying risks with the managerial approach for mitigating, controlling, and managing them.

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Appendixes

Appendix A

Biographies of Committee Members

Kenneth F. Reinschmidt (National Academy of Engineering), *Chair*, is professor of civil engineering and holds the J. L. Frank/Marathon Ashland Petroleum LLC Chair in Engineering Project Management at Texas A&M University. He retired from Stone & Webster as senior vice president. He was appointed chair of this committee for his combination of expertise in the disciplines of civil engineering, project management, cost estimating, and the management of large-scale construction projects, including nuclear and fossil fuel power plant construction. He held various positions at Stone & Webster, including president and CEO of Stone & Webster Advanced Systems Development Services, Inc., and manager of the consulting group in the Engineering Department. In these positions he was engaged in structural engineering, operations research, cost analysis, construction engineering and management, and project management. Prior to his work at Stone & Webster, Dr. Reinschmidt was a senior research associate and associate professor in the Civil Engineering Department at the Massachusetts Institute of Technology, where he was engaged in interdisciplinary research on power plant engineering, design, construction, and project management. Dr. Reinschmidt served as chair of the committee that produced the recent NRC report *Improving Project Management in the Department of Energy* and was reviewer of the NRC report *Assessing the Need for Independent Project Reviews in the Department of Energy*. He is a former member of the Building Research Board of the NRC and served or chaired several other NRC committees, including the Committee on Integrated Database Development, the Panel for Building Technology, the Committee on Advanced Technology for Building Design, and the Committee on Foam Plastic Structures. He has also served on several National Science Foundation review panels on construction automation, computer-integrated construction, and engineering research centers. He obtained his B.S., M.S., and Ph.D. degrees from the Massachusetts Institute of Technology.

Don Jeffrey (Jeff) Bostock retired from Lockheed Martin Energy Systems, Inc., as vice president for engineering and construction with responsibility for all engineering activities at the Oak Ridge nuclear complex. He is serving on this committee because of his experience with managing projects as a DOE contractor. He has also served as vice president of defense and manufacturing and manager of the Oak Ridge Y-12 plant, a nuclear weapons fabrication and manufacturing facility. His career at Y-12 included engineering and managerial positions in all of the various manufacturing, assembly, security, and program management organizations. He also served as manager of the Paducah Gaseous Diffusion Plant, which provides uranium enrichment services. He was a member of the committees that produced the NRC reports *Proliferation Concerns: Assessing U.S. Efforts to Help Contain Nuclear and Other Dangerous Materials and Technologies in the Former Soviet Union* and *Protecting Nuclear Weapons Material in Russia*. Mr. Bostock also served as a panel member for the annual NRC assessment of the Measurement and Standards Laboratories of the National Institute of Standards and Technology. Mr. Bostock has a B.S. in industrial engineering from Pennsylvania State University and an M.S. in industrial management from the University of Tennessee. He is a graduate of the Pittsburgh Management Program for Executives.

Donald A. Brand (National Academy of Engineering) retired from the Pacific Gas and Electric (PG&E) Company as senior vice president and general manager, engineering and construction business unit. He more recently was a lecturer at the University of California at Berkeley, teaching construction management. Mr. Brand was appointed as a member of this committee because of his expertise in the management of the design, engineering, and construction of large, complex energy-related facilities. During his 33 years with PG&E, he carried out numerous managerial and engineering responsibilities related to the design, engineering, construction, and operation of fossil fuel, geothermal, nuclear, and hydroelectric generating facilities, as well as of electrical transmission, distribution, and power control facilities. Mr. Brand's industry activities have included membership on the Electric Power Research Institute's Research Advisory Committee and on the Association of Edison Illuminating Companies' Power Generation Committee. He has been a member of numerous NRC committees. He belongs to numerous professional societies and is a registered professional engineer in California. He received a B.S. in mechanical engineering and an M.S. in mechanical (nuclear) engineering from Stanford University. He also graduated from the Advanced Management Program of the Harvard University School of Business.

Allan V. Burman is president of Jefferson Solutions, a division of the Jefferson Consulting Group, a firm that provides change management services and acquisition reform training to many federal departments and agencies. He serves as a member of this committee because of his expertise in federal acquisition, procurement, and budget reform. Dr. Burman provides strategic consulting services to private sector firms doing business with the federal government as well as to federal agencies and other government entities. He also has advised firms, congressional committees, and federal and state agencies on a variety of management and acquisition reform matters. Prior to joining the Jefferson Consulting Group, Dr. Burman had a long career in the federal government, including serving as administrator for federal procurement policy in the Office of Management and Budget (OMB), where he testified before Congress over 40 times on management, acquisition, and budget matters. Dr. Burman also authored the 1991 policy letter that established performance-based contracting and greater reliance, where appropriate, on fixed-price contracting as the favored approach for contract reform. As a member of the Senior Executive Service, Dr. Burman served as chief of the Air Force Branch in OMB's National Security Division and was the first OMB branch chief to receive a Presidential Rank Award. Dr. Burman is a fellow and member of the board of advisors of the National Contract Management Association, a principal of the Council for Excellence in Government, a director of the Procurement Round Table, and an honorary member of the National Defense Industrial Association. He is also a contributing editor and writer for *Government Executive* magazine. Dr. Burman obtained a B.A. from Wesleyan University, was a Fulbright Scholar at the Institute of Political Studies, University of Bordeaux, France, and has a graduate degree from Harvard University and a Ph.D. from the George Washington University.

Lloyd A. Duscha (National Academy of Engineering) retired from the U.S. Army Corps of Engineers in 1990 as the highest-ranking civilian after serving as deputy director, Engineering and Construction Directorate, at headquarters. He serves as a member of this committee because of his expertise in engineering and construction management and his roles as principal investigator for the NRC report *Assessing the Need for Independent Project Reviews in the Department of Energy* and member of the committee that produced the NRC report *Improving Project Management in the*

Department of Energy. He served in numerous progressive Army Corps of Engineer positions in various locations over four decades. Mr. Duscha is currently an engineering consultant to various national and foreign government agencies, the World Bank, and private sector clients. He has served on numerous NRC committees and recently served on the Committee on the Outsourcing of the Management of Planning, Design, and Construction Related Services as well as the Committee on Shore Installation Readiness and Management. He chaired the NRC Committee on Research Needs for Transuranic and Mixed Waste at Department of Energy Sites and serves on the Committee on Opportunities for Accelerating the Characterization and Treatment of Nuclear Waste. He has also served on the Board on Infrastructure and the Constructed Environment and was vice chairman for the U.S. National Committee on Tunneling Technology. Other positions held were president, U.S. Committee on Large Dams; chair, Committee on Dam Safety, International Commission on Large Dams; executive committee, Construction Industry Institute; and the board of directors, Research and Management Foundation of the American Consulting Engineers Council. He has numerous professional affiliations, including fellowships in the American Society of Civil Engineers and in the Society of American Military Engineers. He holds a B.S. degree in civil engineering from the University of Minnesota, which awarded him the Board of Regents Outstanding Achievement Award.

G. Brian Estes is the former director of construction projects at Westinghouse Hanford Company, where he directed project management functions supporting operations and environmental cleanup of the Department of Energy Hanford nuclear complex. He was appointed as a member of this committee because of his experience with DOE, as well as other large-scale government construction and environmental restoration projects. He served on the committee that produced the recent NRC report *Improving Project Management in the Department of Energy* and has served on a number of other NRC committees. Prior to joining Westinghouse, he completed 30 years in the Navy Civil Engineer Corps, achieving the rank of rear admiral. Admiral Estes served as commander of the Pacific Division of the Naval Facilities Engineering Command and as commander of the Third Naval Construction Brigade at Pearl Harbor. He supervised over 700 engineers, 8,000 Seabees, and 4,000 other employees in providing public works management, environmental support, family housing support, and facility planning, design and construction services. As vice commander, Naval Facilities Engineering Command, Admiral Estes led the total quality management transformation at headquarters and two updates of the corporate strategic plan. He directed execution of the $2 billion military construction program and the $3 billion facilities management program while serving as deputy commander for facilities acquisition and deputy commander for public works, Naval Facilities Engineering Command. He holds a B.S. in civil engineering from the University of Maine, an M.S. in civil engineering from the University of Illinois, and is a registered professional engineer in Illinois and Virginia.

David N. Ford is an assistant professor of civil engineering at Texas A&M University. He serves as a member of this committee because of his expertise in evaluating project management with analytical methods and simulations. He researches the dynamics of project management and the strategy of construction organizations, as well as teaching project management and computer simulation courses. Current research projects include an investigation into the causes of failures to implement fast-track processes and the value of contingent decisions in project strategies. Prior to his appointment at Texas A&M, Dr. Ford was an associate professor in the Department of Information Sciences at the University of Bergen in Norway. He was one of two professors to develop and lead the graduate program in the system dynamics methodology for 4 years. Dr. Ford's research during this time focused on the dynamics of product development processes and included work with Ericsson Microwave to improve that company's product development processes. Dr. Ford designed and managed the development and construction of facilities during 14 years in professional practice for owners, design professionals, and builders. The projects varied in size and facility type, including commercial buildings, residential development, industrial, commercial, and defense facilities. He serves as a reviewer for the journals *Management Science, The Journal of the Operational Research Society, Technology Studies,* and *System Dynamics Review*. Dr. Ford received his B.C.E. and M.E. degrees from Tulane University and his Ph.D. from the Massachusetts Institute of Technology in dynamic engineering systems.

G. Edward Gibson, Jr., is a professor of civil engineering, associate chairman for architectural engineering, and the Austin Industries Endowed Faculty Fellow in the Construction Engineering and Project Management program at the University of Texas at Austin. He serves as a member of this committee because of his expertise and research in preproject planning, organizational change, and the development of continuing education training programs for project managers. His research interests include organizational change, preproject planning, construction productivity, international project risk management, electronic data management, and automation and robotics. Dr. Gibson is a co-director of the Center for Construction Industry Studies funded by the Alfred P. Sloan Foundation. He received the Outstanding Researcher Award of the Construction Industry

Institute (CII) for his pioneering work in preproject planning and is an author or coauthor of numerous articles and reports on this subject. He also developed several CII education modules for continuing education and has taught over 140 short courses to industry in such areas as objective setting, team alignment, continuous improvement, preproject planning, and materials management. He received an M.B.A. from the University of Dallas and a B.C.E. and a Ph.D. in civil engineering from Auburn University.

Theodore C. Kennedy (National Academy of Engineering) is chairman and cofounder of BE&K, a privately held international design-build firm that provides engineering, construction, and maintenance for process-oriented industries and commercial real estate projects. Mr. Kennedy serves as a member of the committee because of his experience and expertise with the design, construction, and cost estimation of complex construction and engineering projects. BE&K companies design and build for a variety of industries, including pulp and paper, chemical, oil and gas, steel, power, pharmaceutical, and food processing. BE&K is consistently listed as one of *Fortune* magazine's Top 100 Companies to Work For, and BE&K and its subsidiaries have won numerous awards for excellence, innovation, and programs that support their workers and communities. Mr. Kennedy is the chairman of the national board of directors of INROADS, Inc., and is a member of numerous other boards, including the A+ Education Foundation and the Community Foundation of Greater Birmingham. He is also a member of the Duke University School of Engineering Dean's Council and the former chairman of the Board of Visitors for the Duke University School of Engineering. He is the former president of Associated Builders & Contractors and the former chairman of the Construction Industry Institute. He has received numerous awards, including the Distinguished Alumnus Award from Duke University, the Walter A. Nashert Constructor Award, the President's Award from the National Association of Women in Construction, and the Contractor of the Year award from Associated Builders and Contractors. Mr. Kennedy has a B.S. in civil engineering from Duke University.

Michael A. Price is manager of education programs for the Project Management Institute (PMI), an international association of project management professionals that provides accreditation and training. He was appointed to this committee because of his experience and expertise in developing and evaluating project management training programs. Dr. Price is responsible for the development and implementation of operational plans for all PMI educational programs and initiatives, including accreditation of degrees in project management, selection and coordination of 150 public seminars annually, management of continuing education requirements and record keeping for 22,000 project management professionals, and identification of new educational products and programs to meet the learning needs of the global project management community. Previous to his present position, Dr. Price was director of professional practice for the American Institute of Architects (AIA) and director of programs for architecture and engineering with the Research Center for Continuing Professional and Higher Education at the University of Oklahoma. He is an active member of the AIA and has been a member of the Education System Audit Review Task Group and the site visitation team for the National Architectural Accreditation Board. Dr. Price has a B.S. in environmental design, a B. Arch., an M.Ed., and a Ph.D. from the University of Oklahoma.

Appendix B

Statement of Task

In response to a congressional directive, the National Research Council has appointed a committee to review and assess the progress made by the U.S. Department of Energy (DOE) in improving its project management practices. This study includes evaluation of the implementation of recommendations in the 1999 NRC report *Improving Project Management in the Department of Energy.* The principal goal of this effort is to assess DOE's efforts to improve project management practices, including: (1) specific changes in organization, management practices, personnel training, and project reviews and reporting; (2) an assessment of the progress made in achieving improvement; and (3) the likelihood that improvements will be permanent. These tasks will also require development of a framework for evaluation and performance measures specifically tied to DOE's project management process.

NOTE: The committee made the following recommendation in its 2003 assessment report:

> DOE should develop detailed procedures and guidance for identifying risks, planning strategies to address risks, and managing risks throughout the life cycle of projects, and should require their implementation for all projects. Projects should not pass CD-1 or CD-2 without an effective risk mitigation plan. (NRC, 2004, p. 38)

The DOE Office of Engineering and Construction Management (OECM) requested the committee to provide assistance for following this recommendation by summarizing practices the committee believes constitute excellence in risk management.