RISK ANALYSIS FRAMEWORK FOR COST ESTIMATION

by

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PREFACE

This report is a product of the U.S. Army Corps of Engineer's Risk Analysis for Water Resources Investments Research Program managed by the Institute for Water Resources. This report documents research investigating the possibilities of incorporating risk analysis techniques into the Corps' cost estimating processes. The general purpose of this report was to identify the concept of uncertainties that are inherent in the production of a project cost estimate and how the application of risk and uncertainty techniques can serve to manage these by providing project staff and decision-makers with improved information. The case study is key in illustrating how these general concepts can be adapted and applied to a specific project. The idea is that although each individual Civil Works project is different from any other, the same theoretical concepts can be applied to the specific features of any project by Corps District personnel with expert knowledge in their field about the project being planned. Therefore, the goal of this report is not only to illustrate the presence of uncertainties and their potential effects, but also to show Corps field and headquarters personnel of the feasibility and benefits of researching, refining, and adopting such analytical procedures in actual practice.

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Dr. Charles Yoe served as the principal investigator for PMCL, and completed this work with the assistance of Mr. Phillip Letting, an economist with PMCL. Mr. Jack Kiefer of PMCL provided contract management and review.

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I. INTRODUCTION

Costs are the one constant in the U.S. Army Corps of Engineers' nine business programs. Costs are a key concern in planning, design, construction, operation, maintenance and regulation, the Corps' six major types of activities. Costs matter. Estimating costs, often from very little information, is one of the most common and important tasks performed in the conduct of the Corps' business and accomplishment of its missions.

Cost estimation is prediction. Little in cost estimating is certain. There is an inherent need for accurate forecasts of costs in all of the Corps' business program activities for obvious reasons. Costs are used in a variety of ways. Consider the following uses of a cost estimate (adapted from Uppal, 1995).

- From a cost estimator's viewpoint the cost estimate represents an estimated required expenditure for the project/activity under consideration, based on the agreed upon scope of work.
- From management's perspective, the cost estimate determines whether a particular project or activity goes forward or not.
- From a non-federal partner's point of view, the cost estimate determines whether or not they will support the project or activity under consideration.
- From Congress' viewpoint, the cost estimate can influence authorization and appropriation decisions.
- From a contractor's perspective, the cost estimate determines whether or not they can be successful in bidding and winning a contract and in making a profit on the work.

A risk analysis framework for estimating costs holds considerable promise for improving the quality of cost estimates for Civil Works projects because it provides opportunities to explicitly address much of the uncertainty inherent in the cost estimating process. At a time when cost estimators are being asked to provide more and better cost information earlier in project planning and design than ever before, every opportunity to improve the quality of cost estimating should be explored and exploited. The purpose of this report is to demonstrate the feasibility of using risk analysis to improve both the process of cost estimating and the quality of the cost estimates.

COST ESTIMATION AS PREDICTION

The American Association of Cost Engineers (AACE) defines cost engineering as "that area of engineering practice where engineering judgment and experience are utilized in the application of scientific principles and techniques to the problems of cost estimation, cost control, and profitability." Cost estimating reflects a step-by-step plan of a project. This plan is translated into a dollar value by applying unit costs to the quantities identified in the plan. Cost estimators predict how much of an item will be purchased, what will be paid for it, when it will be purchased, and, generally, where it will be bought. The concept of a cost estimate as a prediction will be used throughout this report to emphasize the fundamentally uncertain nature of cost estimation. This uncertainty renders cost estimation procedures much more amenable to risk analysis techniques.

The uncertainty inherent in a cost estimate is greatest when the available information is of the smallest quantity and lowest quality. As information improves, i.e., more and better information becomes available, the uncertainty in the cost estimate is gradually reduced. Until, at the extreme, all costs have been incurred and costs are known with certainty. Figure 1-1 illustrates the trade-off between information and uncertainty.

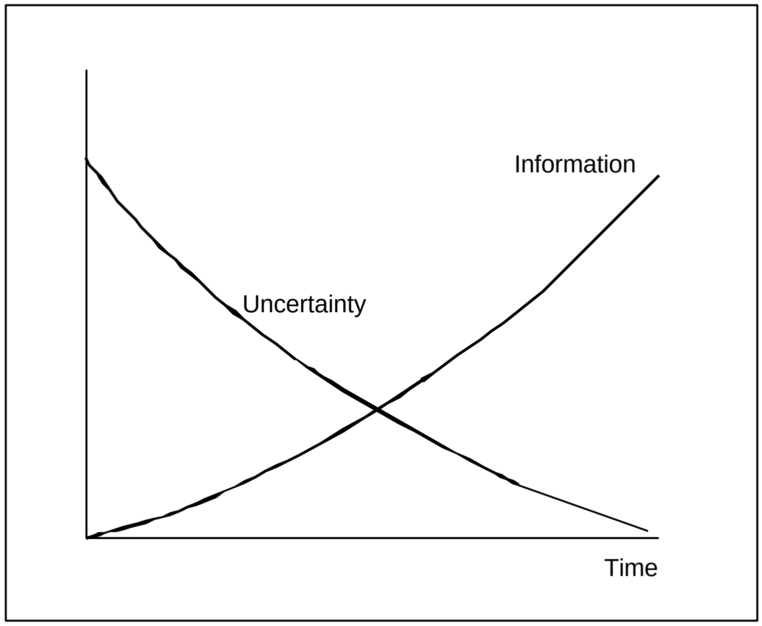

FIGURE 1-1

UNCERTAINTY – INFORMATION TRADE-OFF

The information that reduces uncertainty does not come cheaply. Because reducing uncertainty requires information and acquiring information takes time and money, a good cost estimate must strike a balance between how much information is required and how much residual uncertainty is acceptable. As long as the cost estimate remains a prediction, rather than the report of a finished project, there will be some degree of uncertainty. It is also important to note that the information required to reduce some uncertainty attending a cost estimate, for example, random acts of nature that can affect costs, may be unavailable at any cost.

When uncertainty cannot be reduced because it is impossible or not cost effective to do so, it can either be ignored at the estimator's peril or it can be addressed in a variety of ways. In this report, a risk analysis framework for addressing the uncertainty inherent in the task of cost estimating.

TYPES OF COST ESTIMATES

There are countless terms and definitions used to describe the types of estimates prepared by cost estimators. The Corps of Engineers has spawned many of these. Estimates are often defined by the basic stages or phases in project design. It is not uncommon in the construction industry to hear about cost estimates for the planning/evaluation stage (also known as: screening, preliminary, quickie, back-of-the-envelope, order-of-magnitude, guesstimate, rough, gross, scope, estimate); the basic design stage (aka: preliminary, budget, or semi-detailed, or estimate);

and the detailed engineering construction estimate (aka: definitive, appropriation, lump sum, or detailed, estimate).

In the Corps of Engineers Civil Works Program, cost estimates are prepared for the reconnaissance phase, the feasibility phase, the planning, engineering and design phase, the construction phase, and the operation, maintenance, repair, rehabilitation, and replacement (OMRR&R) phase. Two major types of estimates used in Civil Works construction are the Total Current Working Estimate (TOTAL CWE) and the Government Estimate. ER 1110-2-1302 Civil Works Cost Engineering defines these cost estimates. The TOTAL CWE consists of all project costs and will vary as design details are refined (*i.e., as uncertainty is normally and systematically reduced)* at each phase in project development. The Baseline Cost Estimate (BCE), developed to support the recommended scope and schedule in the Feasibility Report, is the TOTAL CWE at this specific point in time. The Government Estimate is an independent construction cost estimate prepared as if the Government were in competition for the contract award.

Cost estimates are also prepared for other programs as well. These include the continuing authorities program, dam safety assurance program, dredging projects, beach fill and nourishment, and emergency work. The requirements for these estimates and the uses to which they are put vary with the specific program.

USES OF COST ESTIMATES

There are a great many stakeholders interested in the cost estimate of a Civil Works project. Included are the project team, the Corps District, Division and Headquarters, Congress, the local partner, potential bidding firms, and the ultimate contractors. Each wants slightly different information from a cost estimate, interprets it differently, and accordingly may make somewhat different uses of the estimate as well. Meeting the various information demands and uses of the various stakeholders' places quite a burden on the cost estimators.

The cost estimate, as the output of the step-by-step plan of construction, is used as the best indicator of the resources that will be required to complete the project. This is important information for Congress and other decision makers, depending on the program, who will have to authorize and appropriate funds for construction. It is also important information for everyone involved in the budget process. The non-Federal partner has a vital interest in knowing their share of the project costs. Economists and financial analysts use this information to determine if the project meets economic efficiency criteria and if it is financially viable. Planners use cost estimates to compare plans. Contractors use the plan and earlier cost estimates as a basis for their bids. Cost control, scheduling, accounting and other analytical and management functions rely on the cost estimate as well.

RISK ANALYSIS FRAMEWORK

If the many users of the various cost estimates get better information, it stands to reason that in time they should all be able to make better decisions with that information. Hence, the potential benefits of any framework that improves the quality of the information available to these people would be rather widespread.

If the uncertainty inherent in a predictive cost estimate can be reduced or effectively addressed, the quality of the cost estimate should be improved. Better cost estimates can lead to better decisions by anyone who uses the cost estimate. Probability is the language of uncertainty and the probabilistic methods (and non-probabilistic methods as well) of addressing the uncertainty in cost estimates presented in this report form the basis for a risk analysis framework for preparing cost estimates.

PURPOSE OF REPORT

The primary purpose of this research report is to demonstrate the feasibility of incorporating risk and uncertainty analysis techniques into the Corps' more common cost estimation activities under a variety of authorities and budgets. This is done in a discussion of principles, concepts and techniques, and a case study demonstration.

AUDIENCE

The research summarized in this report was conducted for the specific purpose of exploring the potential for risk analysis methods in cost estimation work for the Corps of Engineers Civil Works program. Thus, the primary general audience for this report is Corps personnel. The primary specific audience is cost estimators. The report assumes the reader is generally familiar with Corps policies, jargon, and procedures. The most likely users of this information are cost estimators (including real estate), planners, engineers, and operations and maintenance personnel.

Most of the research results are generally applicable to any construction cost estimation activity. For that reason, much of this material is of interest to an audience that extends beyond the Corps. This secondary audience includes cost estimators, engineers, and planners among non-federal partners and the construction industry.

ORGANIZATION OF PAPER

This report has six chapters. Chapter II provides an introduction to risk analysis. This chapter presents a three-part risk analysis model. It also describes its three components in an intuitive fashion. With risk analysis defined, Chapter III explores the reasons for doing risk analysis of cost estimates. Improving the accuracy of estimates and the decisions made from them are the two most compelling reasons for performing a risk analysis. Several specific examples of each are offered here.

The fourth chapter presents an overview introduction to some risk assessment methods that have proven useful in cost estimating. These include a generic strategy, sensitivity analysis, Monte Carlo simulation and range estimation. A case study that applies a combination of sensitivity analysis and Monte Carlo simulation is presented in Chapter V. A risk analysis of the dredging costs associated with improvements to Port Sutton Terminal Channel in Tampa Bay Harbor is presented. The report closes with a chapter on findings and recommendations for further consideration.

SUMMARY AND LOOK FORWARD

This chapter introduces the idea that cost estimating and cost estimates in the Civil Works Program can be improved through risk analysis. Cost estimation is a predictive activity. As such it is replete with uncertainty. Reducing or addressing that uncertainty can only improve the quality of cost estimating and the decisions made with the resulting cost estimates over time.

The next chapter introduces the reader to the language, concepts and models of risk analysis. It is written for a reader with no prior knowledge of these concepts.

II. RISK ANALYSIS OVERVIEW

INTRODUCTION

Risk is the chance of a bad thing happening. Analysis is the separation of the whole into its component parts. Risk analysis in the Civil Works Program is a systematic process for describing and quantifying risks associated with processes, actions, or events; taking steps to manage those risks; and communicating about the risks and management actions with all interested parties. Risk analysis comprises risk assessment, risk management and risk communication. A risk analysis of costs therefore necessitates assessing the risks, managing the risks and communicating about those risks to others.

This chapter explains these concepts in an intuitive fashion. It begins with some basic definitions, presents a risk analysis model, and then examines each of the components of the model.

THE LANGUAGE OF RISK AND UNCERTAINTY

To discuss a new topic a new language is needed. Here are a few definitions that are being adopted for use with the Corps' Civil Works Program. This section departs from the oversimplified definitions of the opening paragraph and begins with risk itself.

> *Risk is a characteristic of a situation, action, or event in which a number of outcomes are possible, the particular one that will occur is uncertain, and at least one of the possibilities is undesirable.*

Thus defined, it might be suggested that risk is the chance of a bad thing happening. The simplicity of this notion confounds some people. Is playing the lottery risky; after all, there is a chance of becoming a millionaire. There is also the chance of losing the dollar, so it is risky.

Foundation conditions, the proportion of rock in a channel, and the cost of a cubic yard of concrete at a particular time and place provide ready examples of risks in cost estimating. There are many outcomes possible, it is not known for certain which will happen, and it is easy to identify the least favored of the outcomes.

One might wonder if any unknowns are not risky? The answer is sure. For example, one may not know how to use the M32 version of M-CACES or CEDEP. But there are not several outcomes, the answer is certain and there is nothing undesirable here. One may need help or some experience using this cost estimating software but it can be done. Some things are uncertain but not risky.

Are uncertain geotechnical foundation conditions at a particular location risky? Isn't that a lot like the software example? The conditions are a fact that one simply does not know. Now entering into a question of perspective, it is clearly a situation in which one is uncertain. From a given vantage point there could be several possibilities and the actual condition is unknown. Some of the possible conditions are more desirable than others. That, in turn, makes some conditions less desirable than others. Some uncertain situations are also risky. So one can face a situation like that shown in Figure 2-1. All risks are uncertain but not all uncertainty is risky. Thus, uncertainty is defined as follows:

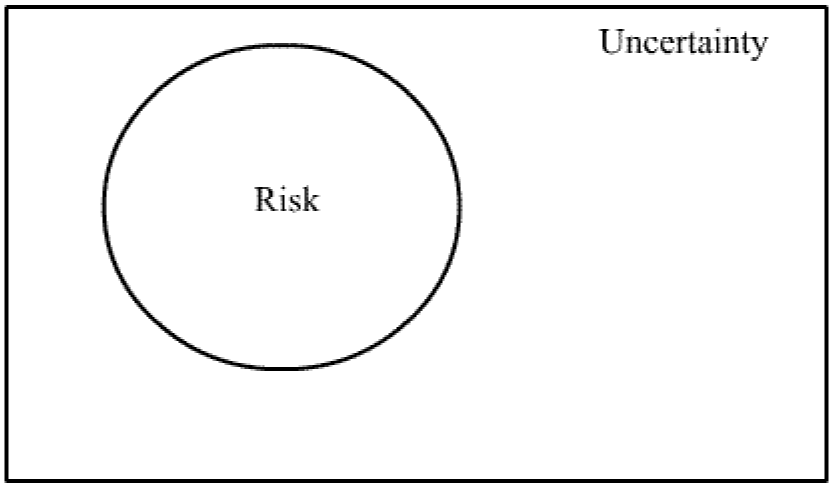

FIGURE 2-1

RISK AND UNCERTAINTY VENN DIAGRAM

Uncertainty is a situation in which a number of possibilities exist and which of them has occurred, or will occur, is unknown.

Risk analysis as practiced by the Corps of Engineers refers to the analysis of those things that are risky and uncertain. To add a degree of difficulty to the language it's important to note that there may be uncertainties about specific elements of some risky situations. How many outcomes are possible? When might they occur? How likely are they? What is the nature and magnitude of the undesirable consequence? Describing a risky situation adequately often requires one to address the uncertainty in the situation as well.

Thus, risky situations are by definition uncertain situations. Risks may, themselves, involve some uncertainties. The uncertainties attending these risks may or may not themselves be risky. So there exists a wheels-within-wheels kind of definition of terms. Graphically, it may be presented as shown in Figure 2-2.

In a cost context, imagine that the project cost estimate is unknown (the big rectangle) in part because excavation costs associated with dredging are risky (the big circle). This could be because the foundation conditions in the channel are uncertain (the next rectangle) and have some risky elements (the next circle) and so on. But do not panic. One does not have to break down or distinguish the risks from the uncertainties in this way.

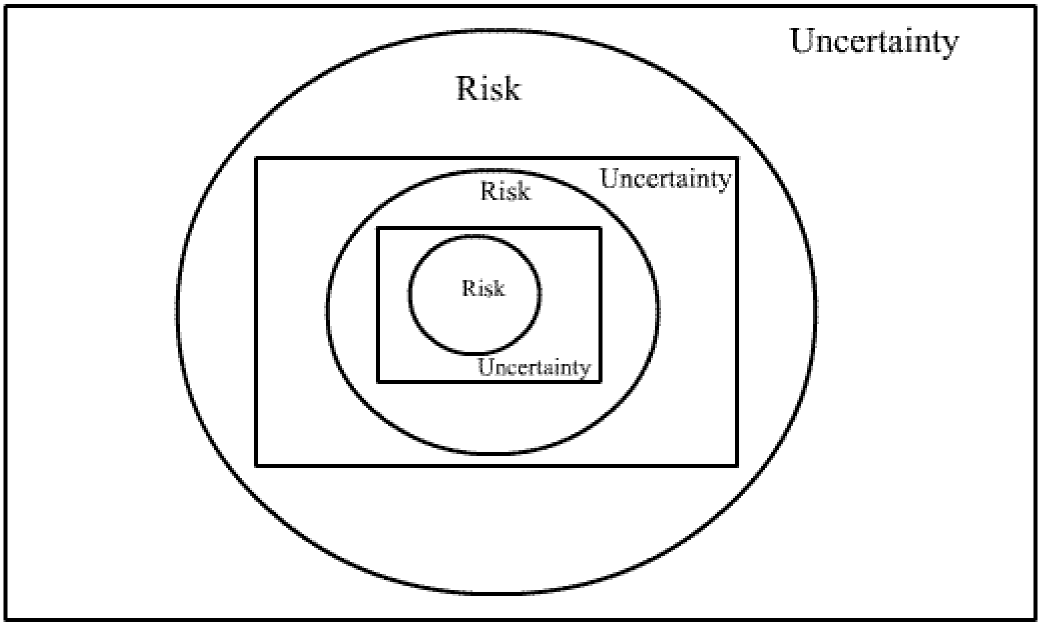

FIGURE 2-2

UNCERTAINTY, RISK AND UNCERTAIN RISKS

There can be lesser risks imbedded within greater risks; or uncertainties that are not risky embedded within risks, and so on. When analysts talk about risk analysis, they are talking about the analysis of all relevant risks and uncertainties. They make no practical distinction between risk analysis and uncertainty analysis. Although a distinction is sometimes drawn in the professional literature, for the practical purposes of the Corps of Engineers' Civil Works Program it is a distinction without a difference. Thus, risk and uncertainty analysis can be considered as synonymous terms. So then risk analysis is defined as follows:

Risk analysis is the process of separating the whole of risk into its component parts by assessment of the risk and related uncertainties for the purpose of efficacious management of the risk, facilitated by effective communication about the risks.

It is reasonable to assume that good risk analysis includes the proper consideration and analysis of all relevant uncertainties. The components of a risk analysis: risk assessment, risk management, and risk communication, are discussed at length in the chapters that follow. For the sake of completeness, their definitions follow without further discussion.

Risk assessment is a systematic process for quantifying and describing the nature, likelihood and magnitude of risk associated with some substance, situation, action or event, including consideration of relevant uncertainties.

Risk management is the process of identifying, evaluating, selecting, implementing and monitoring actions taken to alter levels of risk, fully cognizant of the relevant uncertainties. The goal of risk management is scientifically sound, *cost-effective, integrated actions that reduce risks while taking into account social, cultural, ethical, political and legal considerations.*

Risk communication is the open, two-way exchange of information and opinion about risk leading to better understanding of risks and better risk management decisions. It provides a forum for the interchange of information with all concerned about the nature of hazards, the risks, the risk assessment, and how risks should be managed. It helps assure the unambiguous interchange of information among those affected by the outcome of the risk assessment activities.

The professional literature shows that these definitions are not universally nor perhaps even widely accepted. It has been the practice of most organizations and disciplines to adopt definitions and meanings that meet their own specific needs. That tradition is honored by continuing it. However, an effort has been made to stay as close as possible to what seems to be a developing consensus on meaning. This represents a departure from some of the terminology used by the Corps in the past. It also marks a departure from the language found in many of the Corps' past reports and guidance.

A distinction between uncertainty analysis and risk analysis will no longer be made. The commonly used term "risk-based analysis" should be understood to be synonymous with risk analysis. When this new language seems to conflict with the old language, the new language is preferred. Changing definitions and nuances in meaning are an inevitable result of an evolving field of analysis. It is quite possible that the meaning and use of these and other terms will continue to evolve in the years ahead. For now, these are the working definitions of these terms for purposes of the Corps' Civil Works Program.

RISK ANALYSIS

Risk analysis is the cornerstone for decision making under uncertainty. There are many models of risk analysis. The model presented below is, therefore, not the only possible way of thinking about risk analysis. It is in use by most Federal agencies and many other governmental and international organizations. More importantly, it is a rational model that describes in a broad, overarching way the major tasks of risk analysis.

The risk analysis model used in the business programs of the Civil Works Program comprises three separate but not always distinct components. They are risk assessment, risk management, and risk communication. For the moment, risk assessment can be considered as the technical, analytical work required to describe the major risks and uncertainties of interest in an analysis. Risk management is the process of deciding what to do about the risks that have been assessed. Risk communication is the exchange of information among risk assessors, decision makers, the public and other interested parties throughout the risk analysis.

Conceptually these components can be represented as shown in Figure 2-3.

FIGURE 2-3

RISK ANALYSIS MODEL

The figure indicates the simultaneous and distinct, yet overlapping, nature of the three components of a risk analysis. Although these components are presented and discussed as if they are quite unique, in fact it is often difficult in practice to say where assessment ends and management begins.

Thus, a risk analysis of a cost estimate requires these three components as well. There needs to be a technical assessment of the risks (the outcomes, their likelihood's and their desirability), management of these risks, and communication of and about these risks.

RISK ASSESSMENT

Risk assessment is the component of risk analysis in which analysts describe the risks complete with their associated uncertainties. The product of a risk assessment is a description of what is known about the risks under consideration. Risk assessment is the systematic, scientific characterization of potential adverse effects associated with hazardous substances, processes, actions or events.

A RISK ASSESSMENT MODEL

Risk assessment is a systematic process for quantifying and describing the nature, likelihood and magnitude of risk associated with some substance, situation, action or event including consideration of relevant uncertainties.

At a more intuitive level, risk assessment is the work required to adequately answer the following questions of any decision context in which they are applied:

- What can go wrong?
- How can it happen?
- How likely is it?
- What is the magnitude of the bad event should it happen?

Ask and answer these questions and a risk assessment has been done. Qualitative data and methods lead to qualitative answers and qualitative risk assessment. The models and methods used to answer these questions are all acceptable, so long as the answers obtained are adequate for decision-making.

Risk assessment should include an evaluation of the relevant uncertainty. Describing the uncertainty does this as does quantifying what is known and not known about the risks being assessed in a decision framework.

AN EXAMPLE

Driving is risky, yet a majority of Americans do it. What can go wrong when driving? The car might not start, one can run out of gas, have a flat tire, or have an accident. How might it happen? Human error, mechanical failure, weather, visibility and road conditions are some of the factors that can explain how an accident happens. How likely is it that an accident will occur in any one particular fashion? One might say it is not very likely but it is possible. That is a qualitative assessment of the likelihood. With access to the insurance industry's statistics, one might be able to say there is an eight percent chance of having an accident this year (Laudan, 1994).

Given that an accident occurs, how bad might it be? It could result in delay in arrival, property damage, personal injury, or death. Having differentiated these magnitudes of potential outcomes, the likelihoods of more specific outcomes might be identified. For example, there is a 1 in 5,800 chance of being killed in a motor vehicle accident this year (Laudan, 1994).

That is a simple risk assessment. It involved no complex models. All it took was a little bit of common sense, some experience and *The Book of Risks.* Not all risk assessments will be so simple, but all, done well, will answer the same four questions with more or less information and more or less sophisticated techniques.

Applied to a cost estimate, the process is the same. What can go wrong? A cost overrun is one answer. How can that happen? That answer varies from project to project. How likely is it, remains another situation specific question, as does the consequences of the possible outcomes. Hopefully, the relevance of these questions to the cost estimation process is clear to anyone who has done any cost estimating.

A Good Risk Assessment Is . . .

Transparent—this is what was done; this is why it was done
Reproducible—can be duplicated by others
Comprehensive—covers all that is important
Understandable—others can follow it
Scientifically valid—based on accepted practices
Flexible—answers all relevant questions
Simple—but not too simple
Practical—suited to importance of analysis
Honest—contains nothing that cannot be explained
Objective—the risk assessor should be disinterested in the outcome
Constant—the answer should be the same no matter which stakeholder the assessor represents
Clear—quickly and easily understood
Logical—it makes sense
Accurate—gets the question right, defines it carefully, gets the answer right

RISK MANAGEMENT

This section offers a simple and intuitive model for risk management. It then identifies some broad strategies for risk management and follows with a few elements of what comprises good risk management.

> *Risk management is the process of identifying, evaluating, selecting, implementing and monitoring actions taken to alter levels of risk, fully cognizant of the relevant uncertainties. The goal of risk management is scientifically sound, cost-effective, integrated actions that reduce risks while taking into account social, cultural, ethical, political and legal considerations.*

There is no abundance of risk management models. In fact, there is no consensus at all on how risks are best managed. There are strategies, institutional structures, tools and experience that are described elsewhere. However, there is no formula or recipe for managing risks.

The Corps' planning process provides a rigorous and flexible decision framework that can be readily applied in all nine Civil Works business programs and all six basic activity types. Risk analysis is a decision support tool and the risk management component is but one of many tasks that require consideration during the Corps' decision processes. Because of both the great number and great diversity of decisions being made in the Corps' business programs, a flexible risk management model is needed. To this end, it is suggested that risk management encompasses the work necessary to adequately answer the following questions:

- What can be done to reduce the impact of the risk described?
- What can be done to reduce the likelihood of the risk described?

- What are the trade-offs of the available options?
- What is the best way to address the described risk?

Risk management is directed at the risks that have been assessed. But risk management does not begin when the assessment ends. Risk management begins when the specific questions to be addressed by a risk assessment are identified. For example, what is the likelihood that the base cost estimate will be exceeded? A good risk assessment directs itself toward answering the questions of concern to decision makers. For the purposes of this report, decision makers and risk managers can be thought of as more or less synonyms. They get involved from the beginning of a risk analysis by posing the specific questions to be answered. When one asks what can be done to reduce the impacts or likelihoods of risks, either broad strategies or specific alternatives are being identified.

Benefits of Risk Management

The benefits of successful risk management are many (Chapman 1992). A better understanding of the nature of the risks, e.g., their effects on projects and their interactions, is gained in the process. Better contingency plans can be developed to preempt, reduce or mitigate the effects of risks. Costs can be better estimated and controlled and appropriate risk trade-offs can be made.

Risk management can lead to effective feedback in the planning and design phases of projects as the risk analysis proceeds. The same information can feed forward to construction and operation of the project. Thus, risk management can contribute to the continuity of the project from conception to construction.

The assessment and management of risks can also lead to identification of opportunities as well. That can make planning more interesting. Members of the risk analysis team can better understand likely problems in their own processes of responsibility and problems in other processes that might impact them. This develops teamwork. Attention is focused on specific problem processes and further analysis can be pursued until the study team is satisfied it can handle all foreseeable events. This builds morale and responsibility.

Risk management captures corporate knowledge by formalizing and documenting project specific knowledge and judgments, making revision of the plan easier and development of similar projects in the future easier as well. External political, technical, and environmental influences can be specifically considered in direct relation to the internal assessment of the risks. Appropriate strategies to deal with these complex interactions can be developed.

Successful risk management produces a flexible and general set of verbal, graphical and mathematical models, supported by appropriate computer software. The results of these models are effectively displayed so as to communicate effectively with the various audiences for a risk analysis.

RISK COMMUNICATION

Risk communication is talking and listening. It is asking and answering. It is clarifying, coordinating and comprehending. It is the who, what, where, when, and how of risks and what is being and can be done about them. It is communication among risk assessors. It is communication between risk assessors and risk managers. It is communication between risk assessors and stakeholders and between risk managers and stakeholders. And it is communication among all these parties in all the combinations as Figure 2-4 illustrates.

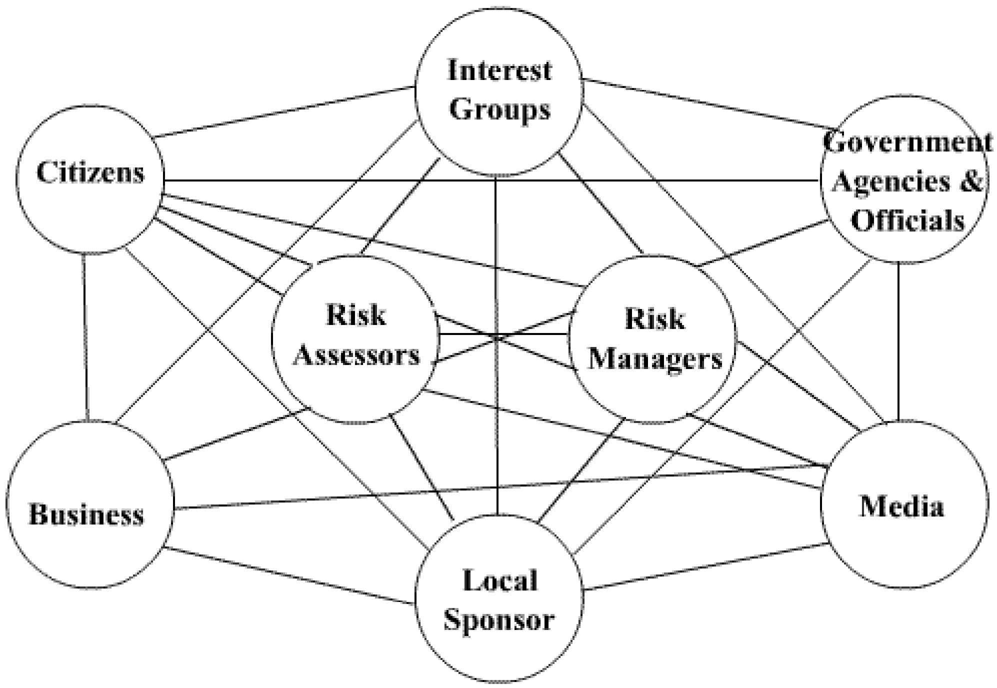

FIGURE 2-4

RISK COMMUNICATION WEB

Risk analysis takes a lot of communication. Few cost estimators may consider themselves risk assessors but many of them will be involved in risk assessment. Cost estimators have to talk to surveyors and geotechnical analysts to decide how best to address uncertainties present in their investigations. Cost estimators have to talk to economists to determine what is needed to provide the necessary cost information or to determine how navigation traffic might disrupt dredging operations. Cost estimators have to explain what they have done to their peers and to their supervisors. There is a lot of talking that has to go on among the study team members to conduct a good risk assessment and to address the uncertainties present.

The public, in particular, needs a meaningful role in risk communication. They need to be consulted as early in the risk analysis process as practical to obtain their views on the risks under investigation and to obtain any specialized knowledge they may have on these or other risks. A two-way conversation should continue with the public throughout the risk analysis process.

One of the principle challenges of a cost estimation risk analysis is to communicate the results of a risk assessment in a manner that aids the decision making process. As demonstrated in a subsequent chapter, simulations can generate a great deal of data. Not everyone is equally comfortable working with quantitative data. Thus finding effective ways to convey, communicate and use the information generated in a risk analysis is a very important challenge to cost estimators.

> *Risk communication is the open, two-way exchange of information and opinion about risk, leading to better understanding of risks and better risk management decisions. It provides a forum for the interchange of information with all concerned about the nature of hazards, the risks, the risk assessment, and how risks should be managed. It helps assure the unambiguous interchange of information among those affected by the outcome of the risk assessment activities.*

A 1993 IWR Report (Russell) identified a risk communication process of four elements to be considered by the planner:

- Objective(s): Why is the communication being undertaken?

- Content of message: What information is to be conveyed in order to accomplish the objectives?

- Form of communication: How should the message be transmitted from the source to the receiver?

- Feedback from the audience: What is being received?

These are just good basic tenants of effective communication. They happen to be about risks.

The model offered here is akin to the assessment and management models. Risk communication is the work required to answer the following series of questions.

- With whom to communicate?
- How to get both the information that is needed and the information others have?
- How to convey the information to be communicated?
- When to communicate?

The answer to the first question, with whom to communicate, identifies the various lines of communication in a risk assessment. As noted at the beginning of this chapter, communication takes place among all the parties to a risk analysis in as many combinations as are possible. The communications will have different parties depending on where in the decision chain the risk analysis is being conducted. The public need not be involved in a discussion of the proper choice of a roughness coefficient. They should be involved in discussions about residual flood risks, risks of dam failure, risks of oil spills and risks associated with other higher-level decisions.

Risk communication is a two-way process. An important part of communication is listening. Some listening is active, asking questions, seeking information and input. Some of it might be passive, simply letting people be heard. It is an entirely different matter when an economist and a hydrologist have to exchange information than it is when an entire community is involved in a complex risk communication issue. But the principles are the same for each communication. The communication needs to be carefully planned and cultivated. Usually, it will not happen by accident.

Conveying the information to be communicated embodies the four element IWR model described above. It presumes that one knows the objectives of the communication and the specific content of the message. How the message is conveyed, i.e., workshops, casual conversations, newsletters, radio talk shows, on web sites, and so on, is an important part of the communication. Knowing what people are understanding from the message is, perhaps, the most important and capstone piece of this process.

Finally, the timing of communication is important. One cannot communicate effectively before having some baseline information and facts. But waiting too late to communicate can be a more serious mistake.

SUMMARY AND LOOK FORWARD

Risk analysis comprises three components: risk assessment, risk management and risk communication. Risk assessment in cost estimation involves doing the work that effectively poses and answers the following questions:

- What can go wrong?
- How can it happen?
- How likely is it?
- What is the magnitude of the bad event should it happen?

Risk management in cost estimation involves doing the work that effectively poses and answers the following questions:

- What can be done to reduce the impact of the risk described?
- What can be done to reduce the likelihood of the risk described?
- What are the trade-offs of the available options?
- What is the best way to address the described risk?

Risk communication in cost estimation involves doing the work that effectively poses and answers the following questions:

- With whom to communicate?
- How to get both the information that is needed and the information others have?
- How to convey the information to be communicated?
- When to communicate?

The next chapter explores the reasons for doing a risk analysis of cost estimation. It looks at some specific ways that accuracy and decision-making might be improved.

III. WHY DO RISK ANALYSIS OF COST ESTIMATES?

INTRODUCTION

Traditional, single-point cost estimates are incapable of providing decision makers with such crucial information as:

- The probability of overrunning the cost estimate at all or by some percentage (e.g., probability of a 20 percent overrun)
- How much different actual costs can realistically be from the baseline estimate (i.e., exposure);
- The most important factors contributing to a project's exposure
- The contingency required to obtain a certain level of confidence in a cost estimate

For these reasons alone, few people in the construction industry would argue that traditional cost estimation methods are as reliable for decision making as probabilistic (risk-based) methods. The feasibility of projects can be more definitively determined and design alternatives can be more effectively compared, whether it is for value engineering or planning purposes, with risk analysis cost estimating techniques. It is easier to arrange financing and to anticipate budget impacts with full knowledge of the range of potential project costs. Risk analysis of cost estimates enables Corps cost estimators and planners to address these and other concerns.

Risk analysis for cost estimation is still a new concept for most Corps cost estimators. Doing something different means change, and getting people to change is a whole lot easier when they understand the reasons for and the value of that change. Therefore, this chapter discusses some of the benefits of cost estimation risk analysis.

Risk analysis, as explained in the previous chapter, is rapidly developing as a decision tool in many areas of endeavor. Toxicologists are analyzing the risks of chemicals, residues, and toxins found in the environment to better understand the risks to human health and safety presented by these substances. These analyses are substantial issues in dredging decisions. Environmentalists are analyzing the risks associated with the introduction of non-indigenous (i.e., exotic) species to new areas, along with the effects of chemical, biological, natural and anthropogenic stressors on ecosystems and their function. Planners are analyzing risks associated with habitat damage and destruction. Engineers began decades ago to analyze risks associated with structure failures. Dam safety has long been an active risk management program for the Corps. Interdisciplinary teams are assessing the risks of innovative technologies like aquifer storage and recovery wells in southern Florida. The risks associated with process failures have long been the focus of engineers of all types.

Within the Corps, risk analysis is considered an integral part of every economic analysis. Flood reduction benefits must be estimated in a risk analysis framework. Risk analysis is the xxx approach required in major rehabilitation analyses. There are research efforts to extend risk analysis to environmental investments and navigation.

Cost estimation is a fundamentally uncertain process that is well suited to risk analysis techniques to address its inherent uncertainties. Risk analysis of project cost is not a new idea, nor is it the invention of the Corps of Engineers. Cost engineering, beginning in the 1970s, has devoted more and more attention to this topic as the cost estimating literature shows. For example, the Association for the Advancement of Cost Engineering offers the *AACE International's Professional Practice Guide to Risk* (Curran) It is a three volume set of 2,230 pages which contains 360 articles related to cost estimation risk analysis. Cost estimation risk analysis is an emerging area of interest across the length and breadth of the construction industry. The Corps must explore this area simply to stay current with the best practices of the construction industry.

From an institutional perspective, the Corps is moving in a direction of doing and requiring more and more risk analysis throughout its programs. This trend is not likely to be reversed anytime soon given the growing interest in risk analysis generally. Although risk analysis of cost estimation is not yet required, it may well become so in the future. It behooves the agency to begin to explore the options and opportunities for using risk analysis sooner rather than later. Procedures that best meet the needs of the agency can be developed and incorporated into plans for development of future cost estimating tools (e.g., software), future guidance, and training needs.

Cost engineers have long recognized and addressed the uncertainty inherent in cost estimation. Contingencies are the primary technique currently used to address these uncertainties. Development of risk analysis contingency methodologies is a priority of this research. Less obvious, but more compelling is the fact that risk analysis of cost estimation can provide more and better information that can lead to improved decision making.

This chapter identifies two broad categories of benefits from cost estimation risk analysis. They are improved accuracy of cost estimates and improved decision making. This chapter develops several specific uses of risk analysis under each of these broad reasons.

IMPROVING ACCURACY WITH COST ESTIMATE RISK ANALYSIS

A point estimate of project costs is very precise. But as long as it is a prediction of a project's true costs, it can be virtually assured that the estimated cost will not be exactly right. If the cost estimators have done their job well, the estimate will be close enough to the true cost so as not to cause anyone who uses the point estimate to suffer any extreme consequences.

In order for cost estimates to be more accurate, it is not sufficient to use a point estimate. A range of values, also called an interval estimate, is always going to be more accurate than a point estimate. The costs will fall within that interval far more often than they will hit that point, but less precision is placed on the interval estimate. A distribution adds a dimension of likelihood to the range estimate, indicating which values in the range are most likely to occur.

Improving the accuracy of cost estimates is, by itself, sufficient reason for using risk analysis in cost estimation. All of the uses of costs mentioned in this chapter as well as all those not mentioned, are bound to be improved with more accurate cost estimates. Getting the costs right is an obvious goal of cost estimation that is often overlooked. Risk analysis of cost estimates provides more and better information about project costs. When information increases in quantity and quality, as it should with a risk assessment, estimates can be more accurate.

Risk assessment asks what can go wrong, how it can happen, how likely it is, and what are the consequences. The improved accuracy of risk assessed cost estimates answers these questions. One learns that costs could be higher or lower. One learns which variables are most likely to produce such an outcome. One can also estimate the likelihood of various outcomes. So think of the improvements in accuracy discussed in the sections below as the results of the risk assessment phase of risk analysis. The meaning of accuracy can be defined as follows.

If a cost estimate states that something will cost $10 and it costs $11, it is wrong. The cost estimate was not accurate. Here, accuracy is defined as the state of being correct. However, some estimates are more or less accurate than others. An estimate of $10.50 is wrong also, but it is not as wrong as an estimate of $10.

The accuracy of an estimate of an unknown value can be improved with the use of an interval, rather than a point estimate . An interval typically is defined by a minimum value and a maximum value. Intervals are generally more accurate than a point estimate, but they are less precise. An estimate of a cost between $10.50 and $11.50 is more likely to be accurate. In the simple example above, it does capture the right answer so it is accurate. However, the interval has a range of $1 and is far less precise than an estimate of $10.75 that has no range at all. The ideal, of course, is an estimate that is both accurate and precise. When predicting uncertain values there is often a trade-off between accuracy and precision when estimates are generated with a limited amount of information[1]. More accuracy usually means less precision and more precision less accuracy. One goal of risk analysis is to enable the analysts to choose the desired combination of accuracy[2] and precision.

Risk analysis offers several options for improving the likelihood that the estimate of an unknown cost will be correct. These include the ability to estimate the probability of a cost overrun, an estimate of exposure to risk, an ability to identify key components of a cost estimate in order to improve the estimation, and consideration of the full range of knowledge about the estimate. Any one of these options is alone sufficient reason to use risk analysis. Collectively, they present a powerful set of tools for improving cost estimating accuracy.

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[1] Gathering more information is often the best way to improve both the accuracy and the precision of an estimate.

[2] Accuracy as used here is better represented by the concept of statistical significance. This study opts for the more intuitive but less rigorous concept of accuracy for the present purposes, however.

A Distribution of Costs

In order to understand the points that follow it can help to have some understanding of what a distribution of cost estimates looks like. A more detailed explanation will be developed in subsequent chapters.

Imagine preparing a single point estimate of the cost of some project. Because cost estimating is predicting, it is not hard to imagine changing one assumption in the cost estimate to arrive at a somewhat different cost. Imagine all of the assumptions one could change one at a time, and then imagine all of the different values one could use for one of those assumptions. Each value produces a different cost estimate. Suppose each cost estimate is entered into a single cell in a spreadsheet.

Now imagine changing two assumptions at a time in all of the various combinations of different values one can imagine. Then imagine changing three assumptions in their seemingly infinite variety of ways as well. Each time the cost is recorded and entered into that spreadsheet.

Once every conceivable alternative cost is calculated, a considerable list of numbers will be generated.(Those numbers comprise a distribution of costs.)

Suppose for argument's sake there are 10,000 costs and 1,000 of them are below $4.4 million. Then one could estimate the probability that the actual cost will be less than $4.4 million as 0.1 (1,000 chances in 10,000). It may help to think of these 10,000 cost estimates when considering the points made below. Selected costs from a 10,000 iteration Monte Carlo simulation of project costs are presented in the table below. These values are used to illustrate the ideas in this chapter.

TABLE 3-1: SELECTED PROJECT COSTS IN MILLIONS

Item	Cost	Item	Cost	Item	Cost
Minimum Observed Cost	$3.33	30th Percentile	$4.77	70th Percentile	$5.49
Maximum Observed Cost	$8.71	35th Percentile	$4.85	75th Percentile	$5.62
Mean Observed Cost	$5.21	40th Percentile	$4.93	80th Percentile	$5.77
5th Percentile	$4.21	45th Percentile	$5.02	85th Percentile	$5.95
10th Percentile	$4.38	50th Percentile	$5.10	90th Percentile	$6.20
15th Percentile	$4.50	55th Percentile	$5.19	95th Percentile	$6.56
20th Percentile	$4.60	60th Percentile	$5.28		
25th Percentile	$4.69	65th Percentile	$5.38		

PROBABILITY OF COSTS EXCEEDING THE ESTIMATE

There is no objective way to estimate the probability that a single-point cost estimate prepared via traditional methods will be exceeded. Risk analysis ofcost estimates can produce a distribution of total costs or any element or subset of total costs. It is simple and straightforward to obtain quantified estimates of the likelihood that a cost estimate will be exceeded once a distribution of costs is estimated. Not only is it possible to estimate the probability that any particular cost estimate will be exceeded, but it is also possible to estimate the probability that it will be exceeded either by a given percentage, such as 20 percent, or by a given amount, such as $1 million.

In the example of 10,000 costs discussed in the textbox, the mean is used as the baseline or best guess cost of $5.21 million. The median is an alternative measure of the best estimate of costs. As the 50th percentile, $5.10 million, this measure may be preferred when there are extremely large or small values in the tails of the distribution of results. The mean is used as the best estimate here because there are no extreme values. In addition, the median is only slightly below the mean, indicating a negligible negative skew in the data. In the simulation, 4,384 cost estimates exceeded the mean value so there is a 0.44 probability of a cost exceeding the mean estimate. To calculate the probability of a 20 percent overrun, simply count how many cost estimates exceed $6.25 million (120 percent of $5.21 million). In this case it was 913 estimates. Thus, there is a 9.13 percent chance of costs exceeding the best estimate by 20 percent or more. In a similar fashion the probability of a cost of $6 million or more or any other cost can be estimated by counting those values. In this example, there is a 13.89 percent chance (1,389 of the 10,000 estimates) that costs will exceed $6 million.

The percentile values in Table 3-1 reveal additional probability information. For example, the 45th percentile is $5.02 million. This means that 45 percent of all the costs estimates were $5.02 million or less.

ESTIMATE EXPOSURE

There is no objective way to estimate one's maximum exposure to cost overruns using the traditional single-point cost estimate. Exposure is defined as the difference between the single-point estimate and the highest realistic estimated cost (Rowland and Curran, 1990). If costs might overrun the estimate, it is important to know just how bad the overrun could be. Risk analysis provides a methodology that enables the cost estimator to estimate the Corps and non-Federal partner's exposure.

In the example of 10,000 cost estimates, one would simply look at the maximum cost estimate of $8.71 million. The difference between the best guess cost estimate ($5.21 million) and this maximum value, or $5.5 million, is the maximum exposure to a cost overrun risk. But, because this maximum cost occurred once in 10,000 estimates, the probability of such an extreme exposure is 0.01 percent. The 95 percent exposure to cost overrun risk is $1.35 million, substantially less. There is a 5 percent risk of incurring an overrun of that amount or greater.

Alternatively, one could use a sensitivity analysis to estimate the exposure. To do so, the worst-case scenario is described, that is all the conditions that would lead to the highest possible costs. Once that is done, the next step is to calculate the highest possible cost and subtract the baseline estimate from it. Although this approach may produce a greater maximum cost than might be observed in a simulation, it would be difficult to determine its likelihood. It could have a 1-in-1,000,000 or less chance of occurring.

Identify Key Components in Exposure

If the probability of any particular overrun is too great or if the exposure is unacceptable, it is in the decision makers' best interests to know how best to reduce that probability or exposure. That could be readily done if the factors (quantities or unit costs) most likely to result in an overrun could be identified. Traditional cost estimating techniques provide no systematic means of determining the key cost factors under conditions of uncertainty. Cost estimating models are often too complex to lend themselves readily to such an analysis of key components.

Risk analysis lends itself readily to such techniques. Simple linear regression of total costs on each variable input or simple Pearson correlations of total costs and each variable input provide a useful ranking of the most important factors. Other techniques, such as comparing input variances to total cost variances, are also available. Thus, cost estimation risk assessment provides several methods for identifying the most important factors in determining the uncertainty in a project's overall costs. In the analysis that produced the example numbers, discussed at length in Chapter V, the resultant material factor proved to be the most significant single variable in the cost estimate.

Full Knowledge of Estimate

As early as the 1970s the single-point cost estimate was being described as laden with disqualifying limitations (Lewis, 1977). One of the most enduring and irrefutable points made about single-point cost estimates is that they fail to reveal all that is known about a cost estimate. Curran (1989) says that typically the analyst harnesses rivers of data, filters it, polishes it, reflects upon it, "Then, finally, makes a selection of 'the right number,' holding it up for all to see." When that winnowing process is complete, the only certainty that can be assigned to this value is that it is going to be wrong. The actual cost will either be higher or lower than the estimated value.

The single-point estimate is a single mystical value that masks a great deal of what is known about project costs. Cost engineers have to filter and polish a great deal of information away in order to get to a single number and no information should be ignored in such a competitive industry. The real world is full of probabilities and ranges of possibilities, not single-point numbers waiting to be counted with certitude. Risk assessment of cost estimates provides a great deal more useful information than a single-point estimate could ever hope to provide. They can reveal best and worst case scenarios. They can describe the variation in possible cost outcomes. They can be used to answer the questions: What can go wrong? How can it happen? How likely is it? What is the magnitude of the bad event should it happen?

In the example shown in Table 3-1, costs could be as low as \$3.33 million or as high as \$8.71 million, a range of \$5.38 million. The range indicates the potential for a wide variety of possible cost estimates. But if the range between the 25th and 75th percentiles is used, one observes that a full half of all of our cost estimates are within \$0.93 million of one another. So although there is great overall variability, meaning extreme cost values vary widely, the most likely costs vary much less.

IMPROVING DECISIONS WITH COST ESTIMATE RISK ANALYSIS

By reducing and addressing the uncertainty about relevant information in the risk assessment step of a risk analysis one can presumably make better decisions in the risk management step of a risk analysis than if that uncertainty was ignored . A cost estimate is often used in benefit-cost analysis to determine whether or not a project is economically feasible and eligible for Federal support. A cost estimate is used as the basis for cost sharing arrangements. Cost estimates form the basis for budget requests. Contractors deciding whether or not to bid on construction contracts use cost estimates. Cost estimates are used as the basis for construction contracts and cost estimates are used to manage project costs.

These activities entail a great many significant decisions. If the cost estimate is inaccurate, mistakes can be made, some of them significant.

One of the most important reasons for knowing the accuracy of a cost estimate is the impact this information has on an agency's or company's management as well as their policies and philosophy with regard to cost engineering. People know what to expect when an estimate is presented to them for review if the confidence level in that estimate is known. The problems associated with providing a good estimate, particularly at a concept stage will be better understood, anticipated and appreciated. As the methods for estimating and reporting costs evolve and change, so too can the agency's or company's policies and philosophies change to accommodate the new and improved information.

Risk analysis of cost estimation techniques is more likely to provide increased accuracy at some cost in precision. Costs can be estimated with ranges, distributions, confidence intervals, and the like. Contingencies can be estimated with greater confidence using risk analysis techniques, as will be shown later in this report. Such estimation is more likely to capture the true project costs than a point estimate that includes a contingency allowance. But it lacks the precision of a single point estimate and it requires people to think differently about costs than they have in the past.

Who cares about more accurate cost estimates and better decisions? The answer is: study and project team members; District, Division, and Headquarters managers; the Office of Management and Budget; Congressional staff and committees; non-Federal partners and State government officials; local citizens; and contractors are among the stakeholder groups with a vested interest in improved cost estimating. With so many decisions relying on cost estimation and so many stakeholders interested in it, the Corps can ill afford not to exploit to the fullest extent possible any tool that improves the accuracy of cost estimation. Risk analysis cost estimation techniques are being used in private industry. The Corps of Engineers simply cannot lag behind in understanding and using these techniques.

CONTINGENCIES WITH CONFIDENCE INTERVALS

The Corps has long used contingencies in its cost estimates quite successfully. What these traditional methods of contingency estimation did not enable cost estimators or decision makers to do, however, was to understand the confidence associated with that point estimate plus contingency. With risk analysis, it is possible to select a contingency so the cost estimator is 60, 70, 80, 90, 95, 99 or any other percent sure that the cost estimate will not be exceeded. Selecting a contingency to acquire a desired level of confidence in a cost estimate is possible under risk analysis cost estimating techniques but not under traditional techniques.

Consider Table 3-2 below. The baseline cost estimate is the expected value. This means the actual cost is as likely to be less than that as more than that. In order to manage the risk associated with cost estimates that underestimate the actual costs, cost estimators add a contingency to their cost estimate. Cost contingencies represent allowances to cover unknowns, uncertainties, and/or unanticipated conditions that are not possible to adequately evaluate from the data on hand at the time the cost estimate is prepared, but must be represented by a sufficient cost to cover identified risks (ER 1110-2-1302 12.a.). They are currently determined based on professional judgment. They are sometimes added to individual quantity or unit cost estimates and again as a lump sum adjustment to total costs.

TABLE 3-2: CONTINGENCIES WITH CONFIDENCE LEVELS

Desired Confidence Level	Required Contingency %	Contingency Amount	Cost Estimate
60	1.3%	$0.07	$5.28
70	5.4%	$0.28	$5.49
80	10.7%	$0.56	$5.77
90	19.0%	$0.99	$6.20
95	25.9%	$1.35	$6.56
99	40.7%	$2.12	$7.33

In the example in Table 3-1, the expected value or best estimate of costs is $5.21 million. Eight thousand of the 10,000 cost estimates were $5.77 million or less. Hence there is an 80 percent (8,000/10,000) certainty the actual cost will be $5.77 million or less. In order to be 80 percent sure that the cost does not exceed the estimate of $5.21 million, the $5.77 million estimate would be used. This requires using a contingency of $0.56 million or 10.7 percent of the baseline cost estimate to achieve a confidence level of 80 percent.

This process is similar to the current method of assigning a contingency. It entails adding a sum of money to the baseline, best guess estimate. The difference now is that the desired confidence level to manage the risk of a cost overrun can be chosen by the cost estimator. Cost estimators are free to use their professional judgment to choose a risk averse (i.e., conservative) cost estimate or a risk seeking (i.e., optimistic) cost estimate.

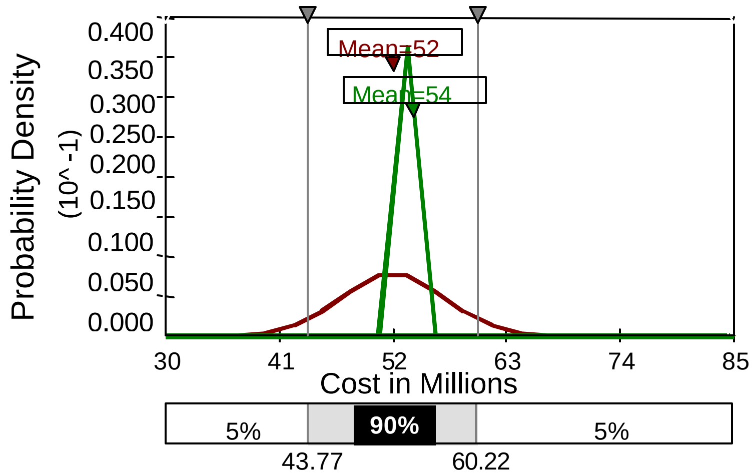
COMPARING ALTERNATIVE DESIGNS

How does the analyst evaluate the costs of two alternative plans or two different designs when one is well known and the other is an experimental design that relies on new technology?

Which cost is more uncertain? Suppose the familiar project has a slightly higher single-point cost estimate. Should it be chosen?

Consider Figure 3-1. Project A has a mean cost of $54 million with a narrow distribution of potential costs because it is a well-known design with time-tested technology. Project B, although it has a slightly lower expected cost at $52 million, has the potential to cost a great deal more or a great deal less than Project A. The uncertainty in its costs are much greater due to the new design and technologies.

Figure 3-1: Comparison of Cost Alternatives



A better-informed comparison of project costs requires a distribution of costs. The higher mean cost might be the better choice when decision makers want to avoid large cost overruns. Comparing single-point cost estimates can be misleading during plan formulation and cost-based screenings of alternative courses of action. To avoid disastrous surprises, a comparison of risk assessment cost estimate results is preferred.

FEASIBILITY

Economic feasibility of a project is usually defined by project benefits in excess of project costs. Project benefits estimates for Corps projects are to be estimated using risk analysis estimates that acknowledge and address the uncertainty inherent in the estimation process. It only makes sense that project costs should be comparably estimated. With a risk analysis estimate of project costs, it is possible to estimate the probability that a project will or will not produce benefits in excess of costs. A single-point estimate of costs implies that a project will or will not produce net benefits. With risk analysis estimates of benefits and costs it is possible to say whether net benefits are more or less likely/risky. In addition, cost risk analysis opens up the possibility of allowing different users of cost data to use the data differently.

Consider the following situation. Suppose project benefits are $5.5 million in accumulated present value so they are directly comparable to the costs used in the example. The best estimate of project costs is $5.21 million. This suggests the benefit-cost ratio is 1.06, and thus this is a marginally feasible project. Ordinarily there would be great pressure on the cost estimators to hold down the cost estimate so the project can go forward.

Suppose that in a perfect world the cost estimator would like to be 90 percent sure of the cost estimate for reasons that relate some to uncertainty and some to the nature of the budget process. In other words, the risk estimator feels a cost estimate of $6.20 million is preferred in order to manage the risks associated with the cost estimate. Suppose this conservative estimate would better suit the non-federal partner, the budget people, Congressional sponsors who do not want to have to go back and ask for more money later, and contractors who might bid on this project. These seem reasonable justification for using a 19 percent contingency of almost $1 million. But that estimate represents a conservative bias, which if used would lead to a BCR of 0.92 and the project would appear to be economically inefficient and unjustified in Corps' jargon.

A risk analysis approach to benefit and cost estimation will produce distributions of costs and benefits. Cost estimators can choose to use a single point estimate from that distribution that best enables them to manage the risks associated with an uncertain cost. Furthermore, economists can use all the information in both distributions for their feasibility analysis. Suppose the cost estimates have a normal distribution with a mean of $5.21 million and a standard deviation of $0.7 million, and benefits have a mean of $5.5 million with a standard deviation of $0.9 million. Calculating the benefit-cost ratio 10,000 times using a Monte Carlo process reveals that the most likely BCR for this project is 1.08. While BCRs as low as 0.34 and as high as 2.27 were obtained in the analysis, there is a 59.86 percent chance that the BCR will be one or more.

This example represents a substantial change in the way the Corps looks at its cost and economic data. It effectively splits the data according to the purposes they are intended to serve. This approach presents an opportunity to improve decision making in both the management of cost risks and the economic feasibility decision making.

ARRANGING FINANCING

Cost estimates provide the basis for non-Federal partners to arrange their financing of a project. A single-point cost estimate gives partners a target level of financing that will ultimately be either too low or too high by various amounts. A risk assessment estimate of costs can help partners manage that risk and better arrange for the proper level of funding. The choice of financing vehicle, e.g. tax revenues vs. bonds, may well depend on the actual cost to the partner. With a risk analysis estimate of costs, partners can better gage their ultimate share of the costs and the funding vehicle to choose. They can also better anticipate the likelihood and impact of overruns on their budget in the near and long term.

An added advantage is that with more complete information, a non-Federal partner can examine the data and apply their own confidence level parameter. For example, if the Corps chose an 80 percent confidence level and their partner prefers a 95 percent level for their financial purposes, nothing prevents the two partners from using the same information differently. It stands to reason that a small local government might be more risk averse than the Corps of Engineers. Risk-based costs provide better information for both partners.

CONSTRUCTION PROFITABILITY

Although the Federal and non-Federal partners are normally non-profit entities, the construction companies that build Corps projects are not. Contractor failures hit a peak in 1975 (Engineering News Record, 1977). In 1976, about 90 percent of construction contracts fell short of their expected profitability (Lewis, 1977). As early as the mid-seventies the inadequacy of the single point cost estimate was coming under fire. The ENR said the impact of uncertainty was felt nowhere more than in the construction industry. Increasing competition has forced narrower profit margins that have continued to the present. This increases the need for greater bid accuracy. Single-point estimates simply do not provide the accuracy required for construction firms to maintain their profitability.

Suppose, for example, a contractor felt the project would cost $6 million to build. The cost data suggests the actual cost, from the government cost estimate, has about a 15 percent chance of equaling or exceeding that amount. Hence, the contractor might decide not to bid on the project or require other methods for managing his expenses. Contractors are forced to live with risk and uncertainty as a daily way of life. Risk analysis cost estimates provide more and better information to contractors. The probability of overruns and exposure to cost risk can threaten not only profitability on a single project but the very viability of a firm. The Corps and its partners owe the construction industry the best information possible for greater bid accuracy.

AIDS COST MANAGEMENT

Risk assessment of project cost estimates now has the capability of identifying the most critical components of a cost estimate. Through a variety of sensitivity techniques it is possible to determine which cost components have the greatest potential to affect project costs favorably or unfavorably. A risk assessment can identify those components for which uncertainty should be reduced to provide better cost estimates. Alternatively, if the uncertainty cannot be reduced prior to construction, these components are identified as in need of careful management during construction in order to keep costs to a minimum. Thus, risk analysis costs aid both the cost estimation and cost management functions of the cost engineer.

For example, preliminary estimates of costs for a case study suggested that vessel traffic disruption of dredging operations might be a significant source of uncertainty in the cost estimate. That possibility began immediate discussion of the need to better define the nature of the vessel traffic in the channel to be dredged. Scheduling shipments around the dredging schedule or dredging around the shipping schedule were immediately discussed as potential cost cutting options. An analysis showed costs could be reduced by as much as 12 percent if disruption dredging to accommodate vessel traffic could be eliminated. Such information would not be available from a single-point estimate of costs.

USEFUL THROUGHOUT LIFE OF PROJECT

Risk analysis of project costs provides information that can be used during the earliest stages of a project's life in plan formulation and in deciding whether to proceed with a project (feasibility). As decisions to proceed are made, the same information can be used during the arrangement of financing, in bid preparation, and in cost management. Potential cost uncertainties can be better investigated during design and specification stages, and can be more carefully monitored and managed during construction to hold down costs. Thus, risk analysis of costs serves the construction project better than a point estimate from concept through completion.

SUMMARY AND LOOK FORWARD

Risk analysis improves information and the quality of decisions made with that information. Cost estimation is inherently uncertain and any technique that reduces or addresses that uncertainty in a rational and systematic way should be used. The construction industry is embracing risk analysis cost estimation techniques. Although these techniques are still in their infancy, the Corps cannot afford to lag behind in their adaptation and use.

Interest in risk analysis continues to grow and spread throughout government and private industry. Risk analysis in cost estimation, begun in earnest in the 1970s, is not a fad; it is the wave of the future. Risk analysis cost estimates are by their very nature more accurate than a traditional point estimate of costs. More accurate estimates can be used to improve the quality of a vast array of decisions that are based in whole or in part on cost estimates.

The next chapter introduces the risk assessment tools that are most likely to be used by cost estimators. It begins with a broad strategy and moves on to the specific approaches of sensitivity analysis, Monte Carlo simulation, and range estimation.

IV. PRACTICAL COST RISK ASSESSMENT METHODS

INTRODUCTION

There is no one right way to do a risk assessment. Risk assessment is not science. It is an organized and more or less structured approach to answering the questions:

- What can go wrong?
- How can it happen?
- How likely is it?
- What are the consequences?.

A good risk assessment focuses as much science as possible into the process and proceeds in a transparent and rational way, separating what is known from what is unknown and treating each appropriately. In this chapter, one broad strategy and three specific tools for conducting a risk assessment of a cost estimate are presented. There are many other tools and techniques, some of which could be quite helpful to cost estimators. Suggestions for additional reading are included near the end of this chapter.

Any specific risk assessment technique is going to require a strategy. It is best to begin by providing a way of thinking about risk assessment that is applicable to any specific tool an estimator might use. Three specific tools are addressed here. *Sensitivity Analysis* is a tool that has been used to a great extent by most cost estimators at one time or another. *Monte Carlo Simulation* is presented as the tool of primary interest because it is the tool that is used most often. Lastly, the tool review concludes with a brief consideration of *Range Estimation* because this technique has enjoyed some attention from cost estimators in the past.

THINKING ABOUT COST RISK

Each discipline trains its people to approach problems in a certain way. Engineers think about problems one way, economists think about them in another way, wildlife biologists think about them differently, and so on. The common denominator is that professional disciplines together with experience, teach how to approach a problem. Each cost estimator is going to have the same basic approach to an estimation problem. It will no doubt be adapted to the individual's needs and experience, but the basic approach is going to be much the same.

When it comes to assessing the risks of a cost estimate it is a different story. Few if any cost estimators were trained as risk assessors. To begin to do risk assessment, an assessor needs a way to think about problems in order to approach them with some general consensus on how to proceed. Providing that way to think about risk assessment is the purpose of this section. The approach is simple:

1. Recognize that uncertainty exists.
2. Identify the key sources of significant uncertainty.
3. Reduce the uncertainty whenever possible.
4. Account for the uncertainty that cannot be reduced.
5. Do not ignore significant uncertainty in cost estimates.

Each of these bullets can be discussed in a chapter or a couple paragraphs. The shorter discussion is opted for here. In time and with practice, cost estimators can tailor the steps to their individual needs.

The first step is the most important one. There will be no risk assessment and no risk analysis unless there is an admission of uncertainty in the work being performed. Things can go wrong. They can go wrong in many ways. The likelihoods of these different outcomes are not all the same and neither are their consequences. Researchers like to take pride in the work they do but must be honest about the limitations of data and their knowledge. Recognizing the uncertainty that exists and admitting to and accepting its existence is step one.

Step two is to realize that not all uncertainties are equally important, some are more important than others. The 80-20 rule, roughly stating that 80 percent of project costs are accounted for by 20 percent of the work elements, is a well-accepted summary of this belief. It is important to rigorously investigate and identify the key sources of significant uncertainty in a cost estimate. There is a tendency for any experienced cost estimator to feel they know what is important. That knowledge should not be shortchanged, but neither should it go unchallenged. Estimators should be aware that they are not always or often aware of the limitations to their own knowledge and be open to the possibility that significant uncertainties might arise from unsuspected areas.

Once the key sources of uncertainty are identified the next step is to reduce it whenever possible. For example, the percent of rock in a channel bottom will have a great influence on excavation costs. If the extent of rock is identified as a significant uncertainty it may be possible to reduce the uncertainty with additional wash or core borings. In other cases, the analyst might collect additional cost data to reduce the uncertainty about unit costs. More cross-sections might be taken to reduce the uncertainty about quantity estimates. Significant uncertainties should be reduced whenever possible within the resource constraints (time, money, personnel, and expertise).

Finally, when significant uncertainty has been identified and cannot be reduced it must be accounted for in an explicit fashion. It is unacceptable to ignore a significant uncertainty in a risk assessment. There are many tools for addressing significant uncertainties in a risk assessment. In the paragraphs below, three significant risk analysis tools that will be useful to cost estimators are discussed in detail.

SENSITIVITY ANALYSIS

Sensitivity analysis is one of the more practical methods of risk assessment. Completing a cost estimate in an uncertain situation requires numerous assumptions. It might be important to know if the results of the estimate are sensitive to the assumptions that have been made. Sensitivity analysis is the systematic variation of key attributes (parameter values, variables, functions, models, unit costs, quantity estimates, production levels, and so on) of an estimate to learn how potential costs change in response to changes in these attributes. Inputs in an analysis are purposefully changed to examine their effects on outcomes of the analysis. A sensitivity analysis may involve the change of a single attribute or combinations of attributes. For example, an estimator might estimate the costs of beach nourishment to be $32 million if the offshore borrow source is used and $41 million if the upland borrow source is used. A sensitivity analysis need not be complex.

In most instances, strategic sets of attributes, called scenarios, are defined and evaluated. Hence, sensitivity analysis is sometimes called scenario analysis. Although any number of scenarios can be defined and evaluated, it is common practice to evaluate an optimistic, pessimistic and most likely scenario. These are not to be confused with worst case and best-case scenarios that are also often evaluated. The primary difference is that optimistic and pessimistic scenarios are considered reasonably possible to occur. Best and worst case scenarios are merely possible in the sense that they are imaginable but not necessarily likely. Selected other scenarios of interest to decision makers may also be evaluated.

A cost estimate that is invariant with respect to the scenario under investigation is a robust one in which the estimator can have a great deal of confidence. If costs change substantially based on the scenario that is realized, it may be necessary to do some additional analysis to reduce the uncertainty about which scenario is most likely to occur. Or additional work may be required to reduce the uncertainty attending key attributes of a cost estimate.

In addition to scenario analysis and evaluating the robustness of decisions, sensitivity analysis can be used to identify those analytical components (work elements, quantities, unit costs, production levels, and so on) that are most important in determining the costs of a project. For example, if there are several variables that are uncertain, one can identify those that are most important to the cost estimate by systematically varying them and observing their effects on total costs, i.e., which variation changes the costs the most.

The advantage of sensitivity analysis is that it can always be done to some extent. Specific scenarios of interest can be reasonably well described. Extreme outcomes, like the maximum or minimum possible costs, can often be estimated. The major disadvantage of sensitivity analysis is that the analyst usually has no idea how likely these various scenarios are. Many people equate possible with probable, which is not the case with sensitivity analysis.

The purpose of a sensitivity analysis of costs, then, is at least two-fold. Sensitivity analyses conducted early in the investigation can help the analyst identify the key parameters, variables and factors in the cost estimate. If one of these values is varied and the result changes significantly, then this identifies an important source of uncertainty or a key parameter. In this case one of two things should be done. First, try to reduce the uncertainty in that key factor if at all possible. Second, if the uncertainty cannot be reduced it must be dealt with and its potential importance in the cost estimation process needs to be explained to decisionmakers and other interested parties.

A second purpose of sensitivity analysis is to examine the cumulative effects of various uncertain factors in scenario analysis. Sensitivity analysis is a controlled and deliberate process. Sensitivity analysis is a valuable tool. It can be a reasonable compromise between a detailed and sophisticated risk assessment and completely ignoring the uncertainty that exists in the cost estimates. Identifying the important variables in an investigation and varying the key parameters while noting the effect on the costs can be an effective way to deal with risk and uncertainty in the Civil Works Program.

MONTE CARLO SIMULATION

The most common method of assessing the risks in estimating the costs of a project is to calculate the costs for hundreds or thousands of possible scenarios and then to study the results of those many calculations. From the thousands of possible cost estimates one can learn what can go wrong, how it can happen, how likely it is and its consequences as well. What is needed, however, is a reliable and cost effective method for calculating these thousands of estimates. The Monte Carlo process[3] is one such method.

During the development of the atomic bomb it was necessary to simulate a wide variety of circumstances given the theoretical uncertainties of the time. The Monte Carlo process was developed and refined to develop values of random variables. It is essentially a sampling process that is a method for generating random values of a random variable based on one or more probability distributions. It generates numbers from any given distribution with a frequency that represents their probability of occurrence in the population from which they are derived. It consists of two general steps. First, a random variable value is generated, usually on the interval [0,1]. Second, this value is transformed into a useful value for the problem at hand.

To illustrate the idea, consider the mid-square method[4] of generating a random variable. For example, suppose a seed value of 4745 is used. Square it and take the middle four numbers, 22<u>5150</u>25. The random value is 0.5150. But in how many problems will that number be relevant? It needs to be transformed into a useful value.

Suppose the analyst must estimate the number of days per year that work will be disrupted by weather. Further suppose that historically this has been between 10 and 50 days annually. To generate a possible number of work days disrupted, a number between 10 and 50 is needed, not a number like 0.5150. Assuming the number of interest has a uniform distribution[5], then the random number can be converted using the formula:

---

[3] This includes the closely allied Latin Hypercube process of sampling.

[4] The mid-square method attributed to John von Neumann was one of the early methods developed to generate random variables. It was soon abandoned because it does not generate true random variables. It is sufficient for the heuristic purposes here, however.

[5] A uniform distribution is assumed to keep the arithmetic simple and not because it is the way such a problem should be approached.

$$(1) \qquad x = a + (b - a)u$$

where x is a random number between 10 and 50, a is the minimum value (10), b is the maximum value (50), and u is the random number generated over the interval [0,1]. Through simple substitution we get:

$$(2) \qquad 30.6 = 10 + (50 - 10).5150$$

Thus, it is assumed that the number of days disrupted per year would be 30.6 or 31 days via this Monte Carlo process. The Monte Carlo process is simply a technique for generating random values and transforming them into values of interest. The methods of generating random or pseudo random numbers are more sophisticated now and the mathematics of other distributions is more complex, but the process is similar to that in this simple example.

Imagine a cost-estimating model in a spreadsheet software package. Individual numbers in a cell can be replaced by a distribution. For example, if the number of days disrupted by weather was assumed to be the average of 21 days, 21 would appear in a cell in the model. Now imagine that it is replaced with a uniform distribution that says the actual number of days is unknown, but it is believed to be between 10 and 50. The choice of a uniform distribution implies that any number in this range is as likely as any other number. When there are more complex relationships, such as some numbers are very likely and others are extremely unlikely, other kinds of distributions are used.

Imagine the Monte Carlo process generating a number like 30.6 that is rounded and used in the cost estimate. Now imagine that a new random number is selected and transformed into a random number between 10 and 50 and costs are calculated with this new number. By keeping track of all the random numbers of days disrupted by weather and the resulting costs associated with them, and then examining several thousands of these numbers, the analyst can learn a great deal about the cost estimate.

Each time a new calculation of the cost is made, it is called an iteration of the model. A simulation is a collection of many iterations. Many simulations employ this Monte Carlo process and they are often called Monte Carlo simulations. Although that is strictly a misnomer (it is a simulation that uses the Monte Carlo process) it is common usage. There are many kinds of simulations that have nothing to do with the Monte Carlo process. The ship simulators at the Waterways Experiment Station are but one example.

To develop some intuition for this tool, consider a project that requires pouring concrete. There are two input variables, the quantity of concrete and the inclusive costs of placing it. Suppose both the quantity and cost of the concrete are uncertain. The best guess is that 1,000 cubic yards of concrete will be needed and it will cost $100 per cubic yard. The resulting cost estimate is $100,000. A simple spreadsheet model is shown below.

Now suppose the project will need at least 800 cy of concrete and no more than 1,100 cy. Furthermore suppose it is known that it will not cost less than $95 but it could cost as much as $200 to place it. The best-case possible is small quantities and low costs; the worst case is just the opposite. The best-case and worst-case scenarios result in costs of $76,000 and $220,000.

Although this is a sufficient job of bracketing what costs could be, this does not tell how likely either of these extreme scenarios will be.

TABLE 4-1: COST MODEL

Concrete (cy)	Cost per cy	Project Cost
1000	$100	$100,000

To incorporate the Monte Carlo process into the model shown in Table 4-1, the analyst must replace one or more of the input variables with distributions. So what distribution will be used? Building on what is known to this point, there are quantities ranging from 800 to 1,100 cubic yards. Is there anything else known about these quantities? Yes, it is known that 1,000 cy is the most likely value of all. A minimum, maximum, and most likely value is enough to define a triangular distribution. For simplicity, this distribution will be used for the example. Likewise a triangular distribution can describe the uncertainty about unit costs. Costs are assumed to have a minimum of $95, a most likely value of $100 and a maximum of $200.

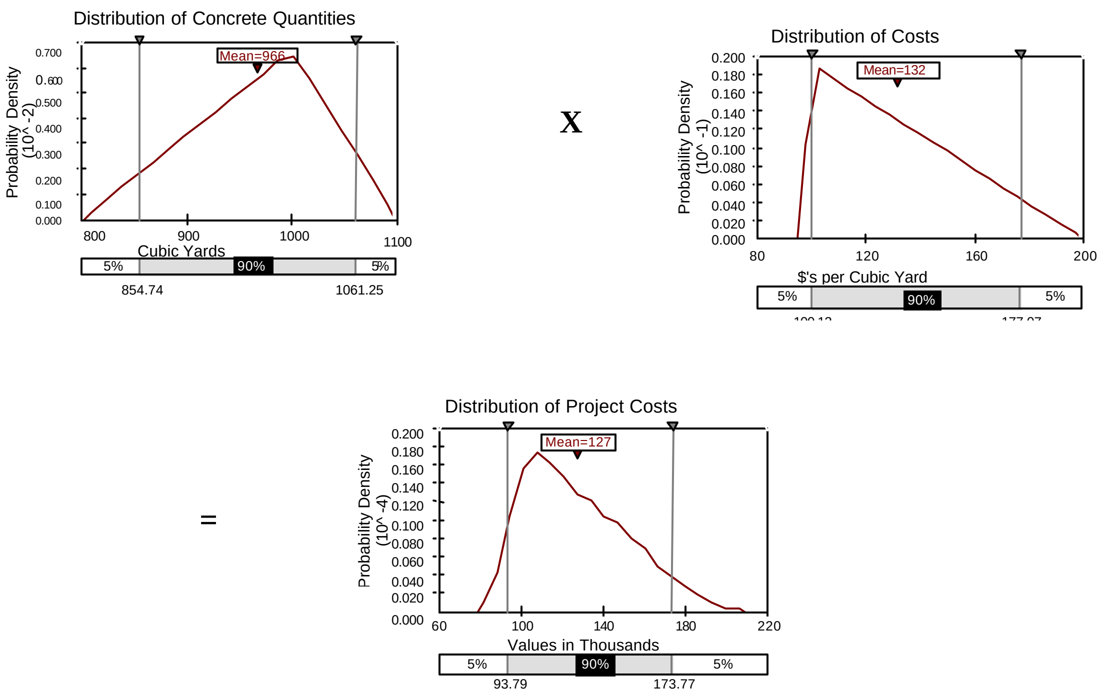
Using commercially available software, one can replace the point estimate of Table 4-1 with two triangular distributions. A Monte Carlo process would take a random number between 0 and 1 and transform it into a number from the interval [800,1100] with a triangular distribution for the quantity estimate. It would do likewise for costs. These two randomly selected values are multiplied together and one possible cost for this hypothetical project is generated. This process is then repeated 10,000 times. The process is illustrated in Figure 4-1, a graphic representation of a Monte Carlo version of the spreadsheet model above.

A value is randomly selected from the distribution on the left while a second value is selected from the distribution on the right[6]. They are multiplied together and the process is repeated 10,000 times to generate the distribution of costs at the bottom of the figure.

The analysis shows costs as low as $78,597 and as high as $209,035; quite a bit different from the previous best and worst-case scenarios. This suggests the chance of either of those extreme scenarios is less than 1-in-10,000. The mean of the 10,000 costs was $127,278, more than the original best estimate. This is because the expected values of the input distributions were different from the best guess point estimates. There is an 11.3 percent chance costs will be less than $100,000, not very likely. There is a 95 percent certainty that the costs will be between $90,922 and $182,008. The analysis showed the uncertainty in cost to be far more significant in determining costs than the uncertainty in quantities. Thus, if there were resources for only one of these variables it would be better to refine the cost data than the quantity data. That is a simple Monte Carlo simulation.

[6] The values selected from the two distributions can be independent of one another, as is the case for this example, or they can be dependent upon one another in any number of ways.

MONTE CARLO PROCESS



The Corps' Civil Works cost estimates are far more complex than this example. But virtually all of them can be reproduced in a spreadsheet model. If so, commercial software can be used to produce a risk assessment using the Monte Carlo process. Special software applications can be developed to add Monte Carlo capability to virtually any cost-estimating program.

RANGE ESTIMATING

Range estimation is an alternative to Monte Carlo simulation. It was developed by and for cost estimators. Interest in range estimating arose in the 1980s and seemed, if the literature is a reasonable gage, to have peaked in the early to mid 1990's, before the commercial Monte Carlo software became more user-friendly and available. Some people find range estimating more intuitively appealing and easier to develop the input data needed to use it. It requires either the proprietary software of a single firm to run, or the user must develop his own software. It is not as readily available as the Monte Carlo software.

Range estimating is driven in part by the notion that analysts unfamiliar with the sometimes complex properties of distributions could misuse Monte Carlo methods of analyzing costs. Poorly specified uncertainties, for example using an inappropriate distribution to describe the uncertainty in an input, could result in model outputs that are misleading. In lay terms, some people are concerned that if the uncertainty in the estimates of costs and quantities is exaggerated so will the potential range in outcomes. Therefore, some of the risk that appears evident will be iatrogenic risk, the result of the method used to estimate the risk.

This description of range estimating is taken largely and at times verbatim from the work of Michael W. Curran, one of the method's principle proponents. Range estimating uses a simple but effective measure of uncertainty: the range. The range is specified by three parameters: the *probability* that the element's actual value will be equal to or less than its target, a *lowest* estimate, and a *highest* estimate (Curran, 1989).

Suppose a work element has a target value, i.e. best guess or most likely value, of $10.05. In range estimating the estimator is asked to estimate the probability that the element's actual value will be less than or equal to the target value. Assume this probability as 75 percent[7], the lowest estimate as $7.80 and the highest estimate as $14.35. The probability measures the likelihood of an underrun, while the lowest and highest values measure the degree of underrun and overrun. In this respect the range is like a contingency that considers underruns as well as overruns. Specification of the range is to take all foreseeable circumstances into account. The range, no matter how subjective it may be is considered far more valuable for decision making than any single number from within it.

Curran describes range estimating as a synergistic combination of Monte Carlo simulation, sensitivity analysis, and heuristics that introduces ranges and other data into a personal computer to obtain the desired results. Although a detailed description of the range estimating algorithm is beyond the scope of this description, it yields results very similar to those produced in a Monte Carlo simulation.

Because range estimating was developed for cost estimating, it once had the advantage of offering outputs that Monte Carlo simulation did not, but now does. These include a priority profile which is the sensitivity function built into Monte Carlo programs that identifies the most significant input variables; and a contingency profile such as was presented in Table 3-2. The principle advantage of range estimating appears to lie in the belief that estimators will find it easier to estimate the three parameters of a range than the parameters of a distribution as required in Monte Carlo analysis.

[7] In other words, there is a 25 percent chance the target value will be exceeded.

V. Cost Risk Analysis Case Study

Introduction

If risk analysis is going to improve the accuracy of cost estimates and improve the decisions made with those estimates it must be practical. That is, the Corps' cost estimators must be able to master and use the techniques of risk analysis. This chapter presents the results of a real application of risk analysis to the estimation of costs for an ongoing Corps project. The results of the risk assessment are being used to help manage and communicate the risk associated with the cost estimate for this project. This case study serves the "proof of concept" research role quite well.

The project description, review of the tools used, and discussion and presentation of the risk analysis that follow demonstrate that risk analysis can be done. The data used in this analysis were real. The judgment required to quantify cost uncertainties were entirely those of District personnel. The lead cost estimator for this project subjected his judgments to the peer review of other estimators in his office.

The Institute for Water Resources solicited the cost estimating function of the Civil Works Program for potential case studies. In the interest of research as well as providing a benefit in participating in a real time cost estimate, rather than an after-the-fact demonstration, two elements were necessary. First, the project had to have a schedule that was compatible with this research project. Second, and most importantly, it would have to have the full support of the District involved.

The Jacksonville District provided the most enthusiastic response to the opportunity to be involved in a cost risk analysis. Several of their personnel were already experimenting with risk assessment techniques. They saw that participation in this research project would provide them with the labor to complete a risk assessment, a luxury they did not yet have. After reviewing a number of potential projects it was decided that a dredging cost estimate offered the best opportunity to apply risk analysis techniques. It was a high priority project that was underway and would be nearly completed during the course of this research. The CEDEP software was an Excel-based program that lent itself well to a Monte Carlo process. Additionally, the cost estimator was interested in and enthusiastic about risk analysis. His interest and enthusiasm were supported by senior staff and management within cost estimating. These qualities provided this research with an ideal opportunity that deserves recognition and gratitude.

This chapter begins the case study with an overview of the project, which is followed by a brief introduction to the CEDEP software used to prepare the cost estimate. The results of the case study are presented in a unique fashion here. The purpose of this research was to demonstrate the feasibility of doing risk analysis of cost estimates, hence, the case study is described more as a risk analysis than as a cost estimate.

The risk analysis results are presented in three overlapping and not always discrete sections: risk assessment, risk management and risk communication. That is not how it would be done in an actual report, of course, but it does help illustrate the components of a risk analysis, one of the central purposes of this report.

PROJECT OVERVIEW

Port Sutton Terminal Channel in Tampa Bay Harbor is a federally authorized private channel that has never been dredged by the Corps. It's authorized dimensions are 200' x 43'. It is currently 34' deep. There is some consideration being given to extending the length of the channel. Agricultural chemicals and oil are the primary commodities currently being transported through this channel.

Alternative depths from 35 to 46 feet are also being considered. In order to make the case study tractable it has been simplified considerably. The focus here is solely on the excavation and mobilization and demobilization costs of the 43-foot dredging alternative for the extended project. No relocation costs are considered, although they will be part of the project costs. These simplifying assumptions were based primarily on the information available at the time of the analysis. It did not include relocations. Although the analysis that follows is for a single alternative, it could easily be repeated as often as possible for shorter channel sections and different depths.

The principle concern with the cost estimate is the amount of rock material that will be encountered. Substantial amounts of rock have been found in other projects in this part of the country. The dredging will be accomplished with a cutter suction pipeline dredge.

CEDEP OVERVIEW

ER 1110-2-1302 Civil Works Cost Engineering (18.c.(3)) says: Dredge cost estimates will be developed using the USACE software systems entitled "Corps of Engineers (sic) Dredge Estimating Program (CEDEP)." Appendix G to the ER provides additional information about CEDEP. There is some confusion about the actual name of the software because the users' manual[8] calls it Cost Engineering Dredge Estimating Program (CEDEP) for Pipeline Dredges. To avoid further confusion we will refer to it simply as CEDEP.

CEDEP was developed to insure that dredging cost estimates can be prepared accurately and efficiently for all types of dredging projects. The program meets the requirements for preparing estimates in lieu of using the Micro-Computer Aided Cost Engineering Systems (MCACES) software according to the users' manual. It is an Excel spreadsheet based program. A detailed description of the software can be found in the users' manual that should be available in the cost estimating offices of most Corps Districts.

In order to provide a general orientation to the structure of CEDEP the basic input tables are provided below. There are additional worksheets on which critical calculations are completed. Since the software has been developed for use with Excel, it is especially well

8 See Draft CEDEP Pipeline, Version 1.0 October 1998.

adapted to doing risk assessments that use the Monte Carlo Process. Table 5-1 shows the basic outputs of the program. These include production and cost measures. Subsequent tables show other input pages in the CEDEP program.

TABLE 5-1: PRINCIPAL OUTPUTS OF CEDEP

229,423 pay c.y. per month	UNIT COST..	$6.23 PER C.Y.	**Select Dredge**
920 cy per hour	EXCAV. COST	$4,341,095	
30" Cutter-Suction Dredge	TIME.......	3.00 MONTHS	

TABLE 5-2: PROJECT TITLES

PROJECT TITLES:		PG 1 of 11
Project Name.................................	Construction - 43' Project Sta 22 - 83+50	Ver. 1.0
Project Location............................	Tampa Harbor, Port Sutton Term. Channel	For Information, Call:
Invit. or Contr. No............................	LRR Plan Alternatives - Risk Analysis File 01.	Julie Davin
Date of Estimate...........................	15 Dec 99	Ph: 509-527-7514
Estimator..	B. Blake	
Checked by..................................		
(Input Project Descriptions on Sheet A)		
Mobilization Bid Item.......................	1	
Excavation Bid Item.......................	2	

TABLE 5-3: TYPE OF ESTIMATE

TYPE OF ESTIMATE			PG 2 of 11
Type of Estimate.......	1	Planning Estimate	
(1) Planning, (2) Bid, or (3) Mod			
INDIRECT COSTS:			
Contractor's Overhead...	19.8	Percent of contract	
Contractor's Profit.....	11.0	Percent of contract	
Contractor's Bond.......	1.0	Percent of contract	

TABLE 5-4: DREDGING PRISM

DREDGING PRISM:

Required....	632,791	C.Y.				
+ Pay O.D....	64,014	C.Y.				
Bid Quantity	696,805	C.Y.				
- Not Dug..	**8,535**	C.Y.		AVE. BANK HEIGHT:		
Net Pay	688,270	C.Y.	@		18.1	ft pay
+ Non-Pay	50,800	C.Y.	@		**1.3**	ft overdig
Gross Volume	739,070	C.Y.			19.4	FT. BANK HT.

TABLE 5-5: MATERIAL FACTORS

MATERIAL FACTORS:

DESCRIPTION	FACTOR	PERCENTAGE		
MUD & SILT	3	**0.00**%		
MUD & SILT	2.5	**0.00**%		
MUD & SILT	2	**12.00**%	DIRECT ENTRY	
LOOSE SAND	1.1	**0.00**%	FACTOR=	**0.00**
LOOSE SAND	1	**4.00**%		
COMP. SAND	0.9	**28.00**%		
STIFF CLAY	0.6	**21.00**%		
COMP. SHELL	0.5	**0.00**%	RESULTANT MATERIAL	
SOFT ROCK	0.4	**35.00**%	FACTOR=	0.61
BLAST. ROCK	0.25	**0.00**%		

TABLE 5-6: PIPELINE CONSIDERATIONS

PIPELINE CONSIDERATIONS: PG 5 of 11

MAXIMUM PIPELINE REQUIRED:		
Floating Pipeline.......	2,000	Feet
Submerged Pipeline......	17,050	Feet
Shore Pipeline...........	1,000	Feet
Total Pipeline on Job:	20,050	Feet
Ave Pumping Distance....	**17,017**	Feet of Pipeline
Pipeline Cost Category...............	0	ROCK
(0) Computed from Material Factor,		
(1) Mud, (2) Sand, or (3) Rock		
Equivalent Pipe.........	1,667	Feet (Theoretical)
Description.............	Vertical Lift of Discharge Pipe.	
Basis of Production:	18,683	Feet (Ave + Equiv)

TABLE 5-7: PRODUCTION ANALYSIS

PRODUCTION ANALYSIS: PG 6 of 11

1	BOOSTER(S)	44,801	L.F. POSSIBLE based on 14200 Tot. H.P.
		18,683	Ft Ave Pumping Distance
		20,050	L.F. Max. on jobsite
40.7	% X 730 HRS/MO = EWT OF (without Boosters)	297	HRS/MO
X 0.90	Booster Factor		
36.7	% X 730 HRS/MO = EWT OF (with Boosters)	268	HRS/MO

TABLE 5-8: OTHER PRODUCTION FACTORS

OTHER PRODUCTION FACTORS: PG 7 of 11

CURRENT DREDGE SELECTED: 30” Cutter-Suction Dredge

Bank Factor for 19.4 ft of Bank ---->		1.10(From Chart)
Bank Factor Override....	0	1.10(Used)
Description............	>	
Other Factor...........	**0.9**	
Description............	Vessel Traffic and other	
Cleanup Dredging........	**12**	Percent Additional Time
		(Cleanup Factor = 0.89)

TABLE 5-9: HISTORICAL PRODUCTION OVERRIDES

HISTORICAL PRODUCTION OVERRIDES: PG 8 of 11

(In order to use this screen, Overrides must be entered for all three categories.)

	Override	Computed	Used
Production (Cy/Hr)......	0	920	920
Operating Time (Hrs/Mo).	0	268	268
Number of Boosters......	0	1	1

TABLE 5-10: OTHER PRICING ADJUSTMENTS

OTHER PRICING ADJUSTMENTS:		PG 9 of 11
Other Monthly Costs:		
1st Input...............	$30,000	Per Month
Description.............	Shore Equipment	
(For Additional Inputs Go to Sheet D\4)		
Fixed Costs:		
1st Input...............	$174,605	Lump Sum
Description.............	Cutter Teeth Replacement	
(For Additional Inputs Go to Sheet E)		
(To Adjust Labor Go To Sheet DB_L)		
(To Adjust Equipment Go To Sheet DB_E)		

TABLE 5-11: LOCAL AREA FACTORS

LOCAL AREA FACTORS:		PG 10 of 11
Present Year............	1998	(Equipment Calculations)
Economic Index..........	5676	(EP-1110-1-8, APP E)
Labor Adjustment Factor.	0.850	(EP-1110-1-8, APP B)
Full Cost of Money Rate.	6	Percent per Year
Dates for Money Rate....	July to December 1999	
Annual Months Available for Dredging:		
Pipeline....	9	Months per Year
Bucket......	10	Months per Year
Hopper.......	10	Months per Year
Current Fuel Price......	$0.95	Per Gallon

TABLE 5-12: HP & BOOSTER FACTOR ADJUSTMENTS

HP & BOOSTER FACTOR ADJUSTMENTS: PG 11 of 11

	Override	Database	Used
Total Available			
Pump Horsepower.......	0	9,000	9,000
Booster Pump HP....................		5,200	5,200
% Loss per booster, when job lasts:			
Less than 1 month (%)	0	15%	15%
More than 1 month (%)	0	10%	10%

Without Booster Losses, this job would last 2.70 months,
therefore, the 10% figure will be used.

The tables above show the major inputs for the calculation of excavation costs. There are numerous references to links to other worksheets that can be found in the actual software. These buttons are not shown in the tables above. The second major component of the CEDEP cost estimate is the mobilization and demobilization cost. The input table for that estimate is shown below at Table 5-13.

RISK ASSESSMENT

Risk assessment is the work required to answer the following questions:

- What can go wrong?
- How can it happen?
- How likely is it?
- What is the magnitude of the bad event should it happen?

This section offers answers to those questions and describes the risk assessment. The overlapping character of the risk analysis tasks will become evident, and that begins with the question: what can go wrong? Costs may be too high or there could be cost overruns. To identify either of these outcomes as "wrong," however, requires a value judgment made by risk managers. Thus, the overlap between and among risk analysis components begins from the outset.

Costs could be too high or there could be cost overruns if the basis for production is lower than expected. A higher percentage of rock in the dredge prism than expected can also drive costs off. Other factors that could lead to high costs or overruns, such as equipment availability or increased shoaling, were known to exist but were not factored into the estimate or risk analysis.

TABLE 5-13: MOBILIZATION AND DEMOBILIZATION COSTS

MOB & DEMOB COST	$743,043

SPECIAL ITEMS (USED FOR BOTH MOB & DEMOB):

Supplies & small tools @	$100/day
Support equipment with operators @	$500/day
Fuel (Plant Idle)	$100 per Day
Subsistence	$25 per Man

MOBILIZATION ITEMS:

1. PREPARE DREDGE FOR TRANSFER TO JOBSITE:

Time Required.....	7	Days
Crew Size..........	10	Men
Work Schedule.....	8	Hrs per Day

2. PREPARE PIPELINE FOR TRANSFER TO JOBSITE:

Time Required.....	7	Days
Crew Size..........	15	Men
Work Schedule.....	8	Hrs per Day

3. TRANSFER PLANT TO JOBSITE:

Distance..........	933	Miles
Towing Speed......	117	Miles per Day
Crew Size..........	5	Men per Shift
Towing Vessel Size	4000	Horsepower
Towing Vessel Cost	$3,933	Per Day
Number of Vessels	1	Each

4. RELOCATE PERMANENT PERSONNEL & MISC. TO JOBSITE:

Travel Time.......	8	Hrs per Man
Travel Expenses...	$100	Per Man
Local Hire........	$200	(Lump Sum)

TABLE 5-13: MOBILIZATION AND DEMOBILIZATION COSTS (Continued)

MOBILIZATION ITEMS (Continued):

5. PREPARE DREDGE FOR WORK AT JOBSITE:

Time Required.....	10	Days
Crew Size..........	10	Men
Work Schedule.....	8	Hrs per Day

6. PREPARE PIPELINE AT JOBSITE:

Time Required.....	10	Days
Crew Size..........	15	Men
Work Schedule.....	8	Hrs per Day

7. OTHER:

Description.......	D/A Preparation
Lump Sum Cost.....	$20,000

DEMOBILIZATION ITEMS:

1. PREPARE DREDGE FOR TRANSFER AWAY FROM JOBSITE:

Time Required.....	2	Days

2. PREPARE PIPELINE FOR TRANSFER AWAY FROM JOBSITE:

Time Required.....	3	Days

3. TRANSFER PLANT AWAY FROM JOBSITE:

Distance..........	467	Miles

4. RELOCATE PERMANENT PERSONNEL & MISC. AWAY FROM JOBSITE:

Include Computed Costs?....	1	YES (0=NO)

5. PREPARE DREDGE FOR STORAGE..........	1	Days
6. PREPARE PIPELINE FOR STORAGE.....	1	Days

7. OTHER:

Description.......	L.S. (CLEANUP)
Lump Sum Cost.....	$10,000

The likelihood of costs that are too high or overrun is discussed in greater detail below. As for the magnitude of the high costs and cost overruns, that too is discussed in detail below. Related to the magnitude of the events that can go wrong are the consequences of their occurrence. Costs could be so high that the federal government will not commit resources to the project. This could happen if the costs exceed benefits. This would be an economic value judgment. Or costs may be so high that a non-federal partner may not be able or willing to commit their share of money to the project. This would be a political value judgment. If cost overruns exceed 20 percent, an authorized project has to be reauthorized. Cost overruns can lead to unexpected financial, legal and political consequences as well. These would encompass policy and other value judgments.

Absent a quantitative discussion of the risks, a qualitative risk assessment is offered. It can be helpful to develop such an assessment at the outset of the risk analysis. It is critically important to identify the questions to be answered in the risk assessment and this is best done in close coordination with risk managers, those people who are going to have to use the risk assessment information to make a decisions. In some cases the assessor and the manager will be the same person. More often the decision will involve far more people up through and including the District Engineer and the DE's superiors.

To conduct the risk assessment for this Port Sutton Channel deepening alternative the Monte Carlo process was incorporated into the CEDEP program. This was done using @RISK version 4.0 and Excel 2000. After the CEDEP was modified for use as a simulation model, the excavation costs and mobilization and demobilizations costs, as well as their total, were calculated 10,000 times. These costs were then analyzed to obtain answers to the questions above.

BUILDING THE SIMULATION MODEL

The next several sections describe how the risk assessment model was built. It begins with the identification of key sources of uncertainty. Next, the report addresses how the uncertainty was quantified. Finally, there is a short description of how the model was developed.

IDENTIFY KEY INPUT UNCERTAINTIES

The input pages of the CEDEP model are presented above. Typically a cost estimator will use these pages to enter the information required to prepare a dredging cost estimate[9]. The lead cost estimator, with input from more senior estimators and managers identified the key uncertainties. The cost estimators examined the variables of each CEDEP input page and based

[9] It is worth noting that it would be a simple matter to do a far more extensive analysis of a dredging cost estimates uncertainty than was done here. CEDEP has fourteen additional worksheets filled with data, calculations and messages in support of the cost estimating function of CEDEP. Many of these could be modified as well. The cost estimators in this case study did not consider that necessary as the input pages allowed them to address the most significant input uncertainties.

on their experience with dredging costs estimates, identified the most significant sources of uncertainty. A summary of these variables is presented below.

The page location refers to the page in the CEDEP model. The key variables in excavation costs are found on pages in the excavation cost input sheet while mobilization and demobilization variables are all on the same page, hence no page is designated. The names used are taken from the CEDEP program and can be checked there. The cell location is provided for the ease of readers familiar with CEDEP, although it is not essential to what follows. The type of distribution used to describe the uncertainty and its parameters are provided. Dependencies among these variables are referenced to the relevant variable by cell location. Cutter teeth replacement costs are related to the amount of material dredged and the amount of rock. This was not possible to detail in the table.

It took less than a half a day of the estimator's time to identify and quantify the uncertainty shown in Table 5-14. A senior cost estimator suggested that it was not necessary to identify even this many variables. The lesson learned, however, was that it was not an undue burden to address that many variables.

QUANTIFYING UNCERTAINTY

Once the potential sources of uncertainty are identified the uncertainty must be quantified. When a value is said to be uncertain, it simply means that its actual eventual (or current) value is not known with 100 percent certainty.

The easiest way to address uncertainty is to replace the point estimates[10] with an interval estimate (See Table 5-14). The simplest interval requires only a minimum possible value and a maximum possible value. These values can be based on professional judgment.

If nothing more than the minimum and maximum values are known and any number in that interval is as likely as any other number, this kind of uncertainty can be described with a uniform distribution. A uniform distribution represents a rather extreme form of uncertainty. It says that the range is known , but there is no idea what numbers in that range are most likely. It is relatively rare that something can not be stated about the most likely values.

Parameters (minimum and maximum for this distribution) may be based on the estimator's professional judgment, historical data, bids, expert opinion, combinations of these or other factors. In this assessment for example, the contractor's overhead rate was uncertain. It is described as being some value between 16.6 and 23 percent. In a deterministic estimate, 16.6 percent would be used. A recent audit showed an overhead rate of 23 percent. These two values were used to define an interval. The cost estimator felt he had no reason to single out any value in this interval over any other, so a uniform distribution was used.

When there is reason to believe that some values in an interval are more likely than other values, a uniform distribution will no longer do. If it is thought that there is a most likely (mode)

[10] A value estimated by a single number is called a point estimate.

TABLE 5-14: CEDEP DREDGING COST ESTIMATE

Excavation Cost Estimation Key Variables	Page Location	Cell Location	Dependent	Distribution Type	Distribution Parameters
Contractor's Overhead...	2	D19	No	Uniform	16.6, 23
Contractor's Profit	2	D20	No	Uniform	10,12
Dredging Area	3	D28	No	Triangle	67% est., 84% est., est.
Required….dredging	3	D30	D31	Triangle	85% est., estimate, 115% est.
+ Pay O.D.…dredging	3	D31	D30	Triangle	85% est., estimate, 115% est.
Ave. Bank Height ft. overdig	3	F35	D88	Triangle	.5,1,2.5
MUD & SILT %	4	D41	No	Triangle	0,0,0
MUD & SILT %	4	D42	No	Triangle	0,0,0
MUD & SILT %	4	D43	No	Triangle	95% of 12, 12 105% of 12
LOOSE SAND %	4	D44	No	Triangle	0,0,0
LOOSE SAND %	4	D45	No	Triangle	95% of 4, 4 105% of 4
COMP. SAND %	4	D46	No	Triangle	95% of 28, 28 105% of 28
STIFF CLAY %	4	D47	No	Triangle	95% of 21, 21 105% of 21
COMP. SHELL %	4	D48	No	Triangle	0,0,0
SOFT ROCK %	4	D49	No	Triangle	95% of 35, 35 105% of 35
BLAST. ROCK %	4	D50	No	Triangle	0,0,0
STIFF CLAY Factor	4	C47	No	Triangle	.5,.6,.7
COMP. SHELL Factor	4	C48	No	Triangle	.4,.5,.6
SOFT ROCK Factor	4	C49	No	Triangle	.3,.4,.5
BLAST. ROCK Factor	4	C50	No	Triangle	.2,.25,.3
Resultant Material Factor	4	F49	B74	Result	Result
Ave Pumping Distance....	5	D59	No	Triangle	14000, 17000, max. pipeline
Equivalent Pipe	5	D63	No	Triangle	500, 2000, 2500
Operating hours per month without boosters	6	B74	F49	Triangle	22.2, 44.4, 55.5
Other Factor....Vessel Traffic Disruption	7	D86	No	Triangle	.85,.9,.95
Cleanup Dredging........	7	D88	F35	Triangle	1,10,25
Cutter Teeth Replacement	7	D106	Complex	Result	Result
Current Fuel Price	10	D123	No	Triangle	.74, 1, 1.1
CEDEP Mob & Demob Cost Estimation					
Distance to Jobsite		E17	No	Triangle	300, 1000, 1500
Towing Speed		E18	No	Triangle	50, 100, 200
Towing Vessel Cost		E21	No	Triangle	3100, 4000, 4700

value then the analyst can use the minimum, most likely, and maximum values to identify a triangular distribution. Imagine an interval on a number line between a minimum and maximum value. Now suppose one of the values in this interval is believed to be more likely than any other. Imagine grabbing that value on the line and raising it above all the other values. The triangle formed by the minimum, maximum and this high point defines the triangular distribution.

CEDEP provides a range of factor values for different types of material found in the channel. Sand is defined as having an index factor value of one. Numbers above this are easier to dredge than sand; numbers below it are harder to dredge. In a single point estimate, the material factor used for soft rock by this cost estimator was 0.4. CEDEP presents the factor range as 0.3 to 0.5. In this risk assessment, the cost estimator said the factor could be between 0.3 and 0.5 but 0.4 was considered to be the most likely value. Hence, a triangular distribution was defined.

Sometimes there is reason to believe the distribution is more complex or more orderly. When a random variable is the result of the addition of many other random variables it often takes a normal distribution. When a random variable is the result of the multiplication of other random variable it often takes a log normal distribution. These well known and well behaved distributions can be described by their parameters, the mean and standard deviation. Many quantitative phenomena observed in reality have normal or log normal distributions.

THE MODEL

The risk assessment model was relatively simple to build once the key variables were identified and their uncertainties described. Cell D19 appears in Table 5-3, above, where 19.8 is shown as the contractor's overhead percent. Instead of using the number 19.8 in the model as would be the case with a deterministic estimate, the estimation would simply replace the value with the formula for a uniform distribution with a minimum of 16.6 percent and a maximum of 23 percent. Replacing the keystrokes "(19.8 with the keystrokes "RiskUniform" (16.6, 23)" does that. The detail is provided to emphasize that it is not a burden to assemble the model. In a similar fashion formulas are entered for each of the uncertain variables to be addressed.

It would be misleading to suggest that risk assessment is a trivial or even a simple task. It can take expertise, knowledge, and experience to know which distribution to use in certain situations. Since this is an introduction to risk assessment any discussion of dependencies among variables in a cost estimate is omitted. The importance of identifying and addressing any and all significant dependencies among input variables cannot be overemphasized. For example, if unit costs go down as quantities go up or vice versa, the model must reflect this. To overlook dependencies can lead to nonsensical results.

Table 5-13 indicates that there were some dependencies in the dredging cost estimation model. The related inputs are identified but the nature of that dependency is not further identified so as not to bog the reader down in extraneous details.

Model building is an iterative process. The contractor built an early version of the model for demonstration and early learning purposes. This was followed by a first cut at identifying and quantifying key uncertainties by the cost estimator. Results of this model run were used to modify and refine the model further to replicate the knowledge and experience of the cost estimator. This entailed refining the quantification of uncertainty and adding details to the manner in which inputs were related to one another. It is wise to build the model iteratively, keeping it as simple as possible but no simpler.

WHAT CAN GO WRONG?

Cost overruns present obvious problems for cost estimators. Cost underruns do not have the same impact, as they do not cause the same problems. The estimator's challenge is to select a cost that has a tolerable chance of overrun without being so high as to threaten the economic feasibility of the project. Therefore, the discussion begins with the notion that a cost overrun is the principle event that can go wrong with a cost estimate. High costs might be another way of saying the same thing. So the first goal of the risk assessment is to identify what can go wrong.

Inasmuch as the purpose of this report is primarily to demonstrate the feasibility of risk analysis of cost estimates, focus will be on total costs only. A separate consideration of excavation costs and mobilization and demobilization costs would reveal slightly different insights, but the purposes of this report are best served by constraining the material to the consideration of a single cost estimate.

The median of the 10,000 costs estimated for this project was $5,104,000. Costs are as likely to be under this value as they are to be over it. The mean cost was $5,207,000. As an expected value, it is the best estimate of project costs. The mean is higher than the median because of the impact of a few extremely high cost estimates in the distribution of possible costs. Bearing in mind the concern with overruns, risk assessment can be used to answer the question, what can go wrong. Table 5-15 presents some results that help answer that question.

Some 4,400 of the generated cost estimates exceeded the mean cost. Defining a cost overrun as all estimates above the mean value, the likelihood of a cost overrun was estimated to be 44 percent. Percentiles are used to better describe that overrun potential. The table shows that 95 percent of all the cost estimates were

TABLE 5-15: COST RISK EXPOSURE

	Item	Exposure
Median Cost	$5,104,022	na
Expected Cost	$5,206,816	na
Minimum Cost	$3,330,044	-$1,876,772
Maximum Cost	$8,711,430	$3,504,614
Chance of Overrun	44%	na
60th Percentile	$5,280,132	$73,316
70th Percentile	$5,487,679	$280,863
80th Percentile	$5,773,545	$566,729
90th Percentile	$6,198,012	$991,196
95th Percentile	$6,564,602	$1,357,786

$6,565,000 or less. That can be interpreted as meaning there is a 95 percent certainty that the project will cost that or less. Could it be more? Sure, after all, there is uncertainty here, but there is only a five percent chance it will cost more than that.

Exposure is the amount by which the best estimate of costs can be exceeded. In this example, the mean cost was used as the best estimate of costs. To the question, what can go wrong, there is one answer. Costs could be as much as $3,505,000 more than the expected value of costs. This value is obtained by subtracting the mean of the 10,000 costs from the maximum of the 10,000 costs. It is a worst case scenario based upon the estimators judgments about the key uncertainties and the nature of that uncertainty.

An alternative to the maximum exposure could be obtained by using the 95th percentile exposure value. One can see that 95 percent of all cost estimates were no more than $1,358,000 greater than the mean estimate. Thus, there is a 95 percent certainty that there will not be an overrun in excess of $1,358,000. Reasoning in this fashion, there is a 60 percent certainty that the cost overrun will be $73,000 or less. The other percentiles values can be interpreted in a similar fashion, and with the raw data (10,000 estimates of costs) any desired percentile can be calculated.

The same data are displayed graphically in Figure 5-1. Select any cost on the cost axis and read across to the cumulative frequency to obtain the percentage likelihood that actual costs will be the chosen amount or less.

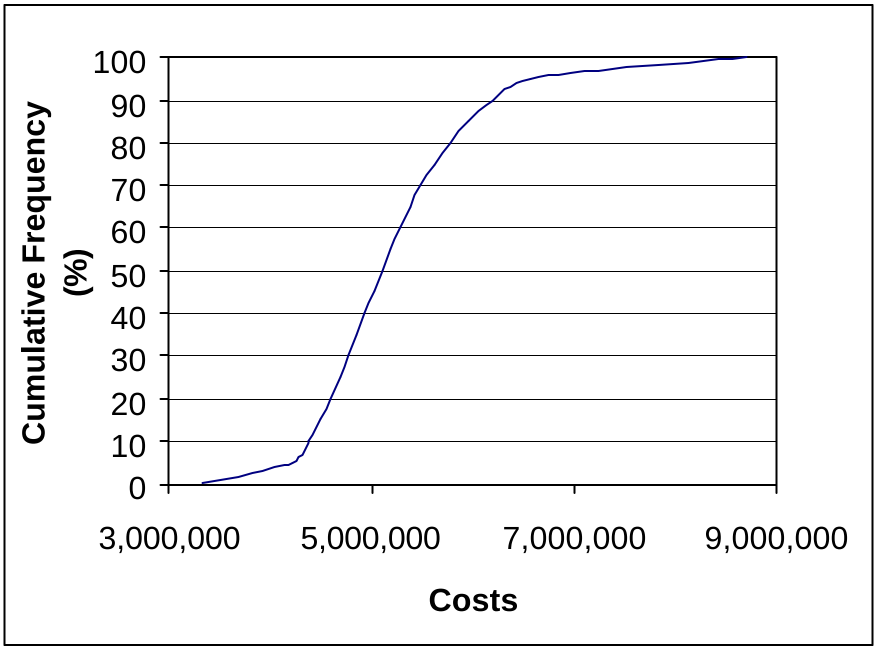


FIGURE 5-1

CUMULATIVE DISTRIBUTION OF COSTS

Alternatively, this information can be presented in a histogram of the total costs as shown in Figure 5-2 below.

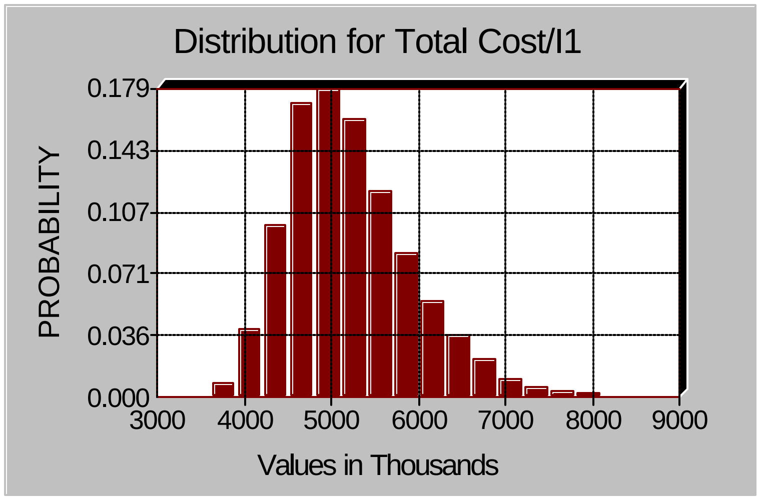


FIGURE 5-2

HISTOGRAM OF TOTAL COSTS

HOW CAN IT HAPPEN?

Armed with an understanding of how high costs might rise, risk assessment can be used to explore how that can happen. The simplest way to do that is to try to determine of all the cells shown in the input tables presented earlier in this chapter, which ones have the greatest influence on the total cost estimate. Figure 5-3 shows the eleven most influential factors affecting the total costs of this project. The larger the bar the greater the influence of the input on total costs.

Productivity (percentage of hours per month of effective work) is shown to have the greatest influence on costs and the relationship is negative, which means as the percentage goes down costs go up. The amount of material dredged is the second largest factor. As the quantity of dredged material increases so does total cost. The third most influential factor is the material factor, i.e., the composition of the dredged material. Table 5-16 shows the factors ranked according to their regression coefficient and a rank correlation coefficient for contrast. The importance ranking is unchanged except for the distance (Distance) the tow has to travel to the project site during mobilization that would be the fifth most important factor instead of the 11^{th}. The bars in Figure 5-3 show the coefficient in Table 5-16.

What is learned from this analysis of simulation results is which of all the potential uncertainties have the greatest impact on total costs. In this sense, it tells us how costs can run over. If production is lower than expected, if there is more material, and if it is rockier than expected, then cost overruns can be expected. The more of the factors shown that are uncertain

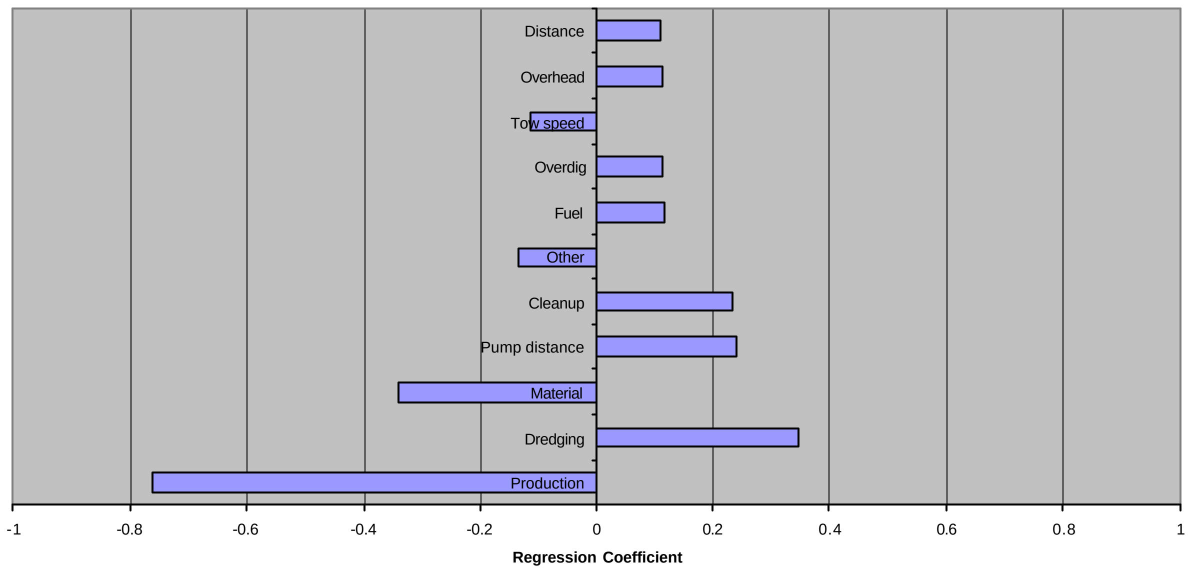


FIGURE 5-3

SENSITIVITY PLOT

TABLE 5-16: RANK OF INPUTS

Input	Regression Coefficient	Rank Correlation
Production	-0.761	-0.732
Dredging quantity	0.346	0.367
Material	-0.339	-0.339
Pump distance	0.241	0.255
Cleanup	0.233	0.121
Other	-0.132	-0.131
Fuel	0.118	0.131
Overdig	0.115	-0.117
Tow speed	-0.115	-0.109
Overhead	0.113	0.101
Distance	0.11	0.124

and having an adverse effect on costs, the greater the chance of an overrun. And that in a nutshell is how the overrun can happen.

It is worth noting that everyone involved with this project indeed assumed that the composition of the dredge material would be the most significant factor, and it is a very important factor. However, it ranked third in importance. An interesting result that enables a couple of important points to be made.

First, risk assessment offers opportunities to analytically test the assumptions and beliefs about what is and is not important in a cost estimate. For the most part, this analysis confirmed the judgments of the cost estimators.

Second, it provides an opportunity to learn about the cost estimate. For example, note the "Other" factor is the sixth most influential input. This is an adjustment to the productivity rate that accounts for disruptions due to vessel traffic, weather and other such influences. In the first version of the model, the uncertainty in this input was under estimated. Early runs of the model indicated this input was the most important of all. This development conflicted with what cost estimators knew to be true and led to some fruitful revisions to the model.

Third, these results can in time increase the understanding but they are not generalizations. Risk assessment of dredging costs has not been done enough for cost estimators to make any generalizations from the results. Hence, it would be a mistake to say that production is always more important than the material composition, for example. In the current, case the geotechnical experts had a great many wash and core borings. They felt they had good information on the composition of the channel bottom. Consequently their estimate of the uncertainty attending the percentage of rock, for example, was quite small, ranging from 33.25 to 36.75 percent with a most likely value of 35 percent. Had there been greater uncertainty, the rock percentage could have emerged as the most significant factor[11].

In time it is quite likely that a core of key inputs will emerge and be identified. This will simplify the analysis of cost risks as analysts will know which factors to focus upon in their estimates. For now, the results of this part of the risk assessment must be taken as anecdotal evidence and not a basis for any generalizations about dredging costs.

HOW LIKELY IS IT?

Knowing that something bad can happen is useful. Knowing how it can happen makes that knowledge even more useful. Knowing how likely something is to happen is more useful still. A Monte Carlo simulation with 10,000 point estimates of costs yields a distribution of costs that addresses this question. The two figures above contain all the information needed to talk about the likelihood of any given cost overrun occurring.

There are many different ways to approach this question. One could choose a specific level of costs, like $5 million and ask the likelihood of it being exceeded. One might choose a specific value because it may represent the maximum investment that is economically feasible. It may represent a spending limit for a program. It could represent the maximum amount a partner is willing to expend or it could represent a 20 percent cost overrun that requires reauthorization of a project.

With 10,000 values, it is simple to count the number of costs that were under or equal to $5 million. The observed frequency becomes the estimate of the probability that such a cost is not exceeded. In the present case that is about a 45 percent chance.

[11] Rock percentage shows up in the Material factor in the table and graph along with the other material components.

The question can also be posed differently. Suppose there is a demand to be 90 percent sure the cost estimate, whatever it is, will not be exceeded. To achieve that level of confidence, the cost estimator would use a cost of $6,198,000 because about 9,000 of the 10,000 calculations were equal to or less than that value. Thus, it is equally easy to identify an expenditure and estimate its probability, or to specify a probability and identify the associated cost.

The data for other information can also be queried. For example, the probability of a $1 million cost overrun or less could be estimated to be 95.1 percent based on the mean cost. Conversely, there is a 4.9 percent chance that a cost overrun in excess of $1 million would be observed. There is a 4.3 percent chance costs will overrun the mean value by 20 percent or more.

There is no requirement that overruns must be linked to the mean cost. Any reference cost could be used. For example, suppose a $4 million cost estimate was used. A 20 percent cost overrun would be $4.8 million, there is a 68.2 percent chance this cost will be exceeded[12].

With 10,000 cost estimates, it is possible to answer most reasonable questions about the likelihood of any particular cost arising. If the raw data outputs from the simulation are saved, it is possible to make more detailed analyses. For example, it is possible to estimate the probability of a cost of $5 million or less when the percentage of rock is 34 percent or less. Such conditional probabilities, although not presented here, represent substantial amounts of information that have gone unused by if not unknown to cost estimators. The potential for exploratory analysis of cost data is a great and untapped one.

WHAT ARE THE CONSEQUENCES?

The most obvious consequences of a cost overrun would be the size of the overrun. That has already been addressed above in the last column of Table 5-15. It is also possible to discuss the consequences of a given cost overrun. Such consequences might include negative net NED benefits (i.e., benefit-cost ratio less than one), loss of support from the non-federal partner, a lack of a plethora of bidders, or a need to get a project reauthorized. In the case of Port Sutton, higher costs could mean an unjustified project or greater difficulty in getting an extension of the authorized channel length.

RISK MANAGEMENT

Risk management is the work required to answer the following questions:

- What can be done to reduce the impact of the risk described?
- What can be done to reduce the likelihood of the risk described?
- What are the trade-offs of the available options?
- What is the best way to address the described risk?

[12] About 31.8 percent of all costs estimated were $4.8 million or less, the complement provides the estimate of the likelihood of an overrun of 20 percent or more.

This section offers answers to these questions. The impact of risk in this case refers to the exposure to overruns. The likelihood refers to the probability of various cost levels being attained. The essential risk management issue for cost estimators is to choose a cost estimate that will best serve the needs of decision makers. As one might expect, this entails some trade-offs. Generally, it is agreed that the best way to handle the uncertainty in a cost estimate is to choose a contingency allowance. These topics will each be addressed in turn.

IMPACT OF THE RISK

What can be done to reduce the impact of the risk described? The impact of the risk is best described as the exposure to cost overruns. By how much could costs be overrun? To address this question there needs to be a baseline measure of costs, for which the mean cost will be used. Impact or exposure is summarized in the table below, extracted from Table 5-15 above.

Costs could be as much as $3.5 million more than the baseline cost estimate. Although there is a small likelihood (1 in 10,000) of such an overrun, it does bound the overrun potential. This would occur only if virtually every quantity and unit cost is realized as unfavorably for costs as possible. In other words, extremely high rock content, extremely large yardage to be removed, extreme disruptions for traffic and weather, and so on. Table 5-16 suggests the inputs that would most likely to occur have to be extremely adverse to obtain such a high cost. Although possible, this is not a likely scenario.

Table 5-17 suggests other levels of exposure that can be expected to occur. There are a few strategies for limiting one's exposure to risk. If the mean is the best estimate of costs and serves as the baseline estimate, exposure can be reduced in one of four ways. One would be to reduce the scale of the project; look at channel depths other than 43 feet. This is a normal part of plan formulation that could serve as a cost risk management option: to limit the exposure to the risk of cost overruns choose a smaller project.

TABLE 5-17: COST RISK IMPACT

	Item	Exposure
Baseline Cost Estimate	$5,206,816	na
60th Percentile	$5,280,132	$73,316
70th Percentile	$5,487,679	$280,863
80th Percentile	$5,773,545	$566,729
90th Percentile	$6,198,012	$991,196
95th Percentile	$6,564,602	$1,357,786
Maximum Exposure	$8,711,430	$3,504,614

A second option would be to try to reduce the uncertainty attending key inputs. If additional analysis of the most significant variables in Table 5-16 and Figure 5-1 would improve the quality, that is reduce the uncertainty, of the input variables, this could effectively reduce the exposure. Take material composition, the third most significant source of uncertainty. If additional wash or core borings, or more detailed calculations of channel bottom composition could provide a more accurate and more precise (i.e., a narrow interval estimate in which there could be more confidence and consequently a different input distribution), additional analysis could reduce the exposure.

Exposure can be reduced in more than one way. The variation in the distribution of project costs could be narrower. Hence, the costs in Table 5-17 could be reduced, resulting in less exposure. Or one might obtain a better baseline cost estimate. Perhaps one that is higher than the current average. Although the range of costs might not be reduced the difference between the baseline and maximum cost might be reduced due to higher baseline costs. A combination of these two impacts is possible also.

Managing project costs is a third option for reducing the impact. A risk assessment can identify the key inputs affecting total costs as was shown in Table 5-17. These inputs can then be looked at to see if there are any options for cost management. For example, one might be able to affect the percentage of rock in the dredging prism by realigning the channel or selecting alternate routes, although this is not an option for a confined channel like Port Sutton Terminal. One important factor in the channel above is called "Other." It includes disruptions to dredging due to traffic disruptions and weather and so on. If relatively few vessels use this channel now it may be possible to schedule their arrivals around the dredging schedule. In extreme cases, it may be possible to divert shipments to another terminal for a short period of time.

The point being made here is a simple one. With the key sources of uncertainty in costs identified, cost estimators and planner can review a list of key inputs such as is found in Table 5-17 and try to identify ways to affect those inputs favorably. Most will be beyond the Corps' control, but careful analysis may well identify unforeseen opportunities for controlling costs.

The fourth and most favored way of reducing one's exposure to cost overrun has been to recognize the uncertainty that does exist in the cost estimates and to choose a contingency that reflects the levels of protection that the analysts want against cost overruns. This is an option that will be developed further below.

Not to be overlooked in this analysis is the potential for a positive impact. Costs may actually be less than the baseline cost estimate. This simply requires a few favorable breaks on some of the assumptions that the analysis made about cost estimate inputs.

LIKELIHOOD OF RISK

What can be done to reduce the likelihood of the risk described? Table 5-17 describes an array of potential impacts, but they are not all equally likely. The probability of an overrun of $73,000 or more is 40 percent. The probability of an overrun of $991,000 or more is 10 percent. Greater impacts are less likely. For this discussion the possibility of cost underruns will be ignored.

To reduce the likelihood of cost overruns the cost estimator needs to intervene in the cost estimate in some way that makes unfavorable results less likely. The generic approaches include the same four options noted above. Rescaling may or may not make overruns less likely.

Improving the information bases is always desirable. One way to do this could be to improve the quality and quantity of the data upon which the estimate is based. This is the same uncertainty reduction strategy expressed above. It reduces likelihood when better data provide a better understanding of what can really happen. There is no guarantee that more data will reduce the likelihood of any event.

Managing project costs is an option that can make some outcomes more likely and others less likely under certain circumstances. For example, scheduling vessel arrivals so the dredging schedule can accommodate them would make unfavorable cost impacts less likely.

The most common way of lowering the probability of a cost overrun, however, is to use contingencies to account for unknowns and provide a safety margin against cost overruns. This will be developed in a section to follow.

RISK MANAGEMENT TRADE-OFFS

What are the trade-offs of the available options? Rescaling the project, improving the information base, managing project costs, and contingencies are four possible options. Each has its strengths and weaknesses.

In navigation planning, it is traditional to look at a variety of project scales. In a channel deepening project, this can mean varying channel depths, lengths and widths. The planning process identifies, evaluates, and compares the various trade-offs involved more comprehensively. Cost estimation, however, takes a more narrow look at trade-offs. Larger projects almost invariably mean greater costs. Larger projects often entail greater uncertainties, simply due to the magnitude of the project, if for no other reason. The basic trade-off here is not obvious to cost estimators. Smaller or larger projects result in different benefits.

More and better information is a common and rational way to reduce uncertainty. The trade-off is obvious. More information means less uncertainty, however, information is not free. It costs time and money and it requires specific expertise to gather, organize, analyze and interpret it. Budget, time and expertise are often in scarce supply for cost estimators. There will always be limits on these essential resources and it is unlikely that any cost estimator anywhere has said, “I have all the information I need, want, and can use.”

The most common way of managing the risks of exposure to cost overruns is through the selection of contingencies to account for the uncertainty in cost estimates. The more the contingency, the less likely a cost overrun will be. Because the contingency becomes part of the official government estimate, the “official” cost estimate rises above the baseline mean. Thus the difference between the higher official cost estimate and the maximum cost estimate is lessened and the impact of the potential overrun is lessened, as is its likelihood. Assigning contingencies is a nearly universal method for managing the risks of cost overruns. However, the benefits of lower impact and likelihood of overruns are not without their costs.

If costs are too high they may fail to be budgeted. Expensive projects may not be authorized. Non-federal partners may be unable or unwilling to support projects that are too costly. The economic feasibility of projects can depend on the cost estimate. So although using a higher contingency does guard against cost overruns, it also threatens the viability of the project itself.

ADDRESSING THE RISK

Contingencies

What is the best way to address the described risk? Cost estimating risks have traditionally been addressed and managed through the use of contingencies. A contingency is an amount added to an unbiased estimate of costs to account for reasonable uncertainties in the estimator's circumstances. Contingencies can take the form of increases in quantity estimates, increases in unit prices, or percentage adjustments to total costs or any subset of total costs. The Corps has reasonably well established procedures and guidance for calculating and handling contingencies.

Risk assessment produces a wealth of information that can be used to help calculate a reasonable contingency. Figure 5-1 is reproduced here for the reader's convenience to facilitate the discussion of contingencies.

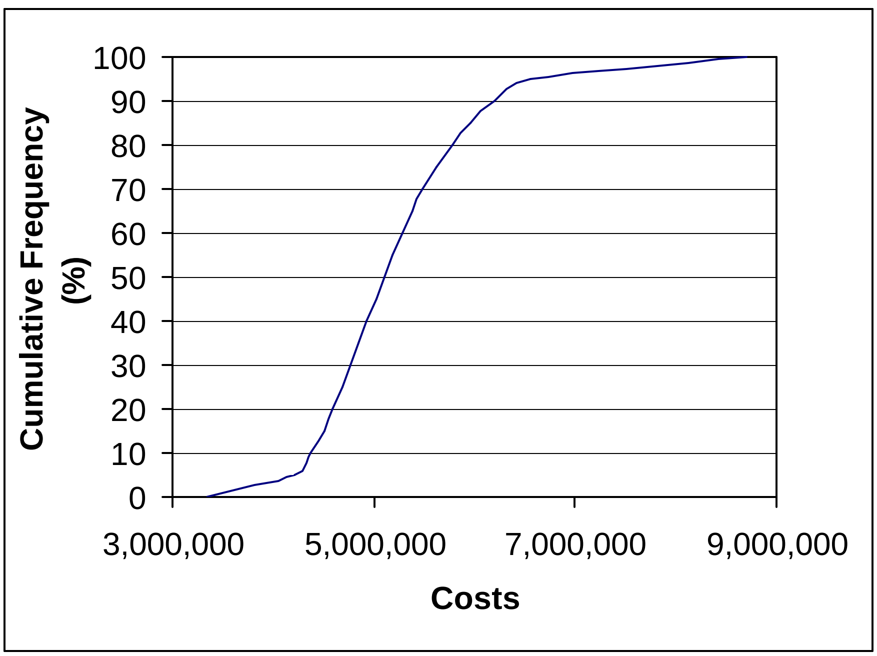


FIGURE 5-1

CUMULATIVE DISTRIBUTION OF COSTS

Consider that the mean of the 10,000 cost estimates and the best estimate of the total costs of the 43-foot deepening project is $5,207,000. Conceptually (the actual resolution of the graph above is not fine enough to do this in fact), one could locate that amount on the horizontal axis, read up to the curve and then over to the vertical axis. Doing this, one would observe that there is a 56 percent chance that costs will be equal to or less than that amount.

Conversely, one could begin at any probability x on the vertical axis, read across to the curve and down to the horizontal axis and say that there is an x percent chance that costs will be this number or less. For example, suppose 20 percent is chosen. Reading from the graph, one would see there is a 20 percent chance the costs would be $4,598,000 or less, or based on the results of the risk assessment, one could say there is 20 percent confidence that the costs will be $4,598,000 or less.

This kind of information provides the cost estimator with a very powerful tool. The analyst can now decide how confident he would like to be that the cost estimate will not be overrun and set the cost accordingly. Suppose for example, one would like to be 80 percent sure there will not be a cost overrun. Reading across from 80 to the graph (the equivalent of choosing the 80^{th} percentile) and down to the horizontal axis indicates an 80 percent chance that costs will be $5,774,000 (from Table 5-17) or less.

So how does the cost estimator get from an estimate of $5,207,000 to an estimate of $5,774,000? The difference between these two estimates is $567,000. If a contingency of $567,000 is added to the best estimate, the cost estimator has in essence purchased an 80 percent level of confidence in the cost estimate. Based on the risk assessment results there is now only a 20 percent chance of a cost overrun.

Suppose that it is deemed too large a chance of a cost overrun, what can the cost estimator do? It is a simple matter to choose any desired level of confidence at all. Table 5-18 reproduces Table 3-2 below. Using a base cost of $5.2 million, one can obtain a 60 percent level of confidence with a 1.3 percent contingency. In like manner, the cost estimator can be 95 percent sure there will be no cost overrun with a 25.9 percent contingency ($1.35 million). To move to 99 percent confidence in no overruns, the contingency jumps to 40.7 percent.

TABLE 5-18: CONTINGENCIES WITH CONFIDENCE LEVELS

Desired Confidence Level	Required Contingency %	Contingency Amount	Cost Estimate
60	1.3%	$0.07	$5.28
70	5.4%	$0.28	$5.49
80	10.7%	$0.56	$5.77
90	19.0%	$0.99	$6.20
95	25.9%	$1.35	$6.56
99	40.7%	$2.12	$7.33

It is often common practice to chose a contingency percentage and apply it to the base cost estimate. This can still be done, but to greater effect now. Suppose, in this example, the cost estimator has determined that a 19 percent contingency is appropriate. Using the table[13], it is observed that a 19 percent contingency, almost $1 million, yields a 90 percent level of confidence that there will be no cost overruns.

The significant innovation risk assessment offers is the ability to say how sure the analyst is that there will be no cost overruns. This affords the cost estimator the opportunity to manage the risk of exposure to overruns. Given the sensitivity of project stakeholders to cost overruns, a variable contingency can be established for each project. In time the Corps may specify a required level of confidence, but for the time being the cost estimator and District decision makers can select the desired level of confidence.

It is worth noting that costs can be set at a level below the mean cost estimate. For example, there is a 20 percent chance costs will be $4.60 million or less. If decisions makers felt there was a compelling reason for choosing such a low confidence level they are certainly free to do so.

Benefit-Cost Analysis

Contingencies have proven to be the best way for cost estimators to manage the risk of exposure to cost overruns. But as has been pointed out elsewhere in this report, costs serve many different purposes, one of which is to enable the analysis of the economic feasibility of a project. The cost estimate can be established using the baseline cost plus a contingency that achieves the desired level of confidence that there will be no overruns. But there is no reason that the economic analysis should be based upon such a conservatively determined estimate of the costs.

To illustrate, suppose the 90 percent confidence level introduced in the example found in Chapter III. Suppose the government cost estimate so determined is $6,198,000. This cost can be used for budgeting purposes, to solicit bids, for the non-Federal partner to arrange financing, and other related uses. It has been strategically estimated to meet certain needs of the agency and its constituents. At this point in time, however, the actual costs remain uncertain.

Again following the Chapter III example, suppose project benefits of $5.5 million. Without a risk assessment the estimated BCR would be 0.92 and net benefits would be -$0.7 million. Recognizing the uncertainty in the estimate there could be pressure brought to bear on cost estimators to go back to their estimate and see if they can reduce the costs. For simplicity, rather than realism, consider reexamining the contingencies. One could argue that if the contingency of $0.99 million was reduced to $0.28 million the costs would fall to $5.49 million and the project BCR would now be above one.

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[13] It is a simple matter to ascertain the confidence level associated with any cost or the cost associated with any confidence level.

Under this scenario, the project is economically feasible and can be moved forward. But the cost estimate is now lower and the likelihood of a cost overrun is increased. There is now a 30 percent chance that costs will exceed the estimate rather than a 10 percent chance. This could have more or less serious ramifications for the budget process, bidding, and the non-federal partner's ability to finance a project whose costs might rise.

Risk assessment of costs provides the Corps with a unique opportunity to take the wealth of information available made available and to use it judiciously for the different purposes that it must serve. A conservative cost estimate can be used for estimating purposes and the entire distribution of costs can be used for the economic feasibility analysis.

Consider that there is a 90 percent chance the actual project cost could be less than $6.2 million. In fact, it could be as low as $3.3 million. Why would the Corps team want to ignore this possibility in the analysis of the economic efficiency of the project? There is about a 70 percent chance the costs are less than the best estimate of benefits, $5.5 million, which makes a compelling argument against using the conservatively determined government cost estimate for the economic feasibility analysis.

Risk assessment provides the opportunity to use the entire distribution of costs, together with the entire distribution of benefits, to more thoroughly investigate the probability that the project is economically efficient. Because the real project benefits have not been estimated at the time of this analysis, it was not possible to complete an actual analysis. Therefore, for expository purposes, this report relies on the hypothetical benefits of Chapter III (normally distributed with a mean of $5.5 million and a standard deviation of $0.9 million) to complete the argument for changing the way the Corps performs its benefit cost analysis.

Net benefits were calculated 10,000 times. The distribution is shown in Figure 5-4. The results show 39.72 percent (or 3,972 net benefit estimates) were below zero, which means there is a 60.28 percent likelihood the project will yield positive net economic benefits. The best estimate of net benefits, the mean, is $0.3 million. Thus, the Corps team could conclude this project is economically efficient.

The benefit cost ratio distribution is shown in Figure 5-5. The mean BCR is 1.08. Thus, this project is most likely economically feasible, a fact that would have been missed had the analysis used the government cost estimate. Recall that the point estimate of the BCR was 0.92. The figure shows that about 60 percent of all the possible BCR's are between 1 and 2. There is even a slight (0.19 percent) chance the BCR will exceed 2.

The feasibility of the project can be summarized numerically as shown in Table 5-19. The table shows the BCR could be as low as 0.34 or as high as 2.58. The median BCR is 1.06. Net benefits range from a negative $4 million to almost positive $5 million. The median net benefits are $285,000.

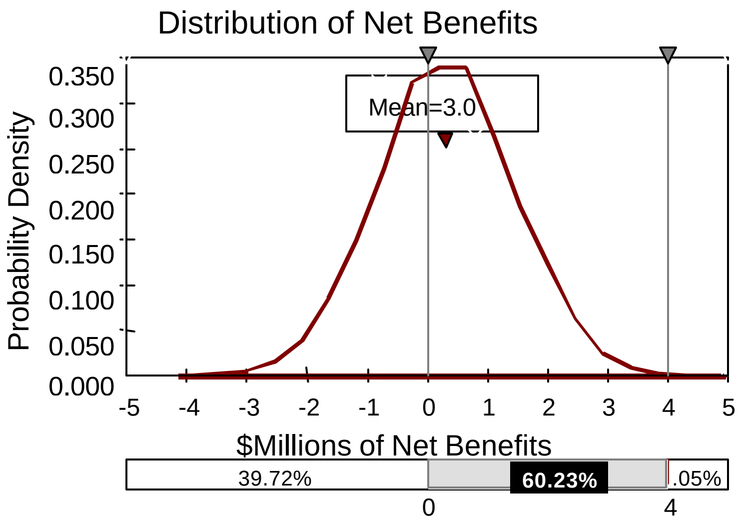

FIGURE 5-4

NET BENEFITS

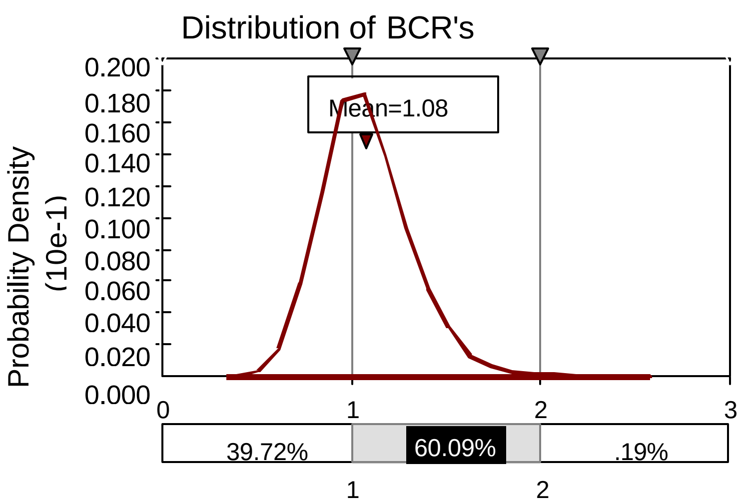

FIGURE 5-5

BENEFIT-COST RATIO

The potential uses of such an analytical framework are wide ranging. Imagine that such an analysis was done for each of the potential channel deepening alternatives, starting at 35 feet. These alternatives could be ranked by their expected BCR and also by the likelihood that the BCR would equal or exceed one.

One could imagine that the new standard for project authorization and appropriation could become the likelihood that the BCR equals or exceeds one or that net NED benefits equal

TABLE 5-19: ECONOMIC FEASIBILITY SUMMARY

Percentile	BCR	Net Benefits $Millions
0	0.34	-4.13
10	0.80	-1.15
20	0.88	-0.65
30	0.95	-0.30
40	1.00	0.01
50	1.06	0.28
60	1.11	0.58
70	1.18	0.89
80	1.26	1.27
90	1.39	1.78
100	2.58	4.96

or exceed zero. Even a project with an expected value (mean) BCR below one could proceed so long as there is some positive likelihood that the BCR exceeds one. That would enable decision makers outside the Corps to determine the viability of a project.

To illustrate this point, suppose project benefits had a mean of $5 million instead of $5.5 million as assumed above. The simulation was repeated with the new mean, everything else equal. The new mean BCR was 0.98 with mean net benefits of -$0.2 million. There would, however, be a 43.5 percent chance the project would be justified, which may be enough to enable decisions makers to decide to proceed despite an expected BCR less than 1.

What this analytical framework requires is a willingness to look at economic analysis a little differently. It never was a certainty, despite the point estimates it relied upon. With a distribution of net benefits, the analyst team has a more realistic view of the possible outcomes when a project is implemented. Risk management would enable decisionmakers to decide whether or not to implement a project. It is not hard to imagine a table like that shown below (Table 5-20) produced from risk assessment results. The table could be for alternative plans in a single study or it could be a comparison of different proposed projects.

TABLE 5-20: HYPOTHETICAL PROJECT ECONOMICS

Project	Mean Net Benefits	Probability of Non-Negative Net Benefits
A	$300,000	70%
B	$1,200,000	48%
C	-$150,000	52%
D	$75,000	37%

Project B has the highest net benefits of the hypothetical projects shown, but it is next to the least likely project to have net benefits greater than or equal to zero. Project C has a greater likelihood of breaking even or better despite its negative mean. The point being made here is that risk assessment affords decision makers with information they never had before, and there could be circumstances in which that additional information might change decisions.

Imagine point estimates of net benefits as shown in column two. Project C would be eliminated from consideration. Now suppose project C is competing with the other projects for construction funds and the decision makers also have the information in column three. By this criterion project C is the second best investment.

Decision makers, armed with the additional information about the likelihood that a project is economically efficient can make better informed choices. Because most projects would have some probability of breaking even or better, a project's fate would need no longer hang on the expected value of net benefits or any other point estimate. This can be an effective means of managing the risks of constructing inefficient projects or failing to construct efficient ones.

Key Uncertainties and Scenarios

Risks can be managed in other ways as well. Previously, it was pointed out how analysis of simulation results can identify key sources of uncertainty in the cost estimate. Key inputs once identified can be addressed systematically to reduce the uncertainty. For example, suppose the analysis was to focus on the material composition, an input identified as important in Table 5-14 above. One risk management option would be to do more wash and core borings or to expend more effort on quantity composition estimates for the dredging prism. This is one potential use of the risk assessment results.

Another possibility is to explore the significance of specific scenarios, such as more rock in the dredging prism material than is predicted. The model could be rerun using a different distribution for rock composition. The resulting costs could be compared to those obtained in the best estimate. If the differences are significant, this would present a powerful argument for allocating more resources to reducing the uncertainty about the amount of rock present.

RISK COMMUNICATION

Risk communication is the work required to answer the following questions:

- With whom to communicate?
- How to get both the information needed and the information others have?
- How to convey the information that needs to be communicated?
- When to communicate?

Starting with the last question, communication between the risk assessor (probably the cost estimator) and the risk managers (probably the cost estimators colleagues and supervisors, as well as the project manager and other managers up the chain of command) should begin immediately. If there are any unique issues or questions to be addressed, they need to be raised before the cost estimate and its risk assessment are begun. This is the only way to assure that the information needed to answer the relevant questions is provided.

Moving now to the first question, there are essentially two risk communication tasks. The first has to do with preparing the risk assessment. It means getting the data needed and using it effectively. This communication begins with the risk assessor and the risk managers. The risk assessor must also communicate closely with the people who will be providing the input information required for the cost estimate. This can include people in surveys, real estate, geotechnical, hydrology and so on. The second task has to do with communicating the results of the risk assessment and the resulting risk management strategies to others.

Getting the information that is needed for a risk assessment and for deliberative risk management is a critical step. Information gathering is something the Corps does quite well but collecting the information in a way that will support a risk analysis is a new and critical step. In fact, it would seem to be one of the most difficult to accomplish unless risk analysis is understood and valued by all parties who provide input to a cost estimate.

It is not enough for the cost engineers to be committed to risk analysis. Support people throughout the organization must be as well. For years these people have been trained to provide a point estimate of critical inputs, like the yardage in a dredging prism, the percentage of rock in the channel bottom, or the cost of land acquisition. These people are professionals with many years of experience. Unless they are familiar with the purposes of a risk analysis and their role in supporting it, they are not likely to provide data in the required form.

For example, suppose geotechnical personnel have provided the cost estimator with estimates of the composition of the dredge material. There is clearly some uncertainty in these estimates. It varies according to the information available and the complexity of the channels geology. Rather than a point estimate it may be preferable to have the parameters of a triangular distribution, i.e., the minimum and maximum possible values and the most likely value. But few people are trained to provide inputs like that.

Experience has shown there are several potential obstacles to obtaining data in the form required for a risk analysis. One of these is that risk analysis is new. New things require change and change can be intimidating. Few people understand what risk analysis is or what it is about. Requiring someone to do something they know nothing about can cause anxiety in many employees and that anxiety is addressed in a wide variety of ways. If education and training support is provided adequately, the healthiest response is to learn the new techniques and begin to use them. Without training or desire to learn, resistance is a common response to new initiatives like this. Resistance can range from passively ignoring the requirements to conscious efforts to subvert, reverse or overturn them.

Providing information in a form suitable for risk analysis is interpreted by some as a challenge to their authority and expertise. Some professionals simply overestimate their own knowledge and experience and consequently think their answer is "the answer." They are offended that anyone would ask them to provide anything but "the answer." These people may respond indignantly to a request an interval estimate, especially when they feel they have good data from which to work. When asked if they would be surprised if the actual quantity were 5 percent more or less they would respond, " Yes."

Others may be less confident but they are unwilling or unable to acknowledge that they labor in a world of uncertainty. When asked if they would be surprised if the actual quantity were 5 percent more or less they would respond, "No," and they would be unable or unwilling to quantify the uncertainty for you.

These situations present the cost engineer with a dilemma. Does one take the point estimate analysis of a colleague and quantify the uncertainty about it oneself? Or does one ignore the uncertainty known to be real and suspected to be significant? Getting cost estimate input data from support personnel in the form required for risk analysis is going to be one of the biggest risk communication obstacles confronted in introducing risk analysis to cost estimates. Fortunately, the problem not as intractable as it may first seem. The Corps' cost estimating community is more than capable of understanding the basics of risk analysis as presented in this report. Careful communication among colleagues at the outset of a cost estimate can assure the required data are obtained in the required form.

As for how to communicate the results of a risk analysis, this report presents about two dozen tables and figures that provide examples of how to communicate about risk assessment results. These were prepared for cost estimators, people who are used to working with quantitative concepts. Communicating complex data to the general public presents its own challenges and the best methods of communicating risk assessment results to risk managers, stakeholders, and the general public will surely evolve as we gain experience with this kind of analysis.

SUMMARY AND LOOK FORWARD

The results of a real risk analysis of the costs of a dredging project have been presented in this chapter. The case study serves as a proof of concept exercise if nothing else. It is possible, even reasonable to do risk analysis of cost estimates.

The discussion of the results demonstrates some of the potential uses of risk assessment information in the Corps program. Using a contingency to achieve a desired level of confidence presents a significant jump in the quality of cost estimation information. Using the entire distribution of costs obtained from a Monte Carlo simulation of costs offers promising and interesting new ways to consider the question of the economic feasibility of projects. The next and last chapter provides some recommendations for expanding the use of risk analysis of cost estimates from research to practical usage.

VI. RECOMMENDATIONS

INTRODUCTION

The results of this demonstration research will stand or fall on its own merits. If the arguments in favor of risk analysis put forth here have merit, cost estimators will be the ones who make that determination. For that reason, no further effort to summarize the findings is made beyond what has already been presented. If risk analysis of cost estimates is to become a common activity for the Corps' Civil Works Programs, there is plenty more to be done. In this chapter a few recommendations about what some of those things might be is offered.

RECOMMENDATIONS

In order to make cost estimation of risk analysis a reality in the Corps' Civil Works Program, a six-point strategy is recommended as follows: (1) Guidance, (2) Tools, (3) Training, (4) Experience, (5) Support, and (6) Feedback.

GUIDANCE

Cost risk guidance is needed if risk analysis of cost estimates is ever to become a reality. There is little incentive for individual cost estimators to begin to use risk analysis techniques on their own without direction, guidance, and examples to follow. First, few people are familiar with the concepts, tools and methods of risk analysis, so they do not see the need or potential for such analysis. Second, even those who do see the potential would be fighting an uphill battle to use and have accepted different techniques, even if they are better. The bureaucracy does not take easily to change.

If risk analysis of cost estimates is going to be developed and incorporated in the Civil Works Program, as it is being done in the Corps' Military Program, it is going to take an institutional commitment. Risk analysis is going to have to be mandated for all or it will not happen. That mandate, if it is undertaken, would be best expressed in a cost risk analysis engineering regulation. This is not a new idea. A proposed draft ER entitled "Procedures for Cost Risk Analysis" dated January 1, 1994 is one of the references for this analysis.

The requirement for risk analysis, the commitment to risk analysis and the basic methods of risk analysis will be most effective if they flow from a seminal ER or other official guidance. Developing such guidance should be one of the first orders of business if cost risk analysis is going to be pursued.

TOOLS

Cost estimators are going to need tools to do risk analysis of their projects. The example presented here is a relatively simple one. Cost estimating procedures can be quite complex. There are at least two schools of thought on the types of tools that will be needed.

Clearly MCACES, CEDEP, PACER, TRACES, and other cost estimating software tools used by the Corps should be user-friendly and compatible with the needs of risk assessors.

At the time of this research, cost estimators for the Military Program were about to award a contract to have MCACES, PACER and TRACES modified to handle some Monte Carlo process capabilities. Concerns about the M-32 version of MCACES at the time of this writing leave the future of that effort uncertain.

It would seem reasonable to expect that if the Corps' Military Program is moving more aggressively in the direction of risk analysis, that eventually the Civil Works Program will follow. There are some in the Civil Works Program who believe they should lead rather than follow. The general feeling is that Civil Works projects have far more complex cost estimating requirements and if tools are to be developed, Civil Works cost estimating personnel should be actively involved in the development.

It would be a relatively simple matter to modify CEDEP to accommodate the types of Monte Carlo processes used for this project. Such modifications should not be undertaken, however, without the full involvement of CEDEP users. Modifying MCACES and other tools is a more complex matter. Although it is beyond the scope of this research to suggest how that should be done, it should be done and with the full involvement of Civil Works cost estimators. Otherwise, they may be saddled with a tool developed by others that ill-suits their needs.

As for different schools of thought, they are these. First, there is a tradition and desire by many to automate as much of the analysis as possible. The Corps has at times favored tools that have become "black boxes." Put values in here and out comes the information needed to turn in an acceptable report. This has the advantage of standardization, one of which is to meet the needs of decision makers.

In the current context, such a tool would identify the most significant sources of uncertainty for the estimator, perhaps using the so-called 80/20 rule[14]. Then it would provide options for selecting a distribution along with options for identifying the distribution's parameters. Output reports would be automated as well.

This type of approach to developing tools can be contrasted with the use of more flexible tools. This could be achieved by teaching Corps cost estimators the basic techniques and theory needed to do risk analysis, then letting them do it in the manner they consider best within some form of regulations stipulated by guidance.

[14] Eighty percent of a project's costs are typically accounted for by 20 percent of the work elements.

Either approach would require the development of cost estimating tools that can support Monte Carlo simulation analysis. The preference recommended here is for the latter approach. It is more training and support intensive but a cost estimator who can think about a project like a risk analyst is going to be far more valuable in the long run than the one who more or less blindly gathers information in the desired format for use in a software program that is more black box than anything else. It is recommended that the Civil Works cost estimators be actively involved in the development of Monte Carlo simulation tools for their work and that the tools be designed for maximum flexibility rather than maximum standardization.

TRAINING

Training is going to be the major component of any effort to use risk analysis in cost estimating. There is likely to be considerable resistance to any effort to require the use of risk analysis in cost estimating. The techniques are generally unknown at this point in time and that can be very threatening to people's self esteem and job security. Any effort to use these techniques must be accompanied by a serious effort to teach and support these techniques. It is critically important that any training effort include professionals that support cost estimating efforts, such as geotechnical, surveys, design, real estate, and others.

Training can take many forms. Many of these methods can be self-taught by some estimators. Reference materials would be needed in order to pick up these skills. Such material could include some of the references to this report. Live in-class training in the Prospect program or other format would be useful. Much of this material could be made available in on-line courses that could be taken as the need arises. IWR staff is skilled in the techniques required to do this analysis and could provide some of the needed training.

The fact that decision makers are going to need some training in how to interpret and use the results of risk analysis cannot be overlooked. Training programs and resources should consider their needs too, which are likely to be different from those of the cost estimators.

EXPERIENCE

Once cost engineers start doing risk analysis of their estimates they are going to learn a great deal about what the most significant sources of uncertainty are. When cost engineers learn the basic techniques and are provided with the tools for doing this type of analysis, they will extend their uses to applications that cannot even be anticipated at this point. However, this is going to take experience with applying the techniques. The results of this experience could be used to develop risk analysis standards, acceptable levels of confidence and such; rules or guidance for selecting a contingency, and so on.

Demonstration projects could be helpful in building some experience base within the Corps. One idea would be to have several Districts undertake a risk analysis of a project. District personnel who have been given sufficient training and support to complete the analysis should undertake these analyses. The lessons learned would be invaluable. It is believed that once field people start to use these techniques they will begin to find uses well beyond those suggested here.

SUPPORT

In addition to training and tools, cost estimators are going to need other support. This could include software products, textbooks, and access to people who can provide the technical support resources needed to supplement their own abilities. Cost estimators will require the support of other Corps elements they rely on for information. Managers will also have to value the effort and results of risk analyses. One valuable form of support will be the channels of communication that will be available for feedback.

FEEDBACK

The initial impetus for doing risk analysis of cost estimates is not going to emerge from the bottom up. If it is to be done it will have to flow from the top down. In time, the feedback from practitioners will be an invaluable aid to improving the conduct and use of risk analysis of cost estimates.

Feedback can be the informal type that comes from peer group interactions on projects and in the office and other networking efforts, or it can be more formal. The Cost Engineering Newsletter could be a useful organ of communication, as could the cost estimators conferences held from time-to-time. However it is done, practitioners of risk analysis need an avenue by which to affect and influence the direction that the guidance, tools, training, experience and support take.

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