hour. If that forming production is not achieved, the cost of the work can increase significantly. When form production falls to 40 sq ft per hour, the wall cost rises by $24.73 per cy; a 12 percent reduction in the forming production rate adds 7 percent to the total wall cost. The estimator must exercise judgment in selecting production rates. Even when using historical data, it is necessary to carefully look at the proposed project and consider if the historical rates should be adjusted.

4.7 CHAPTER 4 REFERENCES

AED Green Book. Equipment Watch, Penton Media, Inc., 2011.
http://www.equipmentwatch.com/Marketing/GreenBook.jsp (Oct. 26, 2011).

Caterpillar Performance Handbook. Caterpillar Inc., Peoria, Illinois, 2011.

Cost Estimating Guidance. U.S. Department of Transportation, Federal Highway Administration, 2007.
http://www.fhwa.dot.gov/ipd/pdfs/project_delivery/major_project_cost_guidance.pdf (Oct. 26, 2011).

Knutson, K., C. J. Schexnayder, C. M. Fiori, and R. E. Mayo. *Construction Management Fundamentals, 2*nd ed., McGraw-Hill Professional, New York, New York, 2008.

Peurifoy, R., C. R. Schexnayder, A. Shapira, and R. Schmitt. *Construction Planning, Equipment, and Methods,* 8th ed., McGraw-Hill Professional, New York, New York, 2011.

Rental Rate Blue Book. Equipment Watch, Penton Media, Inc., 2011.
http://www.equipmentwatch.com/Marketing/RRBB_overview.jsp (Oct. 26,. 2011)

4.8 CHAPTER 4 ADDITIONAL RESOURCES

Assemblies Cost Data. R. S. Means Company, Inc., Kingston, Massachusetts, 2011.

Building Construction Cost Data. R. S. Means Company, Inc., Kingston, Massachusetts, 2011.

Construction Cost Trends. Bureau of Reclamation, 2011. http://www.usbr.gov/pmts/estimate/ cost_trend.html (Oct. 26, 2011).

Heavy Construction Cost Data. R. S. Means Company, Inc., Kingston, Massachusetts, 2011.

Walker's Building Estimator's Reference Book. 28th ed. Frank R. Walker Company, Lisle, Illinois, 2006.

CHAPTER 5

Risk-Based Estimates

5.1 OVERVIEW

Risk-based cost estimates apply risk identification and uncertainty analysis techniques to forecast project contingency. Risks are uncertain events or conditions that could affect the project cost if they occur. Risk-based estimates produce an expected value and a range of project costs. They also provide a ranking of risks to monitor during the project development process to help manage contingency and prevent cost and schedule growth in future estimates. Estimators will typically use risk-based estimates during the planning, scoping, and early design phases. However, estimators can apply risk-based estimates at any point when there is significant uncertainty in the project definition or estimating information.

5.1.1 What Is It?

In its simplest terms, risk-based estimates use risk analysis to forecast costs of unknown, or uncertain, items. They combine traditional estimating methods with risk analysis processes to estimate the uncertain items of work, any uncertain quantities, and possible risk events (Association for the Advancement of Cost Engineering International [AACEI] Risk Committee 2000; Molenaar et al. 2010). Risk-based cost estimates strip all contingency from the line items in the base estimate and estimate contingency values explicitly. The base estimate should contain items without contingency (i.e., no conservatism or "fudge factor" should be included on individual items). Estimates for contingency are made through either a "top-down" value based on historical data or a "bottom-up" value based on the risk events. Top-down contingency estimates relate risks to ranges of contingency from historical data. Bottom-up contingency estimates use simulation to assess (a) risk events through an estimate of a risk's probability of occurrence and magnitude of impact; and (b) uncertainty in costs or quantities by applying ranges of values.

The output of risk-based estimates can be either deterministic (i.e., one number) or probabilistic (i.e., a range of values). Deterministic outputs combine the probability and impact of risk events to develop a single expected value of contingency. Probabilistic outputs combine probability and impact of risk events through simulation to produce a range of values for contingency. The simulation-based portion of the estimate typically focuses on a few key elements of uncertainty and combines Monte Carlo sampling and heuristics (rules of thumb) to rank critical risk elements.

5.1.2 Why Use It?

Risk-based estimating techniques can uncover potential cost escalation and provide useful information for the monitoring and management of uncertainty (Project Management Institute [PMI] 2004; International Organization for Standardization [ISO] 2009). Communication of ranged cost estimates can provide the design team and project stakeholders with a transparent understanding of the uncertainty in early cost estimates. Modeling of contingency can also help to provide a better understanding of the amount that a contractor will include in the bid for project risks at letting. However, developing a risk-based estimate is not a trivial task. Comprehensive risk identification requires the estimator to work with numerous team members in risk identification efforts and data-gathering exercises. The use of simulation modeling to determine contingency requires training and practice.

5.1.3 When to Use It?

Estimators apply risk-based estimates most frequently in the planning, scoping, and early design phases of complex projects. Table 1-3 presents a cost estimating classification and recommends the use of risk-based estimating in project scoping and planning. Complex projects can also benefit from risk-based estimates in early design. In special circumstances, such as design-build, large, or highly complex projects, risk-based estimates can provide great value in terms of estimating potential contingency that a contractor will include in a bid (Anderson et al. 2007 and Molenaar et al. 2010).

Figure 5-1 provides a graphical depiction of when risk-based estimates apply. Figure 5-1 is an extension of Figure 1-3 and Table 1-3. Figure 5-1 illustrates two key points relating to risk-based estimates. First, an estimate at any given point is made up of a base estimate component and a contingency component (see Chapters 1-4). As the project progresses in development, the contingency amount is expected to decrease because the project information is refined and more details become available. Typically, the base estimate increases as some of the contingency is realized and included in the base estimate. The second point that Figure 5-1 illustrates is the transition from a risk-based range estimate to a baseline estimate when moving from the planning to the programming phases. Risk-based estimates can generate the range estimates for the planning and programming phase and can also assist in determining proper contingency in the design phase.

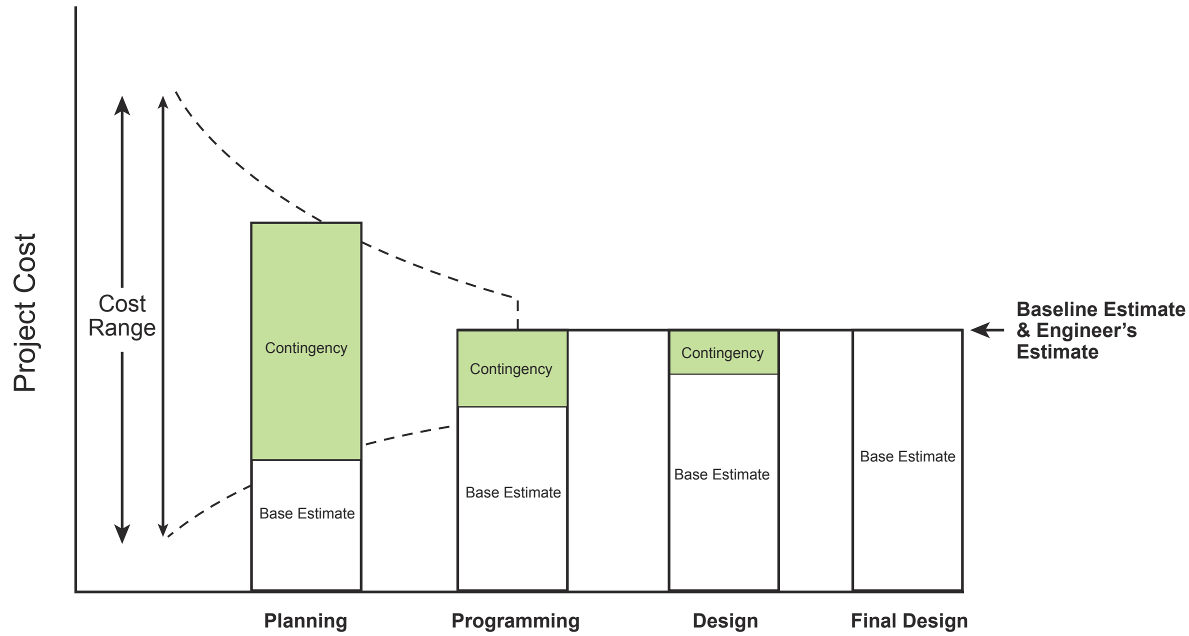

Figure 5-1. Refinement of a Cost Estimate (Molenaar et al. 2010)
(Case where baseline estimate is equal to engineer's estimate).

5.2 KEY INPUTS

The key inputs to a risk-based estimate are an identification and quantification of uncertainty surrounding the project scope (i.e., items of work, quantities of work, rates of production, etc.) and uncertainty surrounding risk events (i.e., a change in design standards, discovery of hazardous material, etc.). Risk-based estimates account for the potential impacts of uncertainty in both of these areas. Sources for these key inputs include:

- A definition of project complexity.
- A list of design and estimating assumptions and concerns.

5.2.1 Project Complexity

Project complexity is a primary input to risk-based estimating. Project complexity drives the level of effort and choice of tools for a risk-based estimate (Molenaar et al. 2010 and Anderson et al. 2008). Project complexity is described in a number of ways. Some descriptions rely on project attributes to convey the project complexity. For example, attributes related to roadways, traffic control approaches, structures, right-of-way, utilities, environmental requirements, and stakeholder involvement are often used to distinguish different levels of project complexity. Table 5-1 provides an example of complexity classification from *NCHRP Report 574: Guidance for Cost Estimation and Management for Highway Projects During Planning, Programming, and Preconstruction*. Each agency is encouraged to develop its own definition of complexity given its specific needs and resources.

Table 5-1. Example of Complexity Classification

Most Complex (Major)	Moderately Complex	Non-Complex (Minor)
• New highways; major relocations • New interchanges • Capacity adding/major widening • Major reconstruction (4R; 3R with multi-phase traffic control) • Require congestion management studies	• 3R and 4R projects that do not add capacity • Minor roadway relocations • Certain complex (non-trail enhancement) projects • Slides, subsidence	• Maintenance betterment projects • Overlay projects, simple widening without right-of-way (or very minimum right-of-way take) and little or no utility coordination • Non-complex enhancement projects without new bridges (i.e., bike trails)

Note: 4R is rehabilitation, restoration, resurfacing, or reconstruction.

NCHRP Report 564: Guidebook on Risk Analysis Tools and Management Practices to Control Transportation Project Costs employs a three-level complexity categorization in Table 5-1 to determine the approach to estimating contingency. Projects in the highest complex category (major projects) may include new highways, major relocations, or reconstruction. Highly complex projects can require a bottom-up, probabilistic-based approach to estimating contingency (Monte Carlo simulation is discussed in detail in Section 5.3.2.3). Projects with minor complexity, such as maintenance projects, may require only a listing of red-flag risks and a top-down contingency estimate based on a percentage of the base cost estimate. Moderately complex projects, such as minor roadway relocations, will typically require a qualitative risk assessment and top-down percentage contingency estimate. However, these projects may also require a deterministic examination of individual risks to ensure that the top-down percentage contingency is adequate (Molenaar et al. 2010). The sections that follow explain all of these methods—risk-based percentage contingency estimate, risk-based deterministic contingency estimate, and risk-based probabilistic contingency estimate.

5.2.2 Design and Estimate Assumptions and Concerns

The other two primary inputs for a risk-based estimate stem from a review of the assumptions made by the designer in the project definition and the assumptions made by the estimator to create the estimate. The designers must make initial project definition assumptions during the planning or scoping phases, or both. Risk-based estimates are often made when limited resources—or no resources—have been invested in design. This is the nature of conceptual design, and it drives uncertainty in the project scope and project cost estimate. Likewise, estimators must make estimating assumptions in planning- and programming-level estimates because very little detail will be available regarding project definition. Estimating and design assumptions serve as triggers for risk identification when creating a contingency estimate.

Two other sources of risk information are risk checklists and risk analyses from similar projects. Estimators that maintain historical risk checklists will improve their chances of identifying potential risks on future projects. However, these historical checklists should not be the primary sources of information. Preferably, they should only be used after conducting an independent and thorough review of the project complexity and the estimating and design assumptions.

5.3 DETERMINE RISK AND SET CONTINGENCY

Determining risk and setting contingency requires experience, judgment, and the proper tools to quantify as much of the project cost estimate uncertainty as practical. An estimator can never completely eliminate the uncertainty or the risks from any cost estimate. Therefore, an estimator needs to include a reasonable contingency amount in a project cost estimate to account for the risk exposure. A reasonable contingency amount must provide coverage for any possible cost overruns, and the estimator must be able to explain why the specific contingency amount is included in the estimate. The risk exposure and the corresponding contingency amount typically decrease as a project advances through project development phases.

This section separates risk identification from risk-based estimating of contingency. Risk identification is common to all risk-based estimating approaches. After discussing risk identification as the approach to determining risk, this guide presents three common risk-based approaches to setting contingency:

- Type I—risk-based percentage contingency estimates.
- Type II—risk-based deterministic contingency estimates.
- Type III—risk-based probabilistic contingency estimates.

5.3.1 Determine Risk

Risk identification is the first step in all risk analysis approaches. It should involve all members of the project team, as risks events can come from any functional area or stakeholder group. Risk identification tools, such as risk checklists, can be helpful. However, brainstorming in a risk identification workshop setting is perhaps the best approach to risk identification, as it will produce a project-specific list of risks and prompt the discussion of critical project elements.

5.3.1.1 Objectives of Risk Identification

The objectives of risk identification are to (a) identify and categorize risks that could affect the project; and (b) document the identified risks. The outcome of the risk identification is a list of risks. Ideally, the list of risks should be comprehensive and non-overlapping. What is done with the list of risks at that point depends on the nature of the risks and the nature of the project. On minor, low-cost projects with little uncertainty (few risks), the risks may simply be kept as a list of red-flag items. The red-flag items can then be assigned to individual team members to monitor (or track) throughout the project development process. They can also be used for risk allocation purposes, as described in Section 5.3.2.3.2. On major, high-cost projects that by nature have greater uncertainty (many risks), the identified risks can feed a rigorous process of assessment, analysis, mitigation and planning, allocation, and monitoring and updating.

The risk identification process should stop short of assessing or analyzing risks so as not to inhibit the identification of "minor" risks. The process should promote creative thinking and leverage team experience and knowledge. In practice, however, risk identification and assessment are often completed in a single step, and this process can be called risk assessment. For example, if a risk is identified in the process of interviewing a team member or expert, it is logical to pursue information on the probability of it occurring, its consequences/impacts, the time associated with the risk (i.e., when it might occur), and possible ways of dealing with it. The latter actions are part of risk assessment, but they often begin during risk identification. For clarity, however, this document will treat the two activities of risk identification and assessment as discrete processes.

5.3.1.2 Risk Identification Process

The risk identification process begins with the team compiling a list of the project's possible risk events. Possible risks are those events or conditions that team members determine would adversely affect the project cost. The identification process will vary depending upon the nature of the project and the risk management skills of the team members, but most identification processes begin with an examination of issues and concerns raised by the project development team. These issues and concerns can be derived from an examination of the project description, work breakdown structure, cost estimate, design and construction schedule, procurement plan, and general risk checklists. Checklists and databases can be created for recurring risks, but project team experience and subjective analysis will almost always be required to identify project-specific risks.

The team should examine and identify project events by reducing them to a level of detail that permits an evaluator to understand the significance of any risk and identify its causes (or risk drivers). This is a practical way of addressing the large and diverse number of potential risks that often occur on highway design and construction projects.

Upon identification, the risks should be classified into groups of like exposures. Classification of risks helps to reduce redundancy and provides for easier management of the risks in later phases of the risk analysis process. Classifying risks aids in creating a comprehensive and non-overlapping list. Classifying risks also provides for the creation of risk checklists, risk registers, and databases for future projects. Table 5-2 provides an example categorization of risks and a risk checklist. It is a summarization of information found in the SHRP2 Report *Guide for the Process of Managing Risk on Rapid Renewal Projects* (Roberds et al. 2011).

5.3.1.3 Risk Characteristics

During the risk identification step, risks can be characterized to aid in later assessment and planning. It is often helpful to think of risk in broader terms of uncertainty. Uncertainty involves both positive and negative events. A risk is defined as an uncertain event or condition and, if it occurs, it has a positive or negative effect on a project's objectives (PMI 2004). However, it is often helpful to separate uncertain events into those that can have a negative effect (risks) and those that can have a positive effect (opportunities). Some estimators choose to use the terminology of both risk and opportunity to characterize uncertainty in their risk management programs. However, teams must be cautious not to overlook risk or focus on solving problems when using the risk/opportunity characterization during the risk identification process. Estimators and project managers may underestimate risk when thinking about uncertain items. It is often better to focus on risks during the identification stage and explore opportunities during the mitigation process.

Another characteristic of risks is that many risk events have triggers. Triggers, sometimes called risk symptoms or warning signs, are indications that a risk has occurred or is about to occur. Triggers may be discovered in the risk identification process and watched in the risk monitoring and updating process.

The identification and documentation of triggers early in the process can greatly help the risk management process.

Table 5-2. Common Transportation Risks and Risk Categories

Environmental Risks	External Risks
• Delay in review of environmental documentation • Challenge in appropriate environmental documentation • Defined and non-defined hazardous waste • Environmental regulation changes • Environmental impact statement (EIS) required • NEPA/404 Merger Process required • Environmental analysis on new alignments required	• Stakeholders request late changes • Influential stakeholders request additional needs to serve their own commercial purposes • Local communities pose objections • Community relations • Conformance with regulations/guidelines/design criteria • Intergovernmental agreements and jurisdiction
Third-Party Risks	**Geotechnical and Site Risks**
• Unforeseen delays due to utility owner and third-party • Encounter unexpected utilities during construction • Cost sharing with utilities not as planned • Utility integration with project not as planned • Third-party delays during construction • Coordination with other projects • Coordination with other government agencies	• Unexpected geotechnical issues • Surveys late or in error, or both • Hazardous waste site analysis incomplete or in error • Inadequate geotechnical investigations • Adverse groundwater conditions • Other general geotechnical risks
Right-of-Way/Real Estate Risks	**Design Risks**
• Railroad involvement • Objections to ROW appraisal take more time or money, or both • Excessive relocation or demolition • ROW Acquisition problems • Difficult or additional condemnation • Accelerating pace of development in project corridor • Additional ROW purchase due to alignment change	• Design is incomplete/design exceptions • Scope definition is poor or incomplete • Project purpose and need are poorly defined • Communication breakdown with project team • Pressure to deliver project on an accelerated schedule • Constructability of design issues • Project complexity (scope, schedule, objectives, cost, and deliverables are not clearly understood)
Organizational Risks	**Construction Risks**
• Inexperienced staff assigned • Losing critical staff at crucial point of the project • Functional units not available or overloaded • No control over staff priorities • Lack of coordination/communication • Local agency issues • Internal red tape causes delay getting approvals, decisions • Too many projects/new priority project inserted into program	• Pressure to deliver project on an accelerated schedule • Inaccurate contract time estimates • Construction QC/QA issues • Unclear contract documents • Problem with construction sequencing/staging/phasing • Maintenance of traffic/work zone traffic control

The risk identification process identifies and categorizes risks that could affect the project. It documents these risks and, at a minimum, produces a list of risks that can be assigned to a team member and tracked throughout the project development and delivery process. Risk identification is continuous, and there should be a continual search for new risks that should be included in the process. The tools and techniques outlined in this section should support the risk identification process, but it will be the people involved in the exercises who are most critical to the success of the process.

5.3.2 Set Contingency

While this chapter focuses on risk-based approaches to estimating contingency, it does not recommend that Monte Carlo simulation is the proper tool for every project contingency estimate. Rather, it suggests a three-tier approach to risk analysis and contingency estimation. The three-tier approach stems directly from project complexity. A determination of the project complexity is made based on the three categories in Table 5-1. This leads to the selection of a risk analysis and contingency estimating approach as shown in Figure 5-2.

Figure 5-2. Three-Tier Approach to Contingency Estimation

Based on an evaluation of where the project falls in the three different levels of complexity, a different type of risk analysis is defined for the project. The three types of risk analysis and contingency estimation correlate directly to the three levels of complexity:

- Type I—non-complex (minor) projects.
- Type II—moderately complex projects.
- Type III—most complex (major) projects.

The three risk analysis types can be briefly described as follows:

- Type I—risk-based percentage contingency estimates: A Type I risk-based approach is the simplest form of risk analysis and should be used for non-complex (minor) projects. A Type I risk analysis involves the development of a list of risks and the use of a top-down percentage of project cost to estimate the contingency.
- Type II—risk-based deterministic contingency estimates: The Type II risk-based approach correlates to moderately complex projects and involves more rigorous risk identification tools. It involves a top-down percentage contingency estimate that is supplemented with a bottom-up estimation of specific contingency items.
- Type III—risk-based probabilistic contingency estimates: A Type III risk-based approach applies to the most complex (major) projects. It will need to be facilitated by individuals trained in quantitative risk management practices. Using a comprehensive and non-overlapping set of risks, the estimator generates a probabilistic estimate of cost and schedule to determine an appropriate contingency.

The type of risk analysis will determine the selection of appropriate risk-related tools for risk identification, risk analysis, and estimation of contingency. All projects, regardless of project size and project complexity, require some form of risk analysis and risk management planning. The basic risk analysis steps remain the same, but the tools and level of effort vary with the risk analysis level.

5.3.2.1 Risk-Based Percentage Contingency Estimates

In the case of minor and some moderately complex projects, transportation estimators commonly determine contingency estimates from a percentage of the base cost. Many states apply a predetermined contingency on their projects (Molenaar et al. 2010). However, this predetermined contingency varies greatly from state to state. The definition of what contingency covers also varies from state to state, and even within agencies across regions or functional units. In an attempt to better account for the unique effects of project complexity and phase in project development, this guide presents a sliding-scale contingency approach that is based on a Delphi study of 23 professional estimators from DOTs around the country (Olumide et al. 2010). This guide recommends the use of the sliding-scale contingency amounts shown in Tables 5-3 and 5-4 and Figures 5-3 to 5-5. However, this general guidance should be adjusted for each DOT given its historical experience and current market conditions.

Table 5-3 provides some typical risks that are representative of each of the three levels of project complexity. Table 5-4 correlates to Figures 5-3 to 5-5 and provides a description of the project complexity, phase of project development, phase description, level of definition, estimate type, and historical data that were used to develop the sliding-scale contingencies.

Table 5-3. Examples of Representative Risks for Project Complexities

Project Type	Most Complex	Moderately Complex	Non-Complex
Representative Risks	• Unresolved constructability issues • Design complexity • Political factors • Complex environmental requirements	• Geotechnical issues • Changes in materials/foundation • Delays in permitting process • Bridge redesign/analysis	• Contractor delays • Changes in program priorities • Errors in cost estimating • Inaccurate technical assumptions

Figures 5-3 to 5-5 present the sliding-scale contingencies based on the results of the Delphi study (Olumide et al. 2010). Design 1, Design 2, and Design 3 correspond to different levels of design completion and project definition (see Table 5-4). For instance for non-complex projects, Design 1 is 15-40 percent level of definition, Design 2 is 40-70 percent, and Design 3 is 70-100 percent level of definition. These three stages of design are 4 years or less from letting using bid-based or cost-based, or both, estimating techniques and historical data.