



## Cost Estimating Improvement Initiative: Literature Review

*Requested by*  
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# Executive Summary

## Background

Caltrans has assembled a team to investigate best practices for cost estimating, including improved methods for determining both capital and support costs. Capital costs include the costs of construction, and support costs include preconstruction costs for such tasks as design and surveying, as well as maintenance costs throughout the life cycle of a facility. Developing better methods of cost estimating is essential to Caltrans' goal of addressing the needs of its partners, including the California Legislature, Federal Highway Administration (FHWA), the California Transportation Commission, local agencies and taxpayers.

To assist in this effort, CTC & Associates conducted a review of literature provided by Caltrans on best practices for cost estimation and management. A second phase of this project will involve a survey of the 12 Caltrans districts that examines the districts' cost estimating methods.

## Summary of Findings

CTC & Associates conducted a literature review of publications provided by Caltrans. The publications were divided into categories based on an assessment of their level of usefulness to Caltrans:

- **Most Useful Publications:** Publications selected for this category include detailed and specific information relevant to cost estimation and management.
- **Useful Publications:** These publications are on point but not as important as those in the first category.
- **Least Useful Publications:** These publications may be relevant but often contain only very general information or information that is less directly related to cost estimation and management than those publications in the previous categories.
- **Caltrans Publications:** These documents are studies or presentations conducted within Caltrans. While the information on cost estimation and management is typically very general, it is important to Caltrans' efforts.

Each of these categories is further subdivided as necessary into the following topics:

- Cost Estimation and Management.
- Risk Management.
- Project Management.
- Financing.
- Staffing.

CTC & Associates also conducted a search for recent literature on cost estimation and management as well as risk management. Links and abstracts for these resources are provided in **Related Research**.

Highlighted below are publications provided by Caltrans and found during the literature search. The publications are grouped by topical categories.

## Cost Estimation and Management

- NCHRP Report 826 presents a framework for developing data-driven preconstruction services (PCS) cost estimating models for highway projects. The framework can be implemented with standard spreadsheet and database software.
- AASHTO's Practical Guide to Cost Estimating covers conceptual (parametric) estimating, historical bid-based estimating, cost-based estimating and risk-based estimating. Tables 1-2 and 1-3 show how each of these estimate types can be applied to different phases of project development. Chapters devoted to each type of estimating give detailed accounts of the steps involved (including, for example, database requirements and construction cost factors for conceptual estimating).
- NCHRP Report 574 details processes for cost estimation and management. See especially Figure 2.2 for an agency-level flowchart for cost estimation practice and cost estimation management, and Tables 2.2 and 2.3 for details of the cost estimation and management processes. NCHRP Report 625 provides an equally detailed breakdown of processes for right of way (ROW) cost estimation and management.
- Also useful is the Project Management Institute's Practice Standard for Project Estimating. More general in its guidance is FHWA's Major Project Program Cost Estimating Guidance, which is geared toward cost estimates for projects seeking federal financial assistance.
- Caltrans' FY 2015-16 Fourth Quarter Project Delivery Report includes several slides on cost estimating, including bulleted lists of best practices, causes of bad estimates, tips for success and ideas to improve estimating. Other Caltrans documents provide reasons for changes in the scope of Caltrans projects; a list of cost estimating tools and techniques; background information on the State Highway Operation and Protection Program (SHOPP); ideas for managing risk; and a list of project financing challenges.
- A review of related research found an ongoing project to develop a procedural guidebook and software tool to enhance the accuracy of cost estimates and project scheduling for Texas metropolitan planning organizations (MPOs). Information about several other recent studies on cost estimation and management was also found.

## Risk Management

- NCHRP Report 658 describes an iterative risk management framework that can be used for both small and large projects. The framework has five steps: risk identification, risk assessment/analysis, risk mitigation and planning, risk allocation, and risk monitoring and control.
- Guides from several state departments of transportation (DOTs) provide very useful information on risk management:
  - Washington State DOT has developed a spreadsheet tool for performing Monte Carlo simulations. An accompanying guide explains how to use this tool to identify and quantify project risks and their influence on project cost and schedule, and to monitor and manage those risks. A Washington State DOT policy letter gives step-by-step procedures for reporting risk-based estimates in its Capital Program Management System (CPMS).

- Georgia DOT has developed a software tool “specifically designed for identification and qualitative assessment of highway project risks during the pre-construction phase of the project.” A comprehensive guidebook for risk analysis accompanies the software tool.
- Nevada DOT’s Risk Management and Risk-Based Estimation Guidelines includes detailed, useful information on processes for risk management and cost estimation.
- Also useful are an FHWA report on transportation risk management, which includes a five-step process of risk identification, analysis, evaluation, treatment and monitoring; the Project Management Institute’s Practice Standard for Project Risk Management, which “provides a benchmark for the project management profession that defines the aspects of Project Risk Management that are recognized as good practice on most projects most of the time”; and an Oregon DOT case study on managing risk, which applies an assessment tool developed as part of the second Strategic Highway Research Program (SHRP 2).
- Less directly useful are an article on the neurological and procedural root causes of “overly optimistic estimates” and an NCHRP report with very general recommendations regarding risk management for state DOTs.
- A review of related research found a recent case study of risk-based estimating practices by Minnesota DOT, as well as several other studies on risk management.

## **Project Management**

- NCHRP Project 20-68A, Scan 7-01, Best Practices in Project Delivery Management, cites Washington State DOT’s project management practices and the way the agency manages risk.
- Also useful is NCHRP Report 821, which “illustrates the effort needed to develop a robust cost estimate and then manage to a baseline budget and scope throughout the project delivery cycle”; and the Project Management Institute’s Guide to Project Management Body of Knowledge, which is the “global standard for project management.”
- More general in their guidance are FHWA’s Guide to Project Management Strategies for Complex Projects, which outlines a five dimensional project management approach for complex projects, and several other FHWA and NCHRP project management guides.

## **Gaps in Findings**

Because of the large number of resources provided by Caltrans for review, CTC was able to provide only a cursory overview of recent research related to cost estimation and management not included in Caltrans’ list, and has included only the abstracts of these studies.

## **Next Steps**

In Phase II of this Preliminary Investigation, CTC will conduct a survey of the 12 Caltrans districts that examines the districts’ cost estimating methods. Each of the 12 Caltrans districts will receive surveys targeted at all nine functional units within each district. After completion of

Phases I and II, Caltrans may require a third phase of research that includes a second round of surveys.

Using the results of this Preliminary Investigation, Caltrans will develop the support and capital cost estimating and management method improvements necessary for addressing the needs of its partners.

## Detailed Findings

### Most Useful Publications

#### Cost Estimation and Management

**Estimating Highway Preconstruction Services Costs—Volume 1: Guidebook**, NCHRP Report 826, 2016.

<http://www.trb.org/Main/Blurbs/174755.aspx>

This guide presents a framework for the development of data-driven PCS cost estimating models for highway projects. It can be implemented with standard spreadsheet and database software as a means for agencies to estimate, at an early stage of project development, how much it will cost to plan, program, permit and design a project. Topics range from the principal sources of PCS costs at various stages of project development to PCS cost estimating methodologies and external trends likely to influence costs.

From page 10:

This guidebook describes the step-by-step process to develop a top-down PCS cost-estimating model with three different data-driven approaches:

- Multiple regression modeling.
- Decision tree analysis.
- Artificial neural network modeling.

Summaries of each chapter follow:

*Chapter 2: PCS Cost-Estimating Process.* “This chapter describes the overall PCS cost-estimating process that is aligned with a typical project development process. The need for three different approaches for estimating PCS costs is explained. The appropriate timing of application and the effectiveness of use are discussed” (page 10). See Figure 2.3 (page 14) for a diagram of the PCS cost-estimating process, and pages 18-19 for information about developing a data-driven model.

*Chapter 3: PCS Database Development and Management.* “This chapter discusses a database development and management process required for a successful implementation of data-driven PCS cost estimating. Some specific topics discussed in this chapter are data collection and cleaning strategies, identification and evaluation of potential input variables, and development/optimization of PCS databases” (page 10). See Table 3.1 (pages 22-23) for factors affecting PCS costs.

*Chapter 4: Top-Down PCS Cost Estimating.* “This chapter explains the development process of top-down PCS cost-estimating models. Three data-driven methods are discussed in detail: multiple regression, decision trees, and artificial neural networks” (page 10).

*Chapter 5: Functional-Level PCS Cost Estimating.* “This chapter discusses the development process of functional-level PCS cost-estimating models. It also discusses the use of a work breakdown structure in developing a functional-level PCS cost-estimating model, discusses

the feedback loop for continuous improvement, and addresses issues in database creation, maintenance, and management” (page 10).

*Chapter 6: Implementing PCS Cost-Estimating Models.* “This chapter discusses important aspects related to the implementation of PCS cost-estimating models in practice, such as the interpretation of PCS cost estimates, incorporation of these estimates into decision-making procedures, tracking of PCS costs throughout the project development process, capturing lessons learned from the use of the framework described in this guidebook and specific models developed by using it, and continuous improvement procedures to optimize the performance of these models” (page 11).

*Chapter 7: Project-Specific PCS Estimating Issues and Contract Administration Guidance.* “This chapter discusses project-specific and contract administration issues associated with the development and use of PCS cost-estimating models. The chapter covers project monitoring strategies, actions required under potential scope changes, how to use the PCS cost estimate to identify and quantify scope creep, and some aspects related to the use of in-house versus external designers/consultants” (page 11).

**Practical Guide to Cost Estimating**, 1st edition, American Association of State Highway and Transportation Officials, 2013.

[https://bookstore.transportation.org/collection\\_detail.aspx?ID=122](https://bookstore.transportation.org/collection_detail.aspx?ID=122)

From the summary:

Part I of the guide covers the following cost estimating techniques:

- **Conceptual** or parametric estimating techniques are primarily used to support development of planning or early scoping phase estimates when minimal project definition is available. Statistical relationships or non-statistical ratios, or both, between historical data and other project parameters are used to calculate the cost of various items of work (i.e., center lane miles or square foot of bridge deck area).
- **Historical bid-based** estimating relies heavily on element or bid items, or both, with quantities and good historical bid data for determining item cost. The historical data normally is based on bids from recent projects. The estimator must adjust the historical data to fit the current project characteristics and location. The historical data must also be adjusted to reflect current dollars. With the use of historical bid data, estimators can easily and quickly prepare estimates.
- **Cost-based** estimating considers seven basic elements: time, equipment, labor, subcontractor, material, overhead, and profit. Generally, a work statement and set of drawings or specifications are used to “take off” material quantities required for each discrete work task necessary to accomplish the project bid items. From these quantities, direct labor, materials, and equipment costs are calculated based on calculated or assumed production rates. Contractor overhead and profit are then added to this direct cost.
- **Risk-based** estimating combines (1) traditional estimating methods for known items and quantities with (2) risk analysis techniques to estimate uncertain items, uncertain quantities, and risk events. The risk-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. This approach is used to establish the range of total project cost and to define how contingency should be allocated to critical project elements.

Tables 1-2 and 1-3 (pages 21-22) provide information about the different types of cost estimating required at different phases of the project development process:

**Table 1-2. Estimate Types and Purposes**

Project Development Phase	Estimate Type, Purpose, and Plan/Program Supported
Planning	<b>Conceptual Estimating—</b> Estimate Potential Funds Needed (20-Plus-Year Long-Range Plan)
	Prioritize Needs for Long-Range Plans (Intermediate-Range Plan—10 years)
Scoping	<b>Scope Estimating—</b> Establish a Baseline Cost for Project and Program Projects (IRP and STIP)
Design	<b>Design Estimating—</b> Manage Project Budgets against Baseline (STIP)
Final Design	<b>Plans, Specifications, and Estimate Estimating—</b> Compare with Bid and Obligate Funds for Construction

**Table 1-3. Cost Estimating Classification**

Project Development Phase	Project Maturity (% project definition completed)	Purpose of the Estimate	Estimating Methodology	Estimate Range
Planning	0 to 2%	Conceptual Estimating—Estimate Potential Funds Needed (20-year plan)	Parametric (Stochastic or Judgment)	-50% to +200%
	1% to 15%	Conceptual Estimating—Prioritize Needs for Long-Range Plans (IRP—10-year plan)	Parametric or Historical Bid-Based (Primarily Stochastic)	-40% to +100%
Scoping	10% to 30%	Design Estimating—Establish a Baseline Cost for Project and Program Projects (IRP and STIP)	Historical Bid-Based or Cost-Based (Mixed, but Primarily Stochastic)	-30% to +50%
Design	30% to 90%	Design Estimating—Manage Project Budgets against Baseline (STIP, Contingency)	Historical Bid-Based or Cost-Based (Primarily Deterministic)	-10% to +25%
Final Design	90% to 100%	PS&E Estimating—Compare with Bid and Obligate Funds for Construction	Cost-Based or Historical Bid-Based Using Cost Estimate System (Deterministic)	-5% to +10%

Chapter 2, “Conceptual Estimating,” presents key inputs to estimates, including good historical cost data and project-related information matched to cost data (page 29), and database requirements (page 30). Section 2.2.3.1 provides construction cost factors, including lane-mile cost factors, bridge cost factors and preliminary engineering. The chapter gives an example of using a computer-based conceptual estimating tool, TRACER, to output “quantities for various items of work, unit prices, and calculations to derive a construction base cost estimate” (page 42).

Section 2.7 provides project examples, and Table 2-9 (page 56) gives an example of a conceptual cost estimate:

**Table 2-9.** Conceptual Estimate of Project A Total Project Cost

Conceptual Cost Estimate		
Project length	95.6 – 87.4 =	8.2 miles
Cost per mile from Table 2-2 (2007 dollars)	\$7,550,000/mile =	\$7.55M/mi
Construction cost (2007 dollars)	8.2 mi x \$7.55/mi =	\$61.91M
10% adjustment for additional drainage, excavation, ponds, plus substantial grading at curve past MP 87.4	+ \$61.91 x 0.10 =	+ 6.19M
2% reduction for economy of scale considerations	–\$61.91 x 0.02 =	–1.24M
Adjusted construction cost (2007 dollars)	\$61.91M + \$6.19M – \$1.24M =	\$66.86M
Adjust to present value from index (4% for 4 years)	$FV = PV(1 + i)^t$ \$66.86M x (1.04) <sup>4</sup> =	\$78.2M
<b>Total construction cost without contingency</b>		<b>\$78,200,000</b>
R/W costs for some acquisitions—assume 5% of total construction cost	\$78.2M x 0.05 =	\$3.9M
PE costs for complex project design—assume 10% of total construction cost	\$78.2M x 0.10 =	\$7.8M
CE costs for large project with no anticipated significant contracting issues—assume 8% of construction cost	\$78.2M x 0.08 =	\$6.3M
Total Project Cost (without contingency)	\$78.2M + 3.9M + 7.8M + 6.3M =	\$96.2M
<b>Total Project Cost Estimate (without contingency)</b>		<b>\$96,200,000</b>

Chapters 3 through 5 give similarly detailed accounts of methods for conducting bid-based, cost-based and risk-based estimates. Part II of the guide covers the following cost management topics:

- Inflationary considerations.
- Letting strategies for cost control.
- Analysis of contractor bids.
- Performance measures for cost estimating.

**Procedures Guide for Right-of-Way Cost Estimation and Cost Management**, NCHRP Report 625, 2009.

<http://www.trb.org/Main/Blurbs/162271.aspx>

This guide presents a five-step, structured approach to ROW cost estimation and cost management (page 3):

1. Determine ROW estimate basis.
2. Prepare ROW base estimate.
3. Determine ROW risk and set contingency.
4. Review ROW cost estimate.
5. Approve and communicate ROW cost estimate.

The guide describes four “distinct but interrelated ROW cost estimating and cost estimating management processes” (pages 3-4):

- **Conceptual ROW Cost Estimating**, which occurs during the Planning phase of project development and supports SHA [state highway agency] long-range plans; generally this phase is where the first estimate is prepared for a project.
- **Baseline ROW Cost Estimating**, which occurs during the Programming phase of project development and supports intermediate plans (10 years or less). Several cost estimates may be prepared before the final estimate of this phase, based on the preferred project alternative, is used to set a Total Project Baseline Estimate. The Total Project Baseline Estimate is often used to move a project into the State Transportation Improvement Program (STIP). The ROW portion of the Total Project Cost Estimate then becomes the ROW budget amount for the project. Management will use this Baseline ROW Cost Estimate to monitor the cost impact of future ROW estimates prepared in response to development of the project design.
- **Updated ROW Cost Estimates** are prepared during the Preliminary Design phase of project development and involve updating estimated ROW cost as designs are prepared leading to the final ROW plans. Updated estimates are reconciled with the Total Project Cost Estimate to help in managing ROW cost and its contribution to total project cost.
- **ROW Cost Management** occurs when the appraisal and acquisition process begins and continues throughout Final Design activities. Actual ROW expenditures are captured and used to forecast total ROW costs. Management is constantly comparing forecasted ROW cost as compared with the updated ROW budget.

Chapter 2 presents an integrated estimating process and cites the four-step cost estimating process described in NCHRP Report 574 (see citation below). Remaining Chapters 4 through 6 give detailed steps for developing ROW conceptual, baseline, and updated ROW cost estimates, and Chapter 7 provides information about ROW cost management.

**Guidance for Cost Estimation and Management for Highway Projects During Planning, Programming and Preconstruction**, NCHRP Report 574, 2007.

<http://www.trb.org/Publications/Blurbs/158464.aspx>

This report provides an overview of cost estimation for highway projects and is cited by many other reports in this Preliminary Investigation.

The following figures and tables in Chapter 2, “Agency Cost Estimation Practice and Cost Estimation Management Processes,” are especially useful:

- Figure 2.1 (page 8) details development phases and activities.
- Figure 2.2 (page 9) provides an agency-level flowchart for cost estimation practice and management.
- Table 2.2 (page 11) details the cost estimation process, and Table 2.3 (page 12) describes the cost estimation management process.

Other chapters detail:

- Cost escalation factors, such as project schedule changes and scope creep, and strategies to address them (Chapter 3).

- A guide for the planning phase of projects (Chapter 5). Figure 5.1 (page 23) presents an overview of cost estimation practice and management. The chapter also covers budget control and risk analysis; Table 5.10 (page 38) lists methods and tools presented in the chapter for use in planning.
- A guide for the programming and preliminary design phase (Chapter 6) and for the final design phase (Chapter 7).

The report identifies the following keys to cost estimation success (page 2):

#### Cost estimation management:

1. Make estimation a priority by allocating time and staff resources.
2. Set a project baseline cost estimate during programming or early in preliminary design, and manage to this estimate throughout project development.
3. Create cost containment mechanisms for timely decision making that indicate when projects deviate from the baseline.
4. Create estimate transparency with disciplined communication of the uncertainty and importance of an estimate.
5. Protect estimators from internal and external pressures to provide low cost estimates.

#### Cost estimation practice:

1. Complete every step in the estimation process during all phases of project development.
2. Document estimate basis, assumptions, and back-up calculations thoroughly.
3. Identify project risks and uncertainties early, and use these explicitly identified risks to establish appropriate contingencies.
4. Anticipate external cost influences and incorporate them into the estimate.
5. Perform estimate reviews to confirm that the estimate is accurate and fully reflects project scope.

## Risk Management

**Risk Based Estimate Self-Modeling**, Washington State Department of Transportation, September 2016.

See Appendix A (guide) and Appendix B (spreadsheet tool).

Washington State DOT developed a spreadsheet tool for performing Monte Carlo simulations, “a powerful mathematical process widely used to conduct quantitative risk analysis. This simulation runs thousands of scenarios of each risk realization while factoring combinations of cost and schedule inputs, risk probabilities and impacts.” The guide explains how to use the tool to assist in “identifying and quantifying project risks and their influence on cost and schedule of the project,” and “to monitor and manage those risks” (page 7). The tool includes worksheets for data input and output that provide visualizations of the impacts of risks on project costs during various project phases. The worksheets provide “a risk register to facilitate prioritization, monitoring and management of these risks.”

*Related Resource:*

**Use of Risk-Based Project Estimates for Budgeting and Project Management**, Instructional Letter IL 4071.02, Washington State Department of Transportation, February 2012.

See Appendix C.

From the introduction (page 1):

The purpose of this Instructional Letter is to provide Washington State Department of Transportation (WSDOT) project management staff with information necessary for the use of risk-based estimating on projects over \$10 million, and to require that all projects regardless of cost shall have a risk matrix to support any established risk reserves.

The letter establishes rules and procedures for the use and reporting of risk-based estimating results (pages 2-3):

1. Establish a baseline cost estimate.
2. Establish the 60th percentile cost estimate.
3. Establish a risk reserve (the difference between (1) and (2)).
4. Evaluate the estimate every six months or sooner under certain circumstances.
5. Update the estimate, if warranted.
6. Assess possibilities for mitigation of risk and include them within the project plan.
7. Enter uninflated base cost and risk reserve estimates in the CPMS.
8. Manage the base cost estimate.
9. Use and adjust the risk reserve, if needed.

See pages 4-5 for documentation and information to support estimates.

**Streamlining Project Delivery Through Risk Analysis**, Georgia Department of Transportation, 2015.

<https://ntl.bts.gov/lib/55000/55600/55647/13-05.pdf>

This study reviewed practices at other state DOTs to develop “a comprehensive guidebook that advances the adoption of risk analysis tools in GDOT [Georgia Department of Transportation], in order to expedite project delivery” (page 9).

From pages 9-10:

The results indicate that typically state DOTs determine the level and methods of risk management based on project size (i.e. dollar value) and complexity of the project. The level of risk management may vary from a simple risk register to a complex quantitative analysis. Moreover, several factors such as lack of training of personnel, lack of sufficient internal infrastructure such as database, lack of existing policies, and lack of risk culture are among the most important challenges and barriers to implement a successful risk management program. After reviewing the literature and current risk management practices by state DOTs, a semi-structured interview was conducted with nine subject matter experts at GDOT.

Researchers used the results to develop a software tool (page 2):

Finally, a software tool specifically designed for identification and qualitative assessment of highway project risks during the pre-construction phase of the project was developed based on the shortlisted risk factors. The software program is equipped with the modification capability of adding new risk items and/or removing some of the predetermined risk factors from the assessment.

Chapter 5 is the manual for the software tool, called Comprehensive Risk Assessment for Transportation (CRAFT), which is “specifically designed for identification and qualitative assessment of highway project risks during the preconstruction phase of the project.”

**Risk Management and Risk-Based Cost Estimation Guidelines**, Nevada Department of Transportation, August 2012.

<https://www.nevadadot.com/home/showdocument?id=4518>

This manual provides “guidance to NDOT [Nevada Department of Transportation] personnel and consultants in best practice methods of risk management and risk-based cost estimation” (page i). It includes detailed, useful information on processes for risk management and cost estimation. Table 1 (page 4) provides a suggested risk management process based on project size. Chapter 2 gives a step-by-step process for cost estimation, including determining an estimate basis, preparing a base cost estimate, reviewing the base cost estimate and determining risks. Subsequent chapters break down these steps further.

*Related Resource:*

**Project Cost Estimation Manual**, Nevada Department of Transportation, November 2015.

<https://www.nevadadot.com/home/showdocument?id=1539>

This manual provides “guidance and instruction to Roadway Designers, Senior Designers and Project Managers for efficiently and consistently developing project cost estimates in the integrated Project Development (iPD) system” (page 5). iPD is Nevada DOT’s software for developing cost estimates for contracts.

**Guidebook on Risk Analysis Tools and Management Practices to Control Transportation Project Costs**, NCHRP Report 658, 2010.

<http://www.trb.org/Publications/Blurbs/163722.aspx>

This guidebook “provides guidance to state departments of transportation for using specific, practical, and risk-related management practices and analysis tools for managing and controlling transportation project costs” (page 5). It describes an “iterative risk management framework” with five steps that can be used for both small and large projects:

1. **Risk identification** is the process of determining which risks might affect the project and documenting their characteristics using such tools as brainstorming and checklists.
2. **Risk assessment/analysis** involves the quantitative or qualitative analysis that assesses impact and probability of a risk. Risk assessment assists in deriving contingency estimates. Quantitative and qualitative risk analysis procedures are applied to determine the probability and impact of risks.
3. **Risk mitigation and planning** involves analyzing risk response options (acceptance, avoidance, mitigation or transference) and deciding how to approach and plan risk management activities for a project.
4. **Risk allocation** involves placing responsibility for a risk to a party—typically through a contract. The fundamental tenants of risk allocation include allocating risks to the party

best able to manage them, allocating risks in alignment with project goals, and allocating risks to promote team alignment with customer-oriented performance goals.

5. **Risk monitoring and control** is the capture, analysis, and reporting of project performance, usually as compared to the risk management plan. Risk monitoring and control assists in contingency tracking and resolution.

Chapter 2 covers project cost estimation and management, and cites the four-step cost estimating process from NCHRP Report 574, which is presented in Table 2.2:

**Table 2.2. Cost estimating process (Anderson et al. 2007).**

<b>Cost Estimating Step</b>	<b>Description</b>
Determine estimate basis	Document project type and scope including <ul style="list-style-type: none"> <li>• scope documents;</li> <li>• drawings that are available (defining percent engineering and design completion);</li> <li>• project design parameters;</li> <li>• project complexity;</li> <li>• unique project location characteristics; and</li> <li>• disciplines required to prepare the cost estimate</li> </ul>
Prepare base estimate	Prepare estimate, including <ul style="list-style-type: none"> <li>• documentation of estimate assumptions, types of cost data, and adjustments to cost data;</li> <li>• application of appropriate estimating techniques, parameters, and cost data consistent with level of scope definition;</li> <li>• coverage of all known project elements;</li> <li>• coverage of all known project conditions; and</li> <li>• check to ensure that estimate is consistent with past experience.</li> </ul>
Determine risk and set contingency	Identify and quantify areas of uncertainty related to <ul style="list-style-type: none"> <li>• project knowns and unknowns;</li> <li>• potential risks associated with these uncertainties; and</li> <li>• appropriate level of contingency congruent with project risks.</li> </ul>
Review total cost estimate	Review estimate basis and assumptions, including <ul style="list-style-type: none"> <li>• methods used to develop estimate parameters (e.g., quantities) and associated costs;</li> <li>• completeness of estimate relative to project scope;</li> <li>• application of cost data, including project-specific adjustments;</li> <li>• reconciliation of current estimate with the baseline estimate (explain differences); and</li> <li>• preparation of an estimate file that compiles information and data used to prepare the project estimate.</li> </ul>

Chapter 3 provides an overview of risk management. Examples of typical risks are given in Table 3.1 (page 17):

**Table 3.1. Typical risks and outcomes across the project phases.**

<b>Project Phase</b>	<b>Planning</b>	<b>Programming</b>	<b>Design</b>
<b>Typical Risks</b>	<ul style="list-style-type: none"> <li>• Fatal or significant environmental economic impacts</li> <li>• Funding uncertainty</li> <li>• Uncertain political and public support</li> <li>• Competing interests and competing projects</li> </ul>	<ul style="list-style-type: none"> <li>• Changes in design requirements</li> <li>• Costs of environmental compliance</li> <li>• Right of way acquisition delays</li> <li>• Technical uncertainties</li> <li>• Funding uncertainty</li> </ul>	<ul style="list-style-type: none"> <li>• Changes in design requirements</li> <li>• Market conditions, permit requirement changes</li> </ul>
<b>Expected Outcomes</b>	<ul style="list-style-type: none"> <li>• Better understanding of environmental, engineering, and construction issues facing each project alternative</li> <li>• Order of magnitude risk costs and possible total cost range for each option</li> </ul>	<ul style="list-style-type: none"> <li>• List of major project risks</li> <li>• Reasonable estimate of risk costs, and probable total project costs and duration</li> <li>• Long list of risk mitigation strategies</li> <li>• Preliminary risk management plan, focused on design and constructability risks</li> <li>• Preliminary risk allocation planning</li> </ul>	<ul style="list-style-type: none"> <li>• Prioritization of risks based on impacts to total project cost and duration</li> <li>• Costs / benefits of risk mitigation and risk allocation strategies</li> <li>• Risk management and allocation plan</li> </ul>

Washington State DOT's cost estimate classification system is given in Table 3.2 (page 18):

**Table 3.2. Cost estimate classification system (WSDOT).**

Project Development Phase	Project Maturity (% project definition completed)	Purpose of the Estimate	Estimating Methodology	Estimate Range
Planning	0 to 2%	Conceptual Estimating – Estimate Potential Funds Needed (20-year plan)	Parametric (Stochastic or Judgment)	-50% to +200%
	1% to 15%	Conceptual Estimating – Prioritize Needs for Long Range Plans (HIP – 10-year plan)	Parametric or Historical Bid-Based (Primarily Stochastic)	-40% to +100%
Scoping (Programming)	10% to 30%	Design Estimating – Establish a Baseline Cost for Project and Program Projects (HIP and STIP)	Historical Bid-Based or Cost-Based (Mixed, but Primarily Stochastic)	-30% to +50%
Design	30% to 90%	Design Estimating – Manage Project Budgets Against Baseline (STIP, Contingency)	Historical Bid-Based or Cost-Based (Primarily Deterministic)	-10% to +25%
Final Design	90% to 100%	PS&E Estimating – Compare with Bid and Obligate Funds for Construction	Cost-Based or Historical Bid-Based Using CES. (Deterministic)	-5% to +10%

Section 3.4 describes a risk management framework and addresses risk identification, assessment, analysis, mitigation and planning, allocation, and monitoring and control. The guide cites the Caltrans risk register as an example (page 35).

Remaining chapters give detailed guides to risk planning, programming, design and implementation, with sections on tools for each phase.

## Project Management

**Best Practices in Project Delivery Management**, NCHRP Project 20-68A, Scan 7-01, 2009. [http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp20-68A\\_07-01.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp20-68A_07-01.pdf)

This guide includes useful examples on project management from other state DOTs, including Washington State DOT:

WSDOT's project management practices are divided into two systems. The first is called the Capital Improvement Preservation Program (CIPP) and focuses on managing projects that do not involve major reconstruction activities. WSDOT uses a customized version of Sciforma's PS8 software to manage schedule cost and other features of these projects.

WSDOT's second program is called the Project Management and Reporting System (PMRS) and is focused on the rest of its capital program. Additional information for this program can be found on the agency's Web site at <http://www.wsdot.wa.gov/projects/projectmgmt/> (page 3-2).

According to the guide, Washington State DOT's Cost Estimate Validation Process (CEVP) program "has clearly addressed risks and helped manage project costs and other factors that could have had negative impacts on its capital program" (page ES-3). Pages 3-7 to 3-9 cover the agency's tools:

WSDOT addresses risks aggressively in the cost estimating function. WSDOT's risk management process is based on the following principles:

- Integral and sound project management.
- Encouraged early planning/action.
- Revealed threats and opportunities.
- Increased understanding.
- Greater transparency.

Fundamental to the process are the answers to two questions: How much will it cost and how long will it take? WSDOT emphasizes procedures that give them an estimate as a range and not as a single number because it believes that approximately right is better than precisely wrong.

Pages 3-9 to 3-10 address delivery methods to mitigate cost and manage risks.

## **Useful Publications**

### **Cost Estimation and Management**

**Practice Standard for Project Estimating**, Project Management Institute, 2011.

<https://www.pmi.org/pmbok-guide-standards/framework/practice-standard-project-estimating>

From the product page:

The standard describes the stages of project estimating. It covers resources, durations, and costs, and explains the concept of progressive elaboration—continuously refining and improving a plan as a project evolves.

Because this book must be purchased, CTC was unable to provide a detailed summary. Caltrans' summary of the book follows:

- Section 1.3 (page 4) addresses the difficulty with estimating early in the project process: "Even though estimates are developed initially at the onset of a project, it is important to think of estimating as a continuous activity throughout the project life cycle. The initial estimates are used to baseline the project resources, schedule, and cost. These estimates are then compared to the project benefit stream in order to determine an early view of the feasibility of the project. As the project progresses and more information is known, the estimates are continually refined and subsequently become more accurate."
- Section 2.2 (page 10), first bullet, provides a useful definition of contingency reserve.

- Section 2.5 (page 12) provides good backup on the range of contingency and zeroing in.
- Table 2-2 in Section 2.8 (page 14) may be good guidance for District COS staff.
- Chapter 4 lists established estimating techniques and provides good definitions.
- Section 4.3.3, first sentence, provides a good justification for bottom-up estimating.

## Risk Management

### **Transportation Risk Management: International Practices for Program Development and Project Delivery**, Federal Highway Administration, Report FHWA-PL-12-029, August 2012.

[https://international.fhwa.dot.gov/scan/12029/12029\\_report.pdf](https://international.fhwa.dot.gov/scan/12029/12029_report.pdf)

From page 2 of the report:

... a U.S. panel traveled to Australia and Europe to learn from their significant experience by conducting a scan of risk management practices for program development and project delivery. The purpose of the scan was to review and document international policies, practices, and strategies for potential application in the United States. The team conducted meetings with government agencies, academic researchers, and private sector organizations that actively participate in risk management efforts. The scan team also visited project sites and personnel who were applying these practices.

Chapter 2 covers risk management strategies, including a five-step process of risk identification, analysis, evaluation, treatment and monitoring (pages 11-12). Page 13 describes risk workshops, pages 14-18 give detailed information on risk registers, and the remaining content of the chapter covers quantification.

Chapter 5 covers project risk management, including the use of Monte Carlo simulations for project cost and schedule risk analysis.

### **Practice Standard for Project Risk Management**, Project Management Institute, 2009.

<http://marketplace.pmi.org/Pages/ProductDetail.aspx?GMProduct=00101169201>

From the product page:

The Practice Standard for Project Risk Management provides a benchmark for the project management profession that defines the aspects of Project Risk Management that are recognized as good practice on most projects most of the time.

The Practice Standard for Project Risk Management covers risk management as it is applied to single projects only. It does not cover risk in programs or portfolios. This practice standard is consistent with the PMBOK® Guide and is aligned with other PMI practice standards. Different projects, organizations and situations require a variety of approaches to risk management and there are several specific ways to conduct risk management that are in agreement with principles of Project Risk Management as presented in this practice standard.

Written for project managers, project team members, supervisors and stakeholders, the Practice Standard for Project Risk Management outlines the principles of effective risk management:

- Plan risk management.
- Identify risks.

- Perform qualitative risk analysis.
- Perform quantitative risk analysis.
- Plan risk responses.
- Monitor and control risks.

This practice standard can be used by project management practitioners to validate the risk management process being employed in a specific situation, project or organization.

(Because this book must be purchased, CTC was unable to provide a more detailed summary.)

**Oregon DOT Case Study: Managing Risk in Rapid Renewal Projects**, SHRP2 Solutions, undated.

[https://www.fhwa.dot.gov/goshrp2/Content/Documents/R09\\_Oregon\\_Training\\_CaseStudy.pdf](https://www.fhwa.dot.gov/goshrp2/Content/Documents/R09_Oregon_Training_CaseStudy.pdf)

This case study details Oregon DOT's use of a risk assessment tool developed through SHRP 2. Detailed in Guide for the Process of Managing Risk on Rapid Renewal Projects (<http://www.trb.org/Main/Blurbs/168369.aspx>), this tool "uses a highly flexible Excel-based template to guide teams through a comprehensive risk management process to identify, assess, analyze, and manage risks that are unique to each project":

During a two-day training workshop hosted by FHWA, ODOT staff applied the product's iterative process and template using a hypothetical case study (QDOT project) to:

- Holistically identify potential risks.
- Determine the likelihood of risk occurrence.
- Calculate the associated schedule, cost, and disruption impacts.
- Devise strategies to monitor and mitigate risks from planning to construction.
- Assess the overall impact of mitigated risks.
- Explore how to implement a risk management plan as part of their overall project delivery process.

## **Project Management**

**Effective Project Scoping Practices to Improve On-Time and On-Budget Delivery of Highway Budgets**, NCHRP Report 821, 2016.

<http://www.trb.org/Publications/Blurbs/173953.aspx>

From the foreword:

NCHRP Report 821: Effective Project Scoping Practices to Improve On-Time and On-Budget Delivery of Highway Projects is a guidebook that demonstrates how a state department of transportation (state DOT) can improve its scoping process and practices to produce a project cost estimate and schedule that facilitate programming decision making and accountability. The guidebook illustrates the effort needed to develop a robust cost estimate and then manage to a baseline budget and scope throughout the project delivery cycle. The guidebook is applicable to a range of project types and is scalable in its ability to accommodate projects of varying complexity.

Part 1 provides research results about the project scoping process (PSP). Project scoping includes three major activities (page 10):

- **Develop the project.** The objective of the first activity of the PSP is to update and refine the project parameters, project definition, and project purpose and need to a sufficient level, which facilitates selection of the best alternative and development of a more accurate baseline scope, cost, and schedule. This includes selecting a PSP team, visiting the site, soliciting public input, refining the project concept, preparing conceptual cost estimates, and summarizing key project characteristics.
- **Analyze alternatives and document findings.** The objective of the second activity of the PSP is to analyze the identified project alternatives and document the findings in order to assess, prioritize, and recommend a preferred alternative for further detailing the next step of the PSP. This includes performing various activities for each of the alternatives, such as ROW research, traffic analysis, survey of existing conditions covering environmental and utility issues, development of the conceptual TMP, and establishment of preliminary scoping cost estimates.
- **Develop a recommended alternative.** The objective of the last activity of the PSP is to develop and document the recommended alternative. This includes developing preliminary drawings, finalizing environmental documentation, finalizing the TMP, determining real property requirements, engaging the public, preparing the baseline cost and schedule, and preparing the project scoping report.

Researchers developed the PSP using the Integrated Definition (IDEF) function modeling technique (page 11).

The guide's framework includes four levels of activities (pages 11-14):

- Level 1 is project scoping.
- Level 2 activities represent the main functions that describe a PSP.
- Level 3, further hierarchical breakdowns of these three activities, describes the details of activities required to perform these functions.

From page 18:

Typically, the PDP [Project Delivery Process] consists of six phases—planning, preliminary design, detailed design, letting, construction and post construction. ... The integration of the PSP in the PDP may include performing some of the planning phase's activities, complete preliminary design phase's activities including environmental process, ROW map development, preliminary utility conflict analysis, etc., and some of the detailed design phase's activities.

The implementation section beginning on page 27 describes three major activities along with subactivities. The steps in project development are described on page 29.

There are five major steps involved in preparing a conceptual cost estimate (pages 47-57):

- **Determine basis for conceptual cost estimate.** Collect and document all information required to serve as a basis for preparing a base conceptual estimate in the next activity.

- **Prepare base conceptual cost estimate.** Prepare the most likely conceptual cost estimate based on what is known, without including contingency dollars to cover estimate uncertainty or risks. An estimate of contingency is covered in the next activity.
- **Determine major risks and set contingency.** Characterize the estimate uncertainty and develop a contingency amount to add to the base estimate to arrive at the total project cost estimate.
- **Review conceptual cost estimate.** Review the conceptual estimate to ensure that it is as complete and accurate as possible based on the project requirements as described in the refined project concept.
- **Approve conceptual cost estimate.** Approve the final conceptual estimate package before the estimate is released to both internal and external project stakeholders.

Appendix A of the report describes a number of tools useful to cost estimation.

**A Guide to the Project Management Body of Knowledge (PMBOK Guide)—5th Edition**, Project Management Institute, 2013.

<http://www.pmi.org/pmbok-guide-standards/foundational/pmbok>

The guide is the “global standard for project management” and “provides project professionals with the fundamental practices needed to achieve organizational results and excellence in the practice of project management.” Section 7 provides information about project cost management, including a discussion of cost estimating in Section 7.2. (Because this book must be purchased, CTC was unable to provide a more detailed summary.)

## Least Useful Publications

### **Cost Estimation and Management**

**Major Project Program Cost Estimating Guidance**, Federal Highway Administration, 2007.

[https://www.fhwa.dot.gov/majorprojects/cost\\_estimating/guidance.cfm](https://www.fhwa.dot.gov/majorprojects/cost_estimating/guidance.cfm)

This brief document has very general guidance about creating cost estimates for major projects. From the introduction:

This guidance is for the preparation of a total program cost estimate for a major project. For the purpose of this guidance, a major project is defined as a project that receives any amount of Federal financial assistance and has an estimated total program cost greater than \$500 million (expressed in year-of-expenditure dollars), or other projects identified as a major project by the FHWA. The total program cost estimate includes construction, engineering, acquisition of right-of-way, and related costs, which will be identified by this guidance. Although this guidance is for major projects, it may also be applied to other projects.

### **Risk Management**

**“Contingency: Why We Get It Wrong, and How to Get It Right,”** W.G. Meyer, *PMI Global Congress 2016—North America Proceedings*, 2016.

Conference session description at

<http://congresses.pmi.org/NorthAmerica2016/Program/sessions/session/2016/09/26/qcemea-2016-calendar/contingency-why-we-get-it-wrong-and-how-to-get-it-right>

Conference paper at <http://wernermeier.org/Files/WG%20Meyer%20Contingency.pdf>

From the abstract:

Time and cost estimates—and the contingency that is added to these estimates—are examples of decisions that are made under risk and uncertainty. Estimation and contingency are two controversial topics in project management and literature is fraught with examples of projects that overran both their estimates and contingencies reserves. In this paper, the neurological and procedural root causes of overly optimistic estimates are explored, and a number of methods for improving the estimates are proposed.

From page 1:

Estimate inaccuracies result from uncertainty, and to counter it, we add allowances, or contingencies, to our cost and time estimates. But contingencies are not remedies for a poor [estimate], and should only make provision for known uncertainties in the estimate. To improve this situation we must first understand the origins of uncertainty in projects.

Contributors to uncertainty include (pages 1-2):

- Inaccurate user requirements.
- Translation of the requirements into a scope of work.
- Translation of the scope into the WBS [work breakdown structure].

Formulas for total cost estimate uncertainty and total time estimate uncertainty are given on page 2.

Most cost estimation techniques don't focus on the root causes of inaccurate estimations, including contingency based on performance of past projects. The contingency reserve (budgeted risks) for projects is developed based on expert judgments, simulations, parametric methods and other methods that "rely heavily on our knowledge of past projects and do not address the underlying reasons for inaccurate estimates" (page 2).

The root causes of uncertainty are biases, heuristics (shortcuts of judgment) and neurology (pages 3-4).

One approach to improving estimates is to "ensure that the estimators are competent to perform the estimate through expert verification and calibration," heuristics awareness training and other methods (pages 4-5).

The following steps are recommended to improve contingency calculations (page 5):

1. **Determine a growth contingency based on the user requirements, scope and WBS uncertainty.** This contingency addresses variations in quantities (hours, units, material, etc.), but not changes in scope.
2. **Develop a high-quality estimate that includes estimate variances using the methods that address biases, heuristics and neurology.** This variance addresses the estimator uncertainty on the assumption that the scope definition is complete.
3. **Identify the systemic risks and the potential impact of these risks.** Reframe as many of them as possible as project-specific risks that have impacts on specific deliverables. This will reduce the number of unsubstantiated historical risks in the project and will make project-specific mitigation plans possible.

4. **Identify and quantify the cost and time impact of project -specific risks.**
5. **Include economic factors such as escalation and foreign exchange fluctuations in the calculations.**

**Executive Strategies for Risk Management by State Departments of Transportation, NCHRP 20-24, 2011.**

Project description at <http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2888>

Final report at [http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-24\(74\)\\_ResearchReport.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-24(74)_ResearchReport.pdf)

Executive summary at [http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-24\(74\)\\_ExecutiveSummary.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-24(74)_ExecutiveSummary.pdf)

From the abstract:

The objective of this study is to describe how Department of Transportation (DOT) leadership currently uses risk management techniques in the conduct of their business and to identify executive strategies that may be useful to DOT leadership for enterprise-wide risk management.

The report gives very general recommendations regarding risk management for state DOTs (see pages 27-29 of the report). Chapter 3 provides more specifics on risk management strategies, including a discussion of the five steps to managing risk (pages 6-12):

1. Identification.
2. Assessment.
3. Analysis.
4. Mitigation and planning.
5. Monitoring and updating.

A discussion of risk analysis that covers Monte Carlo simulation, sensitivity analysis and decision trees begins on page 8.

## **Project Management**

**Guide to Project Management Strategies for Complex Projects**, Federal Highway Administration, SHRP 2 Report S2-R10-RW-2, 2015.

<http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2prepubR10Guide.pdf>

This report outlines a five-dimensional project management (5DPM) approach for complex projects. From the foreword:

The five dimensions are (1) cost, (2) schedule, (3) technical, (4) context, and (5) finance. Successful use of the 5DPM approach involves five methods that are unique for each project:

- Define critical project success factors by each dimension, as required.
- Assemble project team.
- Select project arrangements.
- Prepare early cost model and finance plan.
- Develop project action plans.

See pages 22-23 for factors related to the cost dimension; pages 54-59 for general information on preparing an early cost model and finance plan; and pages 76-80 for information about conducting a risk analysis.

**Accelerating Transportation Project and Program Delivery: Conception to Completion**, NCHRP Report 662, 2010.

<http://www.trb.org/Publications/Blurbs/163936.aspx>

This report “describes how selected transportation agencies have reduced the time required to complete the project delivery process.” Accelerating delivery may save on costs (page 11), but there is no information in this report on cost estimation or management. Chapter 5 provides case studies of various states, including California, on best practices for accelerating project and program delivery.

**Project Management Plan Guidance**, Federal Highway Administration, January 2009.

[https://www.fhwa.dot.gov/majorprojects/pmp/pmp\\_guide\\_jan09.pdf](https://www.fhwa.dot.gov/majorprojects/pmp/pmp_guide_jan09.pdf)

This document assists “the recipient of Federal financial assistance in the preparation of a Project Management Plan to meet the requirements of SAFETEA-LU” (page 1). The plan must include project cost budget and schedule information (page 6).

**Guidance for Transportation Project Management**, NCHRP Web-Only Document 137, 2009.

<http://www.trb.org/Publications/Blurbs/161950.aspx>

Overall, the guidance in this manual is very high level and does not present specific tools for cost estimation or management. For example, very general guidance on developing a consultant’s cost or fee is provided on page 18 of the report:

We now have two methods of developing a budget with the consultant: Bottom up and top down. In the real world a combination of the two is a typical method of negotiating where the consultant develops a budget, the agency deems it too costly and so an examination of the work scope and level of effort to achieve each task ensues. Normally agreement is reached fairly quickly using this method.

There are other methods of developing a budget; the most common is the “Unit Cost Method.” In this case, historic data and experience provides a basis for estimating what it should cost to accomplish a particular design activity. Note that while unit cost method provides an easy method to determine what something should cost, there is no way that unit cost can take into consideration the uniqueness of a particular project or work site.

A common method of unit cost in the transportation field is percent of construction. If we have an estimated construction cost, the cost of design should be roughly 10 to 12 percent of construction. Again, this is a rule of thumb only.

**Selection and Evaluation of Alternative Contracting Methods to Accelerate Project Completion**, NCHRP Synthesis 379, 2008.

<http://www.trb.org/Publications/Blurbs/160310.aspx>

This guide covers five alternative contracting methods that show the highest potential for accelerating project completion. These methods are listed below in order of highest relative potential to accelerate project completion:

- Design–build.
- Incentives and disincentives.
- Cost-plus-time bidding.

- Interim completion dates.
- No-excuse incentives.

However, “data do not support a conclusion that project acceleration using the contracting methods studied in this report either substantially increases or decreases costs. Further study may be necessary. There is some indication in the literature that these five methods often increase cost; the data in this survey do not necessarily support the literature. Further, the data indicate that quality is not adversely impacted with implementation of these five methods, contrary to what the literature often indicates and counter to some of the cited disadvantages from survey responses” (page 1).

Chapter 3 presents key parameters that influence the selection of contracting methods and their impact on project duration, cost and quality.

**Technical Committee on Project Management**, AASHTO Subcommittee on Project Management, undated.

<http://design.transportation.org/Pages/Technical-Committee-on-Project-Management.aspx>

From the web site:

The Technical Committee on Project Management (TCPM) will proactively work within the AASHTO organization to provide member agencies and others with timely, accurate, and forward-looking guidance in the area of project management. This guidance will be focused on managing the development and delivery of quality projects within scope, schedule and budget which provide the best value to the public whom these agencies serve.

## Financing

**Effective Delivery of Small-Scale Federal-Aid Projects**, NCHRP Synthesis 414, 2011.

<http://www.trb.org/Publications/Blurbs/165335.aspx>

From the preface:

This report compiles and documents streamlined methods for meeting federal funding requirements for small-scale highway projects. A primary objective of this study is to explore ways that state departments of transportation (DOTs) work with local agencies to implement small projects eligible for federal funding. For this study, small-scale is defined as projects administered by state or local transportation agencies that contain federal funding of \$300,000 or less.

Information used in this study was acquired through a review of the literature, a survey of local program agency administrators in each of ten focus state DOTs, and interviews with representatives from several agencies and organizations involved at various levels with the locally administered federal-aid process.

See page 38 of the report for cost requirements for small-scale federal-aid programs. The document does not provide tools for cost estimation or cost management, but mentions the Illinois online HSIP application tool for benefit-to-cost analyses (page 15).

## Staffing

**Forecasting Highway Construction Staffing Requirements**, NCHRP Synthesis 450, 2013.  
<http://www.trb.org/Publications/Blurbs/169458.aspx>

From the summary:

The focus of this synthesis is on identifying factors influencing construction staffing levels required for highway construction and what systems are currently being used to forecast highway construction project staff. The synthesis was carried out using a combination of an on-line survey distributed to the 50 STAs [state transportation agencies], a review of existing tools and methods to forecast construction in use at these agencies, and site visits with non-state transportation agency transportation organizations (such as municipal planning authorities) to collect data on construction staffing.

Chapter 4 covers forecasting methods from various states, summarized on page 30:

Relatively few STAs reported having a formal system for estimating construction staffing requirements for future projects. The formal construction staff forecasting systems in use at the responding STAs represent a diverse set of approaches. Systems in North Dakota and North Carolina are relatively simple systems that rely on using recommended staffing levels for different generic project types. Systems in use in Michigan, Utah, and Texas are more complex and make extensive use of project data available through the STAs' electronic project databases. The approaches also varied in terms of how staff needs were estimated; some used recommended staffing levels based on a project type (North Dakota and North Carolina), some used historical data to develop regression analyses to estimate staffing needs (Texas), whereas others used a historic percentage estimate of staffing costs based on total project costs that could then be converted into staffing estimates.

Of the non-STA agencies visited, SANDAG (San Diego Association of Governments) is most like many transportation agencies in that an ad hoc approach is used to determine construction staffing requirements. Los Angeles Metro, San Francisco MTA, and BART are very similar. Limited in-house staff is utilized and the great majority of construction management oversight services are provided by external consultants. This allows the agencies to maintain minimal employment levels that are supplemented by consultants as needed.

Pages 31-33 provide conclusions on general STA staffing forecasting trends and common characteristics of the forecasting systems.

**Project Delivery Workforce Management Review**, R.C. Johns, G. Baas and T. Helms, Jr., NCHRP Project 20-07, AASHTO Standing Committee on Highways, 2007.

Project description at <http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=1221>

Final report at [http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/20-07\(205\)\\_FR.pdf](http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/20-07(205)_FR.pdf)

Workshop documents at [http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/20-](http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/20-07(205)_FR_AppD.pdf)

[07\(205\)\\_FR\\_AppD.pdf](http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/20-07(205)_FR_AppD.pdf)

From the abstract:

This report presents the results of a study of challenges and best practices in outsourcing and workforce management for state departments of transportation.

A series of workshops with DOTs led to the following best practices for workforce management:

- Starting the college recruiting process during the fall semester.
- Offering flexible internships.
- Promoting public sector work as a lifestyle job.
- Offering educational incentives.
- Implementing formal mentoring programs.
- Encouraging certification programs.
- Utilizing signing bonuses spread over a period of time.
- Offering referral bonuses.
- Allowing overtime pay.
- Setting group performance measures.
- Rotating staff through positions.

## Other

**AASHTO 2014-2019 Strategic Plan Update**, Draft V2, AASHTO Strategic Plan Update Committee, 2014.

[http://sp.www.transportation.org/Documents/NCHRP%202024B\\_94\\_AASHTO\\_StratPlan\\_update\\_draft\\_2014-11-11.pdf](http://sp.www.transportation.org/Documents/NCHRP%202024B_94_AASHTO_StratPlan_update_draft_2014-11-11.pdf)

This plan does not contain any information about cost estimation and management.

## Caltrans Publications

**FY 2015-16 Fourth Quarter Project Delivery Report**, University of California, Davis, October 2016.

[http://www.dot.ca.gov/hq/transprog/ctcliaison/2016/1016/065\\_2bRevised\\_PPt.pdf](http://www.dot.ca.gov/hq/transprog/ctcliaison/2016/1016/065_2bRevised_PPt.pdf)

See Appendix D.

This Caltrans presentation includes several slides on cost estimating, including slide 42, which shows the components of cost estimation:

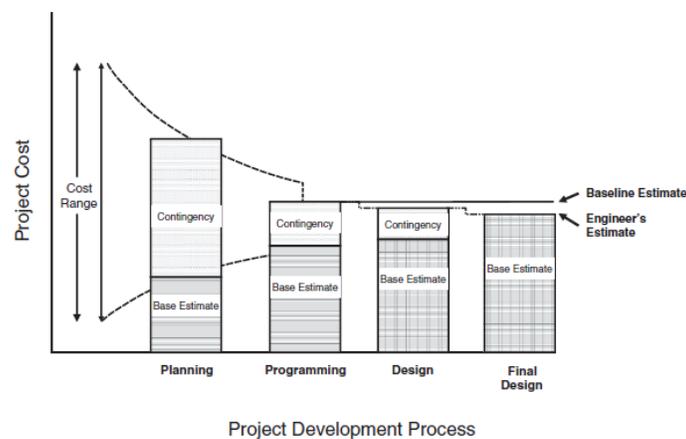


Figure 3.5. Refinement of a cost estimate with engineer's estimate less than baseline cost estimate.

The following best practices are listed on slide 45:

- Always include contingency.
- Avoid making numbers fit a budget.
- Communicate team assumptions.
- Avoid using only high-level breakdowns.
- Double check for commonly overlooked activities.
- Include the accuracy of the estimate.
- Don't forget risks.

Slide 46 attributes the causes of bad estimates to uncertainties, pressure to underestimate and unknown scope. Slide 47 includes the following tips for success:

- Treat each phase of the project life cycle as a separate project when there is significant uncertainty in product scope.
- Develop a WBS structure that is as complete as possible at the start of the project or phase and then update it regularly throughout the project.
- Develop range estimates of effort, cost, and duration for every WBS item.
- Have cost and schedule baselines that include an allowance for risk.

Slide 48 details new ideas to improve estimating:

- Phased programming for project types where scope is fluctuating.
- Risk based estimates—Incorporating risk management and contingencies (known unknowns—[to] rework or to address unclear scope due to lack of project information).
- Creating a management reserve so projects don't need to account for unknown unknowns. Reduces the need for padding.
- Communicate assumptions or risks.
- PERT [program evaluation and review techniques] estimating instead of individual point estimating.
- Leverage capital cost estimating best practices like standard contingencies.
- Independent review of cost estimates.
- Develop expert cost estimating units.
- Estimate in ranges and probability rather than point estimates (e.g., Crystal Ball for structures capital cost).
- Develop estimating tools for functional units.

**Cost Management—Discussion of Initial Project Costs versus Final Approved Project Costs**, University of California, Davis, undated.

See Appendix E.

This document discusses reasons for changes in scope for Caltrans projects, including 1) known risks (such as permitting problems or utilities conflicts); 2) limited resources for preparing project initiation documents, which involve estimating key cost components in ways

that make assumptions about risks; 3) programming with minimal public input; and 4) changing capital costs, which make it difficult to predict both capital and planning costs. The document concludes (page 2):

A lot of judgment is used in planning project costs. Caltrans must consider risks, consider the potential for unknowns, consider the extent of the effort that went into the PID [Project Initiation Document] estimate used to program costs, and then apply escalation factors (capital and support) to determine a number to be used for programming and securing a commitment of programmed funds.

**Estimating**, Caltrans presentation, undated.

See Appendix F.

This presentation compiles information and charts from various sources on cost estimation, including NCHRP Report 574 and the AASHTO Practical Guide to Cost Estimating.

**State DOT Survey WBS & Workload Norms for Project Delivery**, California Department of Transportation, 2016.

See Appendix G.

According to this survey of DOTs, a “majority of the State DOTs use either Parametric method (i.e., historical data, project type, project size, complexity, etc.) or Analogues method (i.e., expert judgment, previous similar project, etc.) to estimate staffing hours/cost” (page 2).

Page 5 includes information about resource cost estimating tools and techniques:

- Analogous estimating: Expert judgment based on actual costs of previous or similar projects, used in early phases when information is limited. Risk: Estimates may overlook unique differences between projects.
- Parametric modeling: Use of project parameters, such as cost and project type, in a mathematical model. Relies on accurate historical information, quantifiable parameters and a scalable model. Risk: Historical data may not be reliable.
- Bottom-up estimating: Estimates of the cost of individual work items summarized to get the total cost. Accuracy increases as work items get smaller. Risk: Cost may increase due to contingencies. To avoid this risk, use PERT estimating.
- Computerized tools.
- Program evaluation and review technique (PERT): A weighted average cost estimate used for each work package based on an optimistic, pessimistic and most likely estimate.

See pages 6-71 for cost estimating methods and documentation from other states.

**Fund Management and the SHOPP**, University of California, Davis, 2016.

See Appendix H.

This two-page document includes background information about SHOPP. From page 1:

- The reduction in Project Initiation Documents (PID) resources over the last half dozen years or so has resulted in less effort being spent on determining the scope, schedule and cost of a project and has transferred more risk into Capital Outlay Support Program.
- The number of projects experiencing changes is increasing due to these risks. One area that has seen this impact is project delays. The six year average of projects being

delayed is \$490 million/year. Over the last four years the average has increased to \$600 million/year.

- The Department is also seeing bid savings on the order of +/- 20% from the programmed amount or approximately *\$400 million/year* at construction award. There are additional savings realized at the time of construction completion.
- The Department has seen recent savings in pre-construction support activities on 2014-15 RTL [Ready to List] projects of 11% and for CCA [construction contract acceptance] projects of 25% (*verifying*).
- The Department continues to manage projects within G12 authority and needs supplemental monies for construction only three percent of the time. This is a 97% success rate.
- Cost savings and delays have put the Department at risk of using all available resources over the last several years.
- There have been and will be some large supplemental requests for additional money in construction tied to [a] handful of very large projects.

Further: “To address these challenges the Department initiated teams to look into improving PIDs, project delays, estimating and contingencies” (page 1). To address cost changes in particular, a “longer term strategy would be to move to a multi-staged programming so that risks can be more effectively managed and reduce the impacts to time, cost and scope” (page 2).

#### **Support to Capital Ratios for CCA Projects**, Rich Williams, 2016.

See Appendix I.

This spreadsheet details SHOPP construction costs by fiscal year and other criteria.

#### **PDT, Project Estimating and Risk Management**, University of California, Davis, 2015.

See Appendix J.

This document includes a bulleted list of ideas for managing risk, including:

- Handing off the risk management register to the Division of Construction.
- Improving the handoff of the risk register from the project manager to the construction engineer.
- Tracking risks over time and documenting supplementals.
- Involving the right team members in identifying project risks.
- Tying risks into the cost estimate so that the risk register has meaning.
- Using the FHWA Sharp tool to help manage utility risks.
- Bringing the risk management plan to executive team meetings.
- Conducting peer reviews of the risk register.
- Using experts to help develop the risk register.

#### **Project Financing Challenges**, University of California, Davis, 2015.

See Appendix K.

This document is a bulleted list of project financing challenges, including support cost increases of 17 percent, inconsistent practice on support escalation, and normal scope/cost/schedule changes.

**Productivity Summary**, University of California, Davis, 2015.

See Appendix L.

This study developed a framework for measuring changes in productivity over time. Researchers suggest replacing the capital outlay support (COS)/capital outlay (CO) ratio typically relied on by Caltrans with a labor productivity indicator. According to the report, the COS/CO ratio of support to capital does not reflect agency productivity or efficiency.

**SHOPP Sustainability Project Delays Team**, Final Report, Rich Williams, July 2015.

See Appendix M.

A Caltrans team evaluated a number of issues related to SHOPP project delays. One of the findings of the team's evaluation was that about 23 percent of SHOPP projects and 18 percent of SHOPP construction capital dollars are delayed one or more fiscal years before the contract for delivery is signed. The team identified several causes related to these issues, including understaffing in the Division of Environmental Analysis, workload underestimation and unrealistic schedules. The report includes recommendations for resolving these issues, including using risk management to identify critical path items and significant delivery risks, and to build contingencies into the project schedule.

## **Related Research**

### **Research in Progress**

**Enhanced Cost Estimating and Project Development Procedures for MPOs**, Texas

Department of Transportation, expected completion date: August 2017.

Project description at <http://trid.trb.org/view/1455574>

From the abstract:

One of the major challenges for Metropolitan Planning Organizations (MPOs) is that their transportation plans can be readily undermined by unrealistic preliminary cost estimates and unachievable project letting dates. This can lead to significant negative repercussions, including delays or cancellations of anticipated improvements, and even cascading effects on the viability of other planned development. To address this problem, this research will deliver a new procedural guidebook and software tool that will enhance the accuracy of Texas MPO's cost estimates and project scheduling. The guidebook will be based on a rigorous analysis of best practices in MPOs and Departments of Transportation (DOTs) from across the nation that have a proven record of success in meeting target costs and letting dates. It will be vetted through multiple levels of analysis and expert review. Meanwhile, the related software tool developed in this project will allow MPOs to validate their cost estimates and scheduling on an ongoing basis, making use of statistical techniques and rigorous empirical data to provide an updated probabilistic range for cost and scheduling outcomes. These tools will allow MPOs to increase their confidence in their budgeting and scheduling, and will ultimately result in greater transportation benefits for the public at a lower cost.

## Cost Estimation and Management

**Bridge Design Effort and Cost Estimation Models—Phase I**, Iowa Department of Transportation, 2017.

Citation at <http://trid.trb.org/view/1445570>

From the abstract:

The estimation of design efforts and costs plays a vital role in authorizing funds and controlling the budget during the project development process. Typically, the design phase consists of various engineering activities that require substantial efforts to deliver the final construction documents for bid preparation. Estimating these efforts accurately and efficiently is critical for transportation agencies in properly allocating funds, time, and resources. Previous studies have reported several problems associated with the estimation of design efforts, such as lack of predictive tools, inaccurate forecasts, and misallocation of efforts. Therefore, there is a need for a proactive scheme to more accurately and reliably estimate design efforts and costs in order to help the design office negotiate more confidently with consulting firms and, ultimately, to enhance the accountability and transparency of funding decisions. In this Phase I study, a master database was first developed that included various attributes of historical pretensioned, prestressed concrete beam (PPCB) bridge design projects completed by consultants. The master database was used to develop PPCB design effort and cost estimation models using multivariate linear regression and artificial neural networks. The prediction models were then tested to evaluate their predictive power by using the mean average percentage error. A case-based reasoning tool was developed to make logical inferences when estimating the design efforts and costs of a new PPCB project. The case-based reasoning approach uses the concept of similarity scores to retrieve the records of the most similar historical bridge design projects. Additionally, a spreadsheet tool was developed to automate the retrieval process. In addition to using the regression models and neural network models developed in this study, users can make reasonable judgements about the required efforts and costs of a new PPCB bridge design project by reviewing historically similar projects.

**“Estimating Annual Maintenance Expenditures for Infrastructure: Artificial Neural Network Approach,”** Wubeshet Woldemariam, Jackeline Murillo-Hoyos and Samuel Labl, *Journal of Infrastructure Systems*, Vol. 22, No. 2, 2016.

Citation at <http://trid.trb.org/view/1378039>

From the abstract:

This paper presents an artificial neural network (ANN) approach for purposes of estimating annual expenditures on infrastructure maintenance and demonstrates the application of the approach using a case study involving rural interstate highway pavements. The results of this exploratory study demonstrate that not only is it feasible to use ANN to derive reliable predictions of annual maintenance expenditures (AMEX) at aggregate level, but also it is possible to identify the influential factors of such expenditures and to quantify the sensitivity of AMEX to such factors.

**Assessing the Costs Attributed to Project Delay During Project Pre-Construction Stages**, Texas Department of Transportation, 2016.

<https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6806-FY15-WR3.pdf>

From the abstract:

This project for the Texas Department of Transportation (TxDOT) developed a simple but sound methodology for estimating the cost of delaying most types of highway projects. Researchers considered the cost of delays during the pre-construction phases of project

development: planning and scoping, preliminary engineering, final design, and letting. Researchers developed a simplified model that incorporates 16 user-controlled variables and produces estimates of the effect of project delay on personal and commercial travel and the cost to the general economy. While the methodology is simple, there is no rule of thumb because project delay costs depend on several variables, primarily location, traffic, construction costs, and travel speeds.

**“Impact of Correlation on Cost-Risk Analysis for Construction Highway Projects,”** Dai Tran and Sai Bypaneni, *Construction Research Congress 2016*, 2016.

Citation at <http://trid.trb.org/view/1408941>

From the abstract:

Major construction projects are often constructed by dividing the project into smaller, more manageable segments. Managing these projects is a complex task due to risk and uncertainty. Many studies have proposed risk analysis frameworks to analyze the impact of risk on project outcomes. However, a limited study has addressed the effect of considering correlations on the cost-risk analysis frameworks. Capturing correlation between variables during the risk analysis process is an important, but a challenging task. This paper examines the impact of correlation between project phases/segments on total project cost. The Federal Highway Administrative cost-risk analysis framework was investigated. The correlation coefficient assessment was determined based on a comprehensive review of literature and several risk management frameworks used in transportation and transit sectors. The paper includes a case example that discusses the impact of correlation on the total project cost uncertainty in detail. The findings from this paper contribute to a construction risk analysis and management domain by showing the effect of considering correlation on the cost-risk analysis process. The results from this paper also help the highway industry to better manage their projects by performing a more accurate risk cost estimate.

**“Recommended Practices for the Cost Control of Highway Project Development,”** Minsoo Baek, Kia Mostaan and Baabak Ashuri, *Construction Research Congress 2016*, 2016.

Citation at <http://trid.trb.org/view/1408948>

From the abstract:

Cost escalation is a critical issue that state departments of transportation (DOTs) face throughout project development from concept to completion. A variety of issues and risks impact budgeting and cost management and control activities, which affect adherence to approved project budgets. State DOTs need to utilize effective practices to avoid constant budget adjustments due to cost overruns. The objective of this study is to identify and analyze effective practices for controlling, updating, and maintaining the baseline budget and schedule for highway projects. Through comprehensive interviews with several state DOTs and an extensive content analysis of their guidebooks and manuals, we identify and analyze several effective practices, including those related to budget-based project development for controlling potential costs in the following areas of opportunity: (1) project scope and concept development; (2) concept-level risk identification and assessment; (3) preliminary and final design summary reporting; (4) value engineering and alternative analysis; and (5) cost estimate validation and review. Results of the analysis show that state DOTs struggle with identifying risk factors early in project development and mitigating them during preliminary and final design. The findings can help state DOTs improve their existing practices for highway project budgeting and cost management so that they can maintain initial baseline budgets and schedules while minimizing changes made to them during the project development process.

**Pre-Contract Project Scoping Processes: Synthesis of Practices**, Indiana Department of Transportation, 2016.

<https://ntl.bts.gov/lib/60000/60500/60531/viewcontent.cgi1.pdf>

From the abstract:

Scoping is the process of developing a project's objectives, need, preliminary cost estimate, and preliminary schedule based on a recognized need that the project is intended to address. This study (INDOT/JTRP SPR-3944) was launched by the Indiana Department of Transportation (INDOT)/Joint Transportation Research Program (JTRP) to develop a synthesis of scoping processes in different State Highway Agencies (SHAs). The study was conducted using a qualitative exploratory approach focusing on the review of project scoping practices across different SHAs. Focused interviews with personnel from SHAs along with the review of documents gathered during the literature search and resources provided by SHAs were the avenues used for data collection in the study. The study focused on eleven themes for the assessment of project scoping procedures: (1) primary entity with responsibility for scoping projects, (2) timeline for scoping activities, (3) functional groups within the SHA involved in scoping, (4) cost estimation procedures, (5) application of Context Sensitive Solutions (CSS), (6) addressing maintenance needs, (7) methods of assessing scope creep, (8) tracking the quality and effectiveness of scoping processes, (9) environmental consideration in scoping processes, (10) data collection and data sharing, and (11) scoping practices which have evolved/benefited the SHA. The report presents key findings of the study and provides suggestions for further investigation by INDOT.

**Top-Down Construction Cost Estimating Model/Guide Using a Neural Network Within an Off-the-Shelf Spreadsheet and Database Programs**, Montana Department of Transportation, 2014.

[https://www.mdt.mt.gov/other/webdata/external/research/DOCS/RESEARCH\\_PROJ/top-down\\_cost\\_estimating/PROPOSAL.PDF](https://www.mdt.mt.gov/other/webdata/external/research/DOCS/RESEARCH_PROJ/top-down_cost_estimating/PROPOSAL.PDF)

From the problem statement:

This research seeks to leverage the work completed in (NCHRP 15-51: Guide for Estimating Preconstruction Services Costs, by extending the parametric models developed for preliminary engineering, right of way, etc. to the estimating of construction project cost at the earliest stages of project planning and development. It will deliver a top-down cost estimating model that uses "stock" spreadsheet and database software without the need to purchase special software or hardware (i.e. MS Office products only).

**"Cost and Scope Breakdown Structure for Functional Level Estimating of Consultant Fees,"** Emily Craigie, Douglas Gransberg and David Jeong, *Transportation Research Record* 2573, pages 157-163, 2016.

Citation at <http://trid.trb.org/view/1392426>

From the abstract:

Estimating the cost of preconstruction services (PCSs) during the early phases of highway project development is an important task requiring an increased level of attention. Research has found a link between early investment in PC planning and design services and final project costs. The purpose of this paper is to assess current estimating practices and propose a cost and scope breakdown structure (CSBS) framework to structure functional level estimation of consultant fees. Such a framework is promoted to reduce the chance that underfunded PCSs may degrade postaward construction contract cost certainty. This study found that PCSs were generally viewed as a minor component of a project's budget and were sometimes estimated without subsequent preconstruction cost control or accountability. Current practices for consultant fee estimating by state departments of

transportation (DOTs) documented in this study show little standardization in estimating practices across and within transportation agencies. As a consequence, many individuals are creating their own tools to develop PCS cost estimates. The result is that national and regional consultants that work in more than a single state are forced to expend additional effort to maintain agency-specific work task databases; the cost no doubt is passed back to the agency in increased overhead costs. This study found that application of a CSBS to classify specific work tasks and utilization of a database of previous project cost information promote consistency and aid contract negotiations with consultants.

**“Conceptual Cost-Prediction Model for Public Road Planning via Rough Set Theory and Case-Based Reasoning,”** Seokjin Choi, Du Kim, Seung Han and Young Hoon Kwak, *Journal of Construction Engineering and Management*, Vol. 140, No. 1, 2014.

Citation at <http://trid.trb.org/view/1280858>

From the abstract:

Long-term transportation policies require government officials to predict the cost of public road construction during the conceptual planning phase. However, early cost prediction is often inaccurate because public officials are not familiar with cost engineering practices, and moreover, have limited time and insufficient information for estimating the possible range of the cost distribution. This study develops a conceptual cost prediction model by combining rough set theory, case-based reasoning, and genetic algorithms to better predict costs in the conceptual planning phase. Rough set theory and qualitative in-depth interviews are integrated to select the proper input attributes for the cost prediction model. Case-based reasoning is then applied to predict road construction costs by considering users' difficulties in the conceptual policy planning phase. A genetic algorithm is also used to assist the rough set model and case-based reasoning model to obtain optimal solutions. The result of the analysis shows that the proposed conceptual cost prediction model is reliable and robust compared to the existing cost prediction model.

**“Synthesis of Performance Measures for Highway Cost Estimating,”** Christofer Harper, Keith Molenaar, Stuart Anderson and Cliff Schexnayder, *Journal of Management in Engineering*, Vol. 30, No. 3, 2014.

Citation at <http://trid.trb.org/view/1298711>

From the abstract:

The use of performance measures for evaluating projects or agencies as a whole is not a new idea. Performance measures have been in use for many years in the private and public highway construction sectors for a variety of areas and tasks. The American Recovery and Reinvestment Act of 2009 (ARRA) and federal transportation funding are now requiring state highway agencies to develop and document performance measures throughout their agency operations. However, few highway agencies use performance measures for cost estimating. This study synthesizes, categorizes, and validates existing performance measures for cost estimating of highway projects to assist with improving estimating accuracy. It provides a foundation for the development and use of new performance measures that agencies can share and use to improve estimating procedures. Performance measures for estimating were developed through an extensive literature review and content analysis to synthesize measures specifically for cost estimating in addition to categorizing the cost-estimating performance measures. These categories and performance measures were then validated with a questionnaire and interviews of selected state highway agency estimating experts. The main categories for these performance measures are bidding accuracy, estimating accuracy, competition effects, estimating processes, and contingency amounts. The results

then provide a comprehensive list of valid performance measures for cost estimating in use today by highway agencies and a foundation for developing future measures.

**“Preliminary Engineering Cost-Estimation Strategy Assessment for Roadway Projects,”**

Min Liu, William Rasdorf, Joseph Hummer, Donna Hollar and Shalin Parikhj, *Journal of Management in Engineering*, Vol. 29, No. 2, pages 150-157, 2013.

Citation at <http://trid.trb.org/view/1246388>

From the abstract:

Preliminary engineering (PE) for a roadway project encompasses two efforts: planning to minimize the physical, social, and human environmental impacts of projects and engineering design to deliver the best alternative. State transportation agencies strive to manage these efforts efficiently, seeking to maximize the utilization of limited funding and workforce productivity. Managers need a feasible PE budget, considering both cost and time, early in project development. The results reported herein will provide engineers and managers with a comparative investigation evaluating different strategies for establishing a PE budget during the preconstruction phase of roadway project development. Cost data were obtained for 188 North Carolina roadway projects built between 1999 and 2009. An analysis of the North Carolina DOT data yielded an overall mean ratio of PE cost to estimated construction cost (the PE cost ratio) of 11.7%. The multiple linear regression model was used to develop prediction models to forecast the PE cost ratio of future roadway projects. It was found that while differing regression strategies could reduce prediction error, the improvement was small. In terms of simplicity, using the historical means applicable for widening projects (13.3%), rehabilitation/resurfacing projects (7.7%), and new location/interchange projects (16.5%) proved advantageous over regression modeling because a project manager would not have to estimate any project-specific values at the earliest stages of project development. The lowest of these historical means was significantly different than the two higher means (7.7% versus 13.3% and 16.5%); however, the difference between the two higher means (13.3% versus 16.5%) was not statistically significant. The study analyses also found a significant correlation between a project's PE cost ratio and its PE duration, suggesting that further investigation into PE duration of transportation projects is warranted.

**“Developing Cost Estimation Models for Road Rehabilitation and Reconstruction,”** Jelena Cirilovic, Nevena Vajdic, Goran Mladenovic and Cesar Queiroz, *TRB 92nd Annual Meeting Compendium of Papers*, Paper #13-2037, 2013.

Citation at <http://trid.trb.org/view/1241293>

From the abstract:

The average unit costs of road works vary substantially between countries, and even between projects in the same country, due to a number of factors. In this paper an effort is made to develop prediction models for the unit costs of road works that could be applied for a wide range of conditions in different countries. A specialized dataset was used, which was generated under a World Bank study that included road works contracts from 14 countries in Europe and Central Asia (ECA). Two techniques were used for model development: multiple regression analysis and artificial neural networks. As the major problem found with the data set was missing or incomplete data, classification trees were used as an intermediate step to evaluate the correctness of the selected parameters. Three models were developed using regression analysis, two for the unit cost of asphalt concrete and one for the cost per km of rehabilitation and reconstruction works. The models include as independent variables the price of diesel fuel, country Gross National Income, World Governance Index, Transparency International Corruption Perception Index, percent of local bidders participating in the tender, and climate conditions. The analysis using classification trees confirmed the

appropriateness of the variables selected in the regression analysis. The models developed using artificial neural networks were superior compared to the regression models, using mostly the same parameters. The resulting models could be particularly useful at the strategic level, for planning and optimization of works on road networks in ECA countries.

**“Development of Estimating Tool for Transportation Project Design,”** Trefor Williams, Neville Parker and James Klotz, *TRB 92nd Annual Meeting Compendium of Papers*, Paper #13-2111, 2013.

Citation at <http://trid.trb.org/view/1241332>

From the abstract:

The development of an estimating tool to assist New York State Department of Transportation (NYSDOT) managers is described. The tool was developed using Microsoft Access. It enables managers to input project characteristics and then search a data base of historical projects. The estimating tool returns the staffing levels for similar completed projects. The system was also developed to allow newly completed projects to be added to the data base and to allow for the monitoring of design hours expended for projects that are in progress. Regression analysis was also explored as a means of predicting total project design hours. With the assistance of NYSDOT experts important factors that influence required design hours were identified. Estimating tool users can make a regression prediction for the total project hours using historical projects as input data.

**Cost Estimate Modeling of Transportation Management Plans for Highway Projects,** California Department of Transportation, 2012.

Citation at <http://trid.trb.org/view/1139721>

From the abstract:

Using well-developed Transportation Management Plan (TMP) strategies, work zone safety and mobility can be enhanced while road user costs can be minimized. No tools or systematic modeling methods are available to assist agency engineers with TMP cost estimating. This research included reviewing TMP reports for recent California Department of Transportation (Caltrans) projects regarding state-of-the-art TMP practices and input from the district TMP traffic engineers. The researchers collected Caltrans highway project data regarding TMP cost estimating. Then, using Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) software, the researchers performed case studies. Based on the CA4PRS outcomes of the case studies, a TMP strategy selection and cost estimate (STELCE) model for Caltrans highway projects was proposed. To validate the proposed model, the research demonstrated an application for selecting TMP strategies and estimating TMP costs. Regarding the model's limitation, the proposed TMP STELCE model was developed based on Caltrans TMP practices and strategies. Therefore, other STAs might require adjustments and modifications, reflecting their TMP processes, before adopting this model. A more detailed step-by-step TMP strategy selection and cost estimate process should be included in the TMP guidelines to improve the accuracy of TMP cost estimates.

**“New Approach to Developing Conceptual Cost Estimates for Highway Projects,”** Mounir El Asmar, Awad Hanna and Gary Whited, *Journal of Construction Engineering and Management*, Vol. 137, No. 11, pages 942-949, 2011.

Citation at <http://trid.trb.org/view/1124747>

From the abstract:

Developing a reliable project cost estimate is a challenge for any state highway agency (SHA), especially at the conceptual stage. A conceptual estimate is defined in this paper as

the estimate prepared at the point at which only 30% of the design is complete. This paper describes a statistical approach to producing a reliable conceptual cost estimate when few project design details have been finalized and many assumptions still form the basis of the estimate. This approach used an analysis similar to the program evaluation and review technique (PERT), which is more commonly used in project scheduling, to assign certainty factors to cost estimates. The approach uses a combination of historical bid data for major roadway items whose quantities can be estimated early in the development process and historical percentages for other major components of the project, called allowance and contingency factors. The paper focuses on (1) the methodology developed to analyze the historical bid data; (2) the analysis of 14 highway corridors with 77 projects whose as-bid construction costs were more than \$830 million; and (3) a cross-validation of the approach used to validate the accuracy of the predictive model. By using a PERT-type technique, construction costs were accurately predicted at the conceptual stage within  $\pm 20\%$ . However, approximately 85% of the corridor costs were accurately predicted within  $\pm 15\%$  of the actual cost. The proposed methodology provides a structured and consistent estimating approach that can be used by any SHA that needs to develop total project delivery estimates at the conceptual design stage.

**“Planning-Level Cost Estimation Georgia DOT's Innovative Processes and Procedures,”**  
Jeff Carroll and Dave Cox, *TRB 89th Annual Meeting Compendium of Papers DVD*, Paper #10-1109, 2010.

Citation at <http://trid.trb.org/view/909788>

From the abstract:

The current funding environment creates a critical need to ensure that project cost estimates are as accurate as possible. Thus, cost escalation has become a major concern in virtually every field of capital project development. On top of regular inflation, the volatility of the global oil market is tied directly to most construction related items (primarily asphalt), thereby causing shifts in cost by the rising and falling oil prices. Within the transportation sector, cost escalation has attracted attention at the federal, state, regional, and local government levels for highways, transit, and other modes. In the past five years, Georgia Department of Transportation (GDOT) has experienced significant cost overruns both at the engineering, right-of-way, utility relocation and construction project stages. Due to these overruns, the Department proactively developed new processes and procedures to assist estimating project costs at the planning-level. Reliable planning level project cost estimation is essential for successful project delivery. Since project costs are first estimated at the planning level, this initial estimate must be based on a sound process to ensure a reliable estimate is developed for decision-makers. The dependability of sound preliminary engineering, right-of-way, utility relocation, and construction planning level cost estimates is a major component in the development of a transportation program. If planning level projects costs are not adequately estimated at the planning stage, projects most likely will be delayed or even cancelled once a final cost is developed. The Georgia Department of Transportation Office of Planning and Wilbur Smith Associates led a team that developed a new planning level cost estimation process that created new tools, and processes and procedures that are outlined in a 266-page Cost Estimation Handbook. This innovative project was initiated by GDOT Office of Planning to ensure accurate planning level cost estimates are completed early in the project planning process and to provide decision-makers reliable information to prioritize and develop sound transportation programs. This ground breaking project can assist other state DOTs and metropolitan planning organizations (MPOs) to develop practices that will improve their planning level cost estimation process and stabilize their transportation programs.

## Risk Management

**“Risk-Based Estimating Practices: A Case Study of Minnesota Department of Transportation,”** Ghada Gad, Jennifer Shane and Kelly Strong, *TRB 95th Annual Meeting Compendium of Papers*, Paper #16-4809, 2016.

Citation at <http://trid.trb.org/view/1393793>

From the abstract:

Accurate project cost estimates set internal and external expectations for project funding, prioritization, and cash flow requirements. Inability of transportation agencies to accurately estimate project costs may lead to delays and lack of confidence in the agency’s ability to realize its commitments. There are a plethora of tools and manuals available for transportation agencies to aid in the estimation process while incorporating risks and uncertainties. The objective of this study is to investigate how risk-based estimating is implemented in Minnesota Department of Transportation’s (MnDOT’s) different offices at projects that are approximately at 30% design complete, and provide recommendations on how various efforts could be streamlined to improve the cost estimating process department wide. The methodology of this research included conducting (1) a literature review of DOTs in terms of Risk-Based Estimating (RBE) implementation, (2) interviews with DOT personnel from 5 different offices statewide, and (3) a workshop with DOT personnel to share results and recommendations. Three major recommendations emerged from this study; (1) develop a state wide risk register and use state wide, (2) exchange of knowledge on Monte Carlo simulation use and its benefits, and (3) enhance communication through a yearly estimation state forum. Other than the specific recommendations, the major conclusion that can be drawn is that though there are federal and state guidebooks and technologies available for incorporating risk management process in the estimating process, there is lack of a consistent framework for risk management implementation within the department offices which results in lost learning opportunities for state district offices.

**“Improving Early Phase Cost Estimation and Risk Assessment: A Department of Transportation Case Study,”** Sharareh Kermanshachi, Curtis Beaty and Stuart Anderson, *TRB 95th Annual Meeting Compendium of Papers*, Paper #16-2202, 2016.

Citation at <http://trid.trb.org/view/1392818>

From the abstract:

Early cost estimation, especially cost escalation, has become a major challenge for State Highway Agencies (SHAs). Cost overruns reduce the accuracy level of the construction cost estimate and cause conflict between owners, project managers, and contractors. To address this problem, a case study department of transportation (DOT) was selected to evaluate and improve existing scoping, cost estimation and risk assessment processes. At first, this study identifies nationwide current best scoping, cost estimation and risk assessment practices during early stages of the project. Later, through a series of interviews with some of the case study DOT Districts, the current scoping, cost estimation and risk assessment practices implemented by this DOT staff were identified. The results were compared to those practices identified in national research documents and best practices at other DOTs. Further, a gap analysis comparing this SHA’s current practices to national ideal practices revealed the areas of possible further improvement as risk assessment, review and approval of estimates and estimate documentation. Through pilot studies on three projects from the case study Districts the effectiveness of the improvement recommendations were assessed. Based on the evaluation of the pilot studies many of the recommendations proved to have notable impact on the performance of the case study DOT’s project scope definition, cost estimates, and risk assessments. The final

recommendations are in five areas of cost estimating, documentation, risk assessment and contingency calculation, executive policy and general issues. Depending on the area of concern, recommendations have three levels of policies/practices, processes/tools, and resources.

**Risk-Based Engineers Estimate**, Minnesota Department of Transportation, 2015.

<http://www.dot.state.mn.us/research/TS/2015/201510.pdf>

From the abstract:

The review of any bid depends on the reliability of the estimate it is being compared to, making estimates an essential element in the project approval process. Thus, departments of transportation (DOT) should put great effort in the estimates' preparation as under-estimating can lead to project delays, while over-estimating leads to inefficient use of funds. Since delivering more lump sum projects is an Engineering Services Division strategic initiative in Minnesota Department of Transportation (MnDOT) and since lump sum items are often more difficult to price, it becomes important to develop an effective practice for consistent cost estimating. Risk-based estimating combines both risk management and traditional cost estimating to develop an estimate that includes the risk in the project's cost (Anderson et al. 2007). Risk-based estimating thus serves as an excellent estimating technique that generates reliable estimates. The objective of this research is to:

- Conduct [a] literature review of risk-based estimating.
- Conduct [a] state-of-practice review of risk-based estimating used by DOTs and other construction organizations.
- Based on the state-of-practice and literature review conducted, give recommendations on how these practices can be incorporated into MnDOT's business practice. The recommendations reached through this research are anticipated to help the MnDOT estimating team get a better understanding of risk-based estimating, and how it could be employed in the MnDOT estimation process.

**“Program Risk Management Approach to Reducing Cost Uncertainty in Highway Projects,”** Craig Wilson, Dan Tran and Keith Molenaar, *TRB 94th Annual Meeting Compendium of Papers*, Paper #15-5267, 2015.

Citation at <http://trid.trb.org/view/1339132>

From the abstract:

Project cost estimation can be a challenge in highway design and construction projects due to risks and uncertainties. The initial cost estimates can be prepared in the planning phase and then revised through the programming and design phases of project development. The accuracy of early estimates is often characterized by high levels of uncertainty. Cost overruns in highway design and construction projects are a major problem for state highway agencies. Risk and uncertainty are primary factors that influence cost escalation and schedule delays. Project risk management is a tool to manage cost and time overruns in highway projects. However, this approach considers a project within an organization as an independent component. Although highway projects are often interconnected with other projects or programs, a limited body of research and non-proprietary management tools exist to address the cost uncertainty in highway projects at the program level. This research presents an approach for program risk management and its application in highway design and construction projects. Monte Carlo-based risk models were developed to investigate the impacts of risks and uncertainties on cost estimating at both project and program levels. The model was developed based on a series of interviews with Washington State Department of

Transportation (WSDOT). The results of this study indicate that the use of program-based risk management can increase cost certainty and provide the ability to better allocate resources among multiple projects. The proposed approach was evaluated and verified by experienced professionals in WSDOT to determine its distinct advantages and disadvantages when compared to the traditional approach of project risk management.

**“Rational Method to Determine Design Cost Contingency for Consultant Designed Highway Construction Projects,”** Kate Hunter and Douglas Gransberg, *TRB 93rd Annual Meeting Compendium of Papers*, Paper #14-3967, 2014.

Citation at <http://trid.trb.org/view/1289126>

From the abstract:

The purpose of this paper is to propose a rational method for determining a design cost contingency. The contingency in design is to account for risks such as scope creep and lost design effort throughout the process. In design of transportation projects, the required function of a project is usually well-defined but the amount of time needed to complete the design is difficult to quantify. The proposed method to calculate design contingency can be used by an agency to augment its current method to estimate consultant design fees. This paper details a method for creating a design cost estimate accuracy index from historical budgeted and actual design fee data. The index can be used on future projects to determine an appropriate design contingency. The paper demonstrates the validity of the proposed method by example comparing the data from 26 actual projects from 9 different agencies with published design fee curves from the American Society of Civil Engineers and the Institute of Professional Engineering New Zealand, using linear regression. Since coefficients of determination ( $R^2$  values) exceeded 0.95, the paper concludes that the use of the design contingency will enhance the accuracy of design fee estimates.

**“Risk Based Cost Estimation of Capital Intensive Road Projects Using Monte-Carlo Simulation,”** M. Rao and H.V. Ranade, *International Public Works Conference*, 2013.

Citation at <http://trid.trb.org/view/1265351>

From the abstract:

This paper presents the application and validation of a new and innovative tool developed for accurate risk based estimation of project budgets. Typical capital intensive projects to which this tool can be applied include road reconstruction, road resheet and road rehabilitation projects. Quantitative risk analysis and stochastic modeling using Monte-Carlo Simulation is embedded in the algorithms of the computer code. The tool forecasts a range of possible project costs and the probability of the occurrence of those costs by taking into account uncertainties and associated risks. Application of the tool to capital intensive road projects designed by Harsha Ranade and constructed in 2011 & 2012 demonstrates the validity, usefulness and benefit of the proposed tool. Comparisons of forecasted estimates using this new tool with actual costs and with traditional deterministic methods of cost estimation (such as single-point base-case estimates inclusive of contingency) provide valuable insights that can aid management in evaluating alternatives and make informed decisions when estimating and allocating budgets to a portfolio of road projects.