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

Keith R. Molenaar, PhD
Cost Estimating and Cost Management Capacity Building Workshop

Minneapolis, MN
August 12, 2010
Agenda

• Guidebook Objective and Motivation
• Risk Analysis and Cost Management
• Guidebook Examples
• Guidebook Philosophy
• Conclusions
Objective

To develop a comprehensive guidebook on risk-related analysis tools and management practices for estimating and controlling transportation project costs
Background

Risk Strategy
Identify risks, quantify their impact on cost, and take actions to mitigate the impact of risks as the project scope is developed.
Research Context & Question

• Highway design and construction projects can be technically complex and fraught with uncertainty. Additionally, the technical complexities of transportation projects can be compounded by economic, societal, and political uncertainties.

• Why then do we use deterministic methods for cost estimating and management?
Published Project Risk Management Policy or Procedures
47 of 52 State Agencies

- Yes: 9%
- No: 91%
Published Definition for Contingency
48 of 52 State Agencies

Yes
19%

No
81%
Cost Estimate at Any Phase

Total Project Estimate = Base + Contingency

Risk-related analysis tools and management practices
Refinement of a Cost Estimate

Project Development Process

- Planning
- Scoping
- Design
- Letting

Cost Range

Project Cost

- Highest possible Total Project Cost Estimate
- Significant Risks Realized
- Few Risks Realized
- Lowest possible Total Project Cost Estimate
Refinement of a Cost Estimate
(w/Total Project Cost Estimate = Baseline Estimate)

Cost Range

Base Estimate
Contingency

Planning
Scoping
Design
Letting

Baseline Estimate & Total Project Cost Estimate

Project Development Process
Refinement of a Cost Estimate

(w/Total Project Cost Estimate < Baseline Estimate)
Risk Management Framework

Risk Management Process

- Identify
- Assess/Analyze
- Mitigate and Plan
- Allocate
- Monitor and Control

Scalable for Project Complexity
Adaptable to Project Development Phases
Risk Definitions and Tools

- Risk
- Risk Identification
- Risk Assessment and Analysis
- Risk Mitigation, Planning and Control
Risks Definition

- Risk – *An uncertain event or condition that, if it occurs, has a negative or positive effect on a project’s objectives.*
In a Nutshell: Risk Identification

Identification, categorization and documentation of comprehensive, non-overlapping set of:

- “risks” (potential problems)
- “opportunities” (potential improvements)

Events that might occur, which could change project cost or schedule
Risk Identification - Tools

- Brainstorming
- Expert interviews
- Delphi methods
- Red flag lists
- Risk checklists
Risk Identification - Checklists

DOE

ACEC/AGC

Caltrans

WSDOT

Washington State Department of Transportation
In a Nutshell: Risk Assessment and Analysis

Process of adequately describing, assessing and analyzing the risks

– Risk frequency
– Risk severity

Results in a set of ranked risks or quantified risks for inclusion in risk register
Risk Assessment and Analysis - Tools

• Qualitative Assessment Tools
  – Probability-Impact Matrices

• Quantitative Assessment Tools
  – Expected Value Methods
  – Three-Point Estimate Methods
  – Monte Carlo Simulation Methods
## ASSESSMENT GUIDE

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Consequence</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>B</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
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<tr>
<td>C</td>
<td>L</td>
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<td>L</td>
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<td>L</td>
<td>M</td>
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</table>

**Likelihood Level**
- A: Likely
- B: Unlikely
- C: Remote
- D: Highly Likely
- E: Near Certainty

**Consequence Level**
- Minimal or no impact
- Additional resources required; able to meet milestone
- Minor slip in key milestones; not able to meet need date
- Major slip in key milestone or critical path impacted
- Can’t achieve key team or major program milestone

**Risk Assessment**
- **High (Red)**: Unacceptable. Major disruption likely. Different approach required. Priority management attention required.
- **Moderate (Yellow)**: Some disruption. Different approach may be required. Additional management attention may be needed.
- **Low (Green)**: Minimum impact. Minimum oversight needed to ensure risk remains low.
Probability-Impact Tools

Definition of Impact and Probability Levels

<table>
<thead>
<tr>
<th>Probability Level</th>
<th>Cost ($)</th>
<th>Delay (days)</th>
<th>Probability (%)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>From</td>
<td>To</td>
<td>From</td>
</tr>
<tr>
<td>Very Low</td>
<td>0</td>
<td>1,000,000</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>1,000,000</td>
<td>10,000,000</td>
<td>20</td>
</tr>
<tr>
<td>Moderate</td>
<td>10,000,000</td>
<td>25,000,000</td>
<td>80</td>
</tr>
<tr>
<td>High</td>
<td>25,000,000</td>
<td>50,000,000</td>
<td>120</td>
</tr>
<tr>
<td>Very High</td>
<td>50,000,000</td>
<td>100,000,000</td>
<td>180</td>
</tr>
</tbody>
</table>
Three Point Estimate Tools

The average cost of the item is \( \frac{o+4m+p}{6} \)
Quantitative Assessment Tools

Mean (Expected) Value
Standard Deviation

Range in values

Probability Density Function (PDF)

Cumulative Distribution Function (CDF)

Percentiles
10th
90th
80% confidence interval

Correlation and Dependency

Relative Likelihood Contours
Monte Carlo Simulation Models

Start → Activity A → Activity B → Activity C → End

Histograms for cost and schedule.
Monte Carlo Simulation Models

80% of the values are equal or less than 5.2
Total Project Cost

- 90% chance < $590M
- 50% chance < $625M
- 10% chance < $475M

Histogram showing project cost (in million $) with individual and cumulative probability.
Ranking of Risks

Total Mean Cost Risk

C3. Labor shortage or material procurement issues during construction
S4.1. Other additional scope required - Bangerter
C1.2. Market conditions at time of bid
D25. Uncertainty in pavement design
C13. Additional overhead costs resulting from delays (pre-construction and construction)
D23. Designated as a lifeline facility
R2. Additional cost due to accelerating development within the proposed corridor

Identified Minor Risks (aggregate)

S1. Uncertainty in transit component
S2. Additional aesthetic treatment / elements required
S3. Additional mitigation required
S4.2. Other additional scope required - other

Unidentified Risks (aggregate)

D16. Uncertainty in required ground improvement (excluding surcharging)
D18. Uncertainty in required noise walls
D2. Change alignment near ATK
D15. Other uncertainty in earthwork
C4. Difficult ground conditions during construction
R4. Other issues acquiring ROW
D12. Cannot re-use as much material as assumed
D8.1. Uncertainty in TS&L for other bridge structures - additional bridges
U8. Mt. - water treatment plant
S4.2. Other additional scope required - other
R1. Relocate Elementary
D14. Uncertainty in embankment consolidation

Similar for Opportunities
In a Nutshell: Risk Mitigation and Planning

Assigning responsibility/ownership for risks
- Plan specific actions
- Provide resources/procedures
- Answer who, what, when and how?

Developing plans to address risks
- Maximize cost-effectiveness
- Understand/accept “residual” risk
Risk Mitigation and Planning - Tools

- Risk Register
- Risk Management Plan
- Risk Information System
### PROJECT RISK MANAGEMENT PLAN

<table>
<thead>
<tr>
<th>Priority</th>
<th>Status</th>
<th>ID #</th>
<th>Date Identified</th>
<th>Functional Assignment</th>
<th>Threat/Opportunity Event</th>
<th>SMART Column</th>
<th>Risk Trigger</th>
<th>Type</th>
<th>Probability</th>
<th>Impact</th>
<th>Risk Matrix</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Active</td>
<td>3c</td>
<td>8/7/2002</td>
<td>Environmental Analysis</td>
<td>Residents will want a higher soundwall than needed to mitigate noise.</td>
<td></td>
<td>Risk is occuring if the Revised Noise Study indicates the additional wall height is warranted.</td>
<td>Schedule</td>
<td>High</td>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>

#### Qualitative Analysis

- **Schedule**: High
- **Cost**: High

**Risk Matrix**

- **Probability**: High
- **Impact**: High

![EXAMPLE](image-url)
Risk Management Information System

<table>
<thead>
<tr>
<th>Type</th>
<th>ID</th>
<th>Title</th>
<th>Status</th>
<th>Prob Cost</th>
<th>Created</th>
<th>Last Update</th>
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<tr>
<td>CCO</td>
<td>56</td>
<td>NEW: Cost variance of new viaduct from current change order log/strategy status.</td>
<td>Active</td>
<td>$20,000,000</td>
<td>9/10/2007</td>
<td>9/17/2007</td>
</tr>
<tr>
<td>CCO</td>
<td>61</td>
<td>NEW: Cost variance of various administrative issues associated with the strategy memos from current change order log/strategy status.</td>
<td>Active</td>
<td>$15,000,000</td>
<td>9/10/2007</td>
<td>9/17/2007</td>
</tr>
<tr>
<td>CCO</td>
<td>59</td>
<td>NEW: Cost variance of East Tie-In from current change order log/strategy status.</td>
<td>Active</td>
<td>$10,000,000</td>
<td>9/10/2007</td>
<td>9/17/2007</td>
</tr>
<tr>
<td>CCO</td>
<td>68</td>
<td>NEW: Cost variance of West Tie-In Phase 2 from current change order log/strategy status.</td>
<td>Active</td>
<td>$5,000,000</td>
<td>9/10/2007</td>
<td>9/17/2007</td>
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<tr>
<td>Risk</td>
<td>39</td>
<td>Issues develop with the west area.</td>
<td>Active</td>
<td>$3,750,000</td>
<td>9/14/2006</td>
<td>6/26/2007</td>
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<tr>
<td>CCO</td>
<td>57</td>
<td>NEW: Cost variance of current change order log/strategy status.</td>
<td>Active</td>
<td>$3,000,000</td>
<td>9/10/2007</td>
<td>9/17/2007</td>
</tr>
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</table>
Agenda

✓ Guidebook Objective and Motivation
✓ Risk Analysis and Cost Management
✓ Guidebook Examples
  • Guidebook Philosophy
  • Conclusions
Guidebook Layout and Philosophy

• Introduction
• Cost Estimation and Management
• Risk Management Overview
• Guidebook Framework
• Guide to the:
  – Planning Phase
  – Programming Phase
  – Design Phase
• Implementation and Path Forward
• Tools Appendix
Guidebook Framework

Chapter 5 – Guide to the Planning Phase

Chapter 6 – Guide to the Programming Phase

Chapter 7 – Guide to the Design Phase
Table 6.1 Programming Phase Risk Identification Tools

<table>
<thead>
<tr>
<th>Tool</th>
<th>Minor</th>
<th>Moderately Complex</th>
<th>Major</th>
</tr>
</thead>
<tbody>
<tr>
<td>I2.1 Red Flag Items</td>
<td>●</td>
<td>●</td>
<td></td>
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<tr>
<td>I2.3 Risk Checklists</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>I2.4 Assumption Analysis</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>I2.5 Expert Interviews</td>
<td></td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>I2.6 Crawford Slip</td>
<td>●</td>
<td>●</td>
<td></td>
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<tr>
<td>I2.7 SWOT Analysis</td>
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<td>●</td>
<td></td>
</tr>
<tr>
<td>R3.1 Risk Management Plan</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>R3.6 Risk Workshop</td>
<td></td>
<td>●</td>
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</tr>
<tr>
<td>R3.11 Risk Breakdown Structure</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R3.12 Risk Register</td>
<td>●</td>
<td>●</td>
<td>●</td>
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</table>
Guidebook Outcome

• A Complexity-Based Solution
  – Minor – Risk Identification and Contingency Percentage
  – Moderate – Qualitative Risk Analysis and Identified Contingency Items
  – Major – Quantitative Risk Analysis and Contingency Management
Minor Complexity Example

Red Flag Items
- Design deviation required
- Noise walls required
- Dewatering issues during construction
- Unanticipated 4(f) issue

Maryland Sliding-Scale Contingency

<table>
<thead>
<tr>
<th>Project Phase</th>
<th>Contingency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>35-40%</td>
</tr>
<tr>
<td>Programming and Preliminary Design</td>
<td>25-35%</td>
</tr>
<tr>
<td>Final Design</td>
<td>0-25%</td>
</tr>
</tbody>
</table>
Minor Complexity Example

Sliding Contingency Scale

Phase of Project Development

Percent Contingency

Planning Programming Design 1 Design 2 Design 3

Low MLE High
### Project Descriptions:
- Continuous multi-modal corridor improvement projects from I-5 in Tukwila to SR 522 in Bothell.
- Adds one lane each direction from I-5 to SR 181 in Tukwila.
- Adds two lanes each direction from SR 181 in Tukwila to I-90 in Bellevue.
- Adds one lane each direction from I-90 in Bellevue to SR 522 in Bothell.
- On SR 167, adds one lane between I-405 and S. 180th St.
- Constructs Bus Rapid Transit system with stations, HOV direct access ramps and Park & Ride lots and coaches.
- Expands the vanpool program.

### Project Benefits:
- Reduces congestion and improves freight movement.
- Provides bus rapid transit system from SeaTac to Lynnwood.
- Constructs 2300 new Park & Ride spaces.
- Adds 600 new vanpools and increases commute reduction programs.
- Improves water resources.

### Project Risks:
- Changing environmental requirements for project mitigation (stormwater, wetlands, fish resources and streams) may increase project costs—primarily for added right-of-way purchases.
- Delays in right-of-way purchases may result in construction delays and project cost increases.
- Early stage of project development leads to scope uncertainty.
- Legal challenges and delays in obtaining environmental permits may result in project delay.
- Utility relocations may require extra time to negotiate and complete.

### Schedule:
- End Construction Range: 2013-2014

### CEVP Result:

<table>
<thead>
<tr>
<th>Probability</th>
<th>Project Cost Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>10% chance the cost &lt; $ 4.2 Billion</td>
</tr>
<tr>
<td>0.06</td>
<td>50% chance the cost &lt; $ 4.7 Billion</td>
</tr>
<tr>
<td>0.16</td>
<td>90% chance the cost &lt; $ 5.1 Billion</td>
</tr>
</tbody>
</table>

### What’s Changed Since 2002:
- Scope: Project limits are smaller.
- Schedule: Begin construction range has been delayed up to one year. End construction range has been accelerated two years.
- Costs: Costs have gone down approximately $1 billion due to scope revisions.
- Risk Management: Identifying new strategies for improved environmental clearances and right-of-way processes. Coordinating decision strategies with FHWA.

### Financial Fine Print (Key Assumptions):
- Full project funding becomes available in July 2005. State I-405 Nickel funds will roll-over into this package.
- Inflation escalation is to 2010, the approximate midpoint of construction.
- Additional federal, state, regional and local money may be needed.
- Project cost range includes $18.5 million in past expenses, beginning in 1999.
- Assumes funding decisions do not disrupt or cause construction delays.
Conclusions

1. **Employ all steps** in the risk management process
2. **Communicate cost uncertainty** in project estimates through the use of ranges and/or explicit contingency amounts
3. **Tie risks to cost ranges and contingencies** as a means of explaining cost uncertainty to all stakeholders.
4. **Develop risk management** plans and assign responsibility for resolving each risk
5. **Monitor project threats and opportunities** as a means of resolving project contingency
Conclusions

✓ The simplest representations often work best
✓ While the analysis may be supported by a complex, rigorous, and probabilistically-sophisticated model, it is of little value if it is overly complicated in their representation

http://www.fhwa.dot.gov/programadmin/contracts/cmetg.cfm
Continuous Distribution:
- Normal
- Lognormal
- Triangular

Discrete Distributions

Distribution for Total Project Costs (Current $)

Mean = 499.57

Consequence
a b c d e
 Likelihood
E M M H H
D L M M H
C L L M H
B L L M M
A L L L M

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Conclusions

Other Related Initiatives

• MNDOT CECM Technical Reference Manual
• NCHRP SHRPII R-09 Guide for the Process of Managing Risk on Rapid Renewal Projects
• NCHRP 20-24(74) Executive Strategies for Risk Management by State Departments of Transportation (2011)
• FHWA Risk Management Scan (2011)
• NHI Course on Risk Management
Cost Estimate at Any Phase

Total Project Estimate = Base + Contingency

Risk-related analysis tools and management practices
Risk Control and Contingency
(w/Total Project Cost Estimate = Baseline Estimate)
Resolution of Contingency

- Contingency is applied to account for estimate uncertainty
- Planning estimates use ranges
- Baseline estimate is set at end of Scoping
  - Base estimate is for defined project elements
  - Contingency is for as yet to be defined project elements and possible risk events
- Contingency is resolved in Design/Letting estimates
Resolution of Contingency (Example)

Total Project Cost Estimate Greater Than Baseline Estimate

Total Project Cost Estimate < Baseline Estimate