Probabilistic Cost Estimating using Crystal Ball Software

"You cannot exactly predict an uncertain future"

Presented By:
Jack Young
California Department of Transportation
Division of Engineering Services, Structure Cost Estimates
Caltrans Overview

- Staff of 22,000-24,000 Employees
- Headquarters, 12 Regional Districts and Division of Engineering Services (Structures)
- 50,000 miles of freeway lanes
- Supports Intercity Rail Service
- Many miles of bicycle lanes
- Maintains and Inspects 24,000 State and Local Bridges
- Nearly $10 Billion Dollars Under Contract in Construction

Helpful Links:
- http://www.dot.ca.gov
- http://www.dot.ca.gov/hq/projmgmt/
- http://www.dot.ca.gov/hq/innovfinance/
Structure Cost Estimates Branch
Jack Young
Senior Bridge Engineer

“Caltrans Improves Mobility Across California”
Population of California...44 Million People
Cost Estimation Approaches

Single Point Estimate Plus Contingency

- History indicates a high likelihood that the final Project Costs will exceed the estimated amount.
- To account for possible cost overruns, contingency amounts are added to the total estimate amount.
- Unfortunately, there is no "probability" associated with the likelihood of meeting the programmed cost!

Probabilistic Cost Estimate

- Reveals the full range of cost and associated probability of possible outcomes.
Why Traditional Spreadsheet Analysis Often Fails

• Traditional spreadsheet analysis uses a single value (like the average) to represent uncertain or variable inputs.

• The results are static or deterministic and most likely will be unrepresentative of the range of possible outcomes.

For example, if it takes you an average of 1.5 hours to get to the airport and thru security and you leave 1.5 hours before your flight takes off, you will miss your plane ~ 50% of the time.
Probabilistic Cost Estimate

"Challenges and Opportunities"  

- Cost Estimators recognize that uncertainty and risk will occur.

- Cost estimates are not static or deterministic. They are forecasts that have a range of possible outcomes. Understanding the implications of these ranges leads to more accurate decisions.

- Can Estimators develop a standard process for risk analysis that identifies "challenges and opportunities" and also quantifies risk in unit pricing?
A model is a combination of data and logic constructed to predict the behavior and performance of a process.

Crystal Ball software works with spreadsheet models, specifically Microsoft Excel.

A model is a spreadsheet that has taken the leap from being a data organizer to a predictive analysis tool.
Probabilistic Cost Estimate

"What is Risk?"

Uncertainty about a situation can often indicate risk, which is the possibility of loss, damage, or any other undesirable event.

Most Project Managers and Estimators desire low risk, which would translate to a high probability of success and cost savings.
Probabilistic Cost Estimate

"What is Uncertainty?"

Uncertainty is assessed in cost estimate models for the purpose of estimating the risk (probability) that a specific funding level may or may not be exceeded.

Points to keep in mind when analyzing risk:

How likely is the risk?
How significant is the risk?
Where is the risk?
How do I manage the risk?
A Better Way To Analyze Uncertainty

**Simulation with Crystal Ball**
- Use ranges as inputs
- Thousands of outcomes with associated certainty
- Easy to analyze and communicate

**What-if Analysis**
- Even increments of values
- Multiple outcomes but no associated probabilities
- Difficult to analyze and very time consuming

**Range Estimates**
- Most-likely, best-case, worst-case → 3 outcomes

**Single point estimate**
- One representative value as input → 1 outcome

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**Range of Outcomes**

**Value of Analysis (Betterness)**
Probabilistic Cost Estimate
"Simulation"

What is Simulation?

The application of models to predict future outcomes with known and uncertain inputs.

Why use Simulation?

Measure the behavior of the outcomes given changes in the inputs.

Simulation can be considered a probabilistic framework for analysis.
What is Monte Carlo simulation?

Inputs:
• A computer simulation of N trials calculating multiple (hundreds, thousands) scenarios of your model by repeatedly sampling random combinations of your uncertain inputs.

Outputs:
• Sampling statistics characterize output variation (mean, standard deviation, etc.)
• Predict and Quantify ranges of output (probability/forecast of cost)
• Identify primary variation drivers (sensitivity analysis)
How Does Crystal Ball Appear in MS Excel?

Toolbar

**Define Menu**
- Define Assumption...
- Define Decision...
- Define Forecast...
- Select All Assumptions
- Select All Decisions
- Select All Forecasts
- Select...
- Freeze...
- Copy Data
- Paste Data
- Clear Data...
- Cell Preferences...

**Run Menu**
- Start Simulation
- Reset Simulation
- Single Step
- OptQuest
- CB Predictor...
- Tools
- Save Results...
- Restoring Results...
- Run Preferences...

**Analyze Menu**
- Open Selected Cells
- Assumption Charts...
- Forecast Charts...
- Overlay Charts...
- Trend Charts...
- Sensitivity Charts...
- Scatter Charts...
- Cascade
- Close All!
- Create Report...
- Extract Data...

Setup simulation

Runs the simulation

Views results and creates reports
Which Assumption Curves Do I Use?

- Use distributions based on past historical data or physical principles (normal, log-normal)

- Use expert opinion to develop triangular distribution (Minimum, Most Likely, Maximum value)

- Use bounds with uniform distribution (Minimum, Maximum value)

More realistic, Less conservative

Less realistic, More conservative
Structure Cost Estimate - Crystal Ball Example

- Apply or develop probability curves to a historical data set
- Build a model identifying potential threats and opportunities
- Simulate project bidding 10,000 times using Monte Carlo Simulation
- Develop a probabilistic estimate forecast including a range of likely final costs with associated confidence levels
- Conduct sensitivity analysis and determine largest contributors to cost variance
Overview - Crystal Ball Cost Estimate Model

(Input and Output)
# Probabilistic Structure Cost Estimate

**General Plan Estimate**

**Advance Planning Estimate**

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**Bridge:** Broadway Overcrossing  
**Type:** PC/PS Concrete Girder  
**CU:** 04  
**EA:** 009721  
**Project ID:** 0100006745  
**Design Section:** 17  
**# of Structures in Project:** 1  
**Prices By:** RWP  
**Quantities By:** SAM  

**Model Input**

**In Est:** 06/30/10  
**Out Est:** 07/19/10  
**District:** 04  
**CO:** SM  
**RTE:** 191.06  
**PM:** 16317.05  
**Length:** 205  
**Width:** 117  
**Area:** 23,985  
**Est. No.:** 1  
**Cost Index:** 317  
**Date:** 07/01/10  

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### Contract Items

<table>
<thead>
<tr>
<th>Contract Items</th>
<th>Unit</th>
<th>Minimum</th>
<th>Likeliest</th>
<th>Maximum</th>
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</thead>
<tbody>
<tr>
<td>1 TEMPORARY RAILING</td>
<td>LF</td>
<td>20,796</td>
<td>21,891</td>
<td>25,175</td>
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<td>2 STRUCTURE EXCAVATION (BRIDGE)</td>
<td>CY</td>
<td>500</td>
<td>534</td>
<td>565</td>
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<td>1,425</td>
<td>1,500</td>
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<td>CY</td>
<td>2,730</td>
<td>2,777</td>
<td>2,850</td>
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<td>1,765</td>
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<td>6 PERVIOUS BACKFILL MATERIAL</td>
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<td>740</td>
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<td>7 CIDH CONCRETE PILING</td>
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<td>387,553</td>
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<td>469,143</td>
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<td>8 FURNISH PILING CLASS 140</td>
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<td>10 FURN PC/PS CONCRETE GIRDERS(80'-90')</td>
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<td>11 FURN PC/PS CONCRETE GIRDERS(120'-130')</td>
<td>CY</td>
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<td>12 ERECT PC/PS CONCRETE GIRDERS</td>
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<td>13</td>
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<td>13 STRUCTURAL CONCRETE, BRIDGE</td>
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<td>135</td>
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<td>145</td>
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<td>14 STRUCTURAL CONCRETE, BRIDGE FOOTING</td>
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<td>740</td>
<td>777</td>
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<tr>
<td>15 BAR REINFORCING STEEL (BRIDGE)</td>
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<td>387,553</td>
<td>407,959</td>
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<tr>
<td>16 PNEU PILING CLASS 140</td>
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<td>17 FURNISH STRUCTURAL STEEL</td>
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<td>19 JOINT SEAL ASSEMBLY (MR = 2&quot;)</td>
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<td>20 JOINT SEAL (MR = 2&quot;) max</td>
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<td>21 SLOPE PAVING</td>
<td>CY</td>
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<td>LB</td>
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<tr>
<td>23 MISCELLANEOUS METAL (REINSTR)</td>
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<td>24 CONCRETE RAILING (TYPE 7)</td>
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<tr>
<td>27 TUBULAR HANDRAILING</td>
<td>LF</td>
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</table>

### Item Price Range

<table>
<thead>
<tr>
<th>Item</th>
<th>Minimum</th>
<th>Likeliest</th>
<th>Maximum</th>
<th>Amount</th>
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</thead>
<tbody>
<tr>
<td>TEMPORARY RAILING</td>
<td>$32.00</td>
<td>$35.00</td>
<td>$40.00</td>
<td>$18,655</td>
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<tr>
<td>STRUCTURE EXCAVATION (BRIDGE)</td>
<td>$90.00</td>
<td>$110.00</td>
<td>$130.00</td>
<td>$156,530</td>
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<tr>
<td>STRUCTURE EXCAVATION (BRIDGE)(TYPE D)</td>
<td>$35.00</td>
<td>$40.00</td>
<td>$45.00</td>
<td>$111,080</td>
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<tr>
<td>STRUCTURE EXCAVATION</td>
<td>$27.00</td>
<td>$30.00</td>
<td>$35.00</td>
<td>$656,730</td>
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<td>STRUCTURE EXCAVATION</td>
<td>$900.00</td>
<td>$1,100.00</td>
<td>$1,200.00</td>
<td>$256,300</td>
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<td>$9,000.00</td>
<td>$11,000.00</td>
<td>$12,500.00</td>
<td>$143,000</td>
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<td>STRUCTURAL CONCRETE, BRIDGE</td>
<td>$3,000.00</td>
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<td>$5,750.00</td>
<td>$81,900</td>
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<tr>
<td>STRUCTURAL CONCRETE, BRIDGE</td>
<td>$435.00</td>
<td>$475.00</td>
<td>$529.00</td>
<td>$871,625</td>
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<td>STRUCTURAL CONCRETE, BRIDGE</td>
<td>$520.00</td>
<td>$590.00</td>
<td>$650.00</td>
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<td>$500.00</td>
<td>$550.00</td>
<td>$600.00</td>
<td>$75,000</td>
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<td>BAR REINFORCING STEEL (BRIDGE)</td>
<td>$80.00</td>
<td>$85.00</td>
<td>$90.00</td>
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<td>Bar Rebar</td>
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<td>$90.00</td>
<td>$100.00</td>
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<td>Bar Rebar</td>
<td>$40.00</td>
<td>$48.00</td>
<td>$52.00</td>
<td>$14,016</td>
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</table>
ASSUMPTION CURVE - INPUT

Triangular Distribution

Name: ITEM PRICE - STRUCTURAL CONCRETE, BRIDGE

Minimum $435.00  Likeliest $475.00  Maximum $525.00
# FORECAST PERCENTILES - OUTPUT

<table>
<thead>
<tr>
<th>Percentiles</th>
<th>Forecast values</th>
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<tr>
<td>0%</td>
<td>$4,533,000</td>
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<tr>
<td>10%</td>
<td>$4,786,000</td>
</tr>
<tr>
<td>20%</td>
<td>$4,832,000</td>
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<tr>
<td>30%</td>
<td>$4,864,000</td>
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<tr>
<td>40%</td>
<td>$4,894,000</td>
</tr>
<tr>
<td>50%</td>
<td>$4,921,000</td>
</tr>
<tr>
<td>60%</td>
<td>$4,949,000</td>
</tr>
<tr>
<td>70%</td>
<td>$4,978,000</td>
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<tr>
<td><strong>80%</strong></td>
<td><strong>$5,014,000</strong></td>
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<tr>
<td>90%</td>
<td>$5,062,000</td>
</tr>
<tr>
<td>100%</td>
<td>$5,346,000</td>
</tr>
</tbody>
</table>

Recommended Range
SENSITIVITY CHART - OUTPUT

Sensitivity: BASE CASE ESTIMATE

-20.0%  0.0%  20.0%  40.0%  60.0%  80.0%  100.0%

ITEM PRICE - FURNISH PILING CLASS 140
ITEM PRICE - STRUCTURAL CONCRETE, BRIDGE
QUANTITY - FURNISH PILING CLASS 140
QUANTITY - STRUCTURAL CONCRETE, BRIDGE
ITEM PRICE - STRUCTURAL CONCRETE, BRIDGE FOOTING
ITEM PRICE - DRIVE PILE CLASS 140

29.0%  24.1%  15.9%  7.6%  4.8%  4.1%
In Summary:

Probabilistic Cost Estimate - Pros:

- Forecast results reveal the full range of cost and probability of possible outcomes.
- Sensitivity analysis indicates which inputs drive most of the output variation (threats and opportunities).
- Forces the Estimator to refine the historical item cost data.
- Employs "quantitative" risk management strategies in unit pricing.
- Transparent and defensible input and report output results.
- Excellent backup for cost estimate certification.
- Premium reporting and charting features for Executive summaries.
- Potential to reduce cost estimate contingencies.
- User friendly software (Excel Overlay).
Crystal Ball Software Uses in Transportation Project Cost Estimating

FHWA-Cost Estimate Reviews:

- Cost Estimate Reviews (Mega projects)
  - Marin-Sonoma Narrows, I-5 HOV, I-10 HOV, I-215 HOV, I-405 HOV, Caldecott 4th Bore Tunnel Project, Doyle Drive, etc.

California Department of Transportation
Division of Engineering Services – Structures

- Development of all phases of structure cost estimates
- Depositions
- Transparent/Defensible Back-Up for Cost Estimate Certification
- QC/QA/IQA Practices
QUESTIONS??