Cost Estimation with Crystal Ball
Agenda

- Cost Estimation: Challenges and Opportunities
- The Case for Simulation
- Presenting Crystal Ball
- Case Study 1: Simulation and Contingency
- Introduction to Stochastic Optimization
- Case Study 2: Optimization
- Conclusion and Q & A
Cost Estimation

Challenges and Opportunities
Cost Estimation

• Challenges
  • Cost estimators and program managers recognize that uncertainty and risk will occur.
  • Can estimators develop a standard process for risk analysis that is sufficient for the average practitioner and that identifies and quantifies risk?

You cannot exactly predict an uncertain future.

• Opportunities
  • Cost estimates are not deterministic. They are forecasts that have a range of possible outcomes. Understanding the implications of these ranges leads to more accurate decisions in predicting budgetary success.
The Case for Simulation: 
Modeling Uncertainty and Risk
What is a Model?

A model is a combination of data and logic constructed to predict the behavior and performance of business process or service. Crystal Ball works with spreadsheet models, specifically MS Excel spreadsheet models.

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

Cost analysis spreadsheets are an example of such a model:
What is Risk?

Uncertainty about a situation can often indicate risk, which is the possibility of loss, damage, or any other undesirable event. Most people desire low risk, which would translate to a high probability of success, cost saving, or some form of gain.

Risk is the possibility of loss, damage, or any other undesirable event. (American Heritage Dictionary)
What is Uncertainty?

Uncertainty is unpredictability; indeterminacy; indefiniteness (American Heritage Dictionary)

• Uncertainty is assessed in cost estimate models for the purpose of estimating the risk (probability) that a specific funding level will be exceeded.

Thus, there are several 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?
Why Traditional Spreadsheet Analysis Often Fail

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

• This results in a static, or deterministic, result that might 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.
A better way to analyze uncertainty

Value of Analysis (Betterness)

Range of Outcomes

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
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?

- A system that uses random numbers to measure the effects of uncertainty.

- A computer simulation of N trials where:
  - Each trial samples input values from defined ranges (probability distributions)
  - Applies the input values to the model and records the output

- Outputs:
  - Sampling statistics characterize \textit{output variation} (mean, standard deviation)
  - \textit{Predict and quantify} ranges of output (probability of cost overrun, probability of exceeding deadline)
  - Identify \textit{primary variation drivers} (sensitivity analysis)
How does Monte Carlo simulation work?

1. Define uncertain inputs with a range or set of values. Example: define Environmental Remediation costs for future months as any value between $2.5M and $5.0M, instead of using a single point estimate of $3.0M.

2. Identify key outputs – any calculated value you are interested in analyzing. Example: Total project cost

3. Simulation calculates multiple (hundreds, thousands) scenarios of your model by repeatedly sampling random combinations of your uncertain inputs.

For example, a simulation could generate scenarios combining most-likely site-prep costs with minimum construction costs, OR minimum site-prep costs with maximum construction costs, OR etc…. All based on your definition of uncertainty ranges surrounding your inputs.
Benefits of a Probabilistic Framework

• Honors the definition of risk

• Makes use of all the information available about the uncertainty inherent in the assessment

• Provides direct and indirect measures of the value of information (sensitivity)

• Re-establishes the boundary between risk assessment and risk management.

• Saves money by deriving less stringent – yet fully protective - contingency requirements not based on compounded conservatisms.

• Reveals the full range and probability of possible outcomes – exposure and risk are no longer point values.
Presenting Oracle
Crystal Ball software
Introducing **Crystal Ball**

Crystal Ball facilitates simulation, sensitivity, and predictive analysis of a business process or service which includes uncertain and variable inputs.

**Inputs**

- Normal
- Uniform
- Triangular
- Exponential

**Crystal Ball applied to a model described as formulas in Excel**

**Output**

![Graph showing output](image)
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...
- Restore 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

run the simulation and other tools

view the results, create reports, and export data
## Basic Terminology

<table>
<thead>
<tr>
<th>Crystal Ball Term</th>
<th>Common Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumption</td>
<td>Input, X, independent variable, random variable, probability distribution</td>
</tr>
<tr>
<td>Decision Variable</td>
<td>Controlled variable</td>
</tr>
<tr>
<td>Forecast</td>
<td>Output, Y, f(X), dependent variable</td>
</tr>
</tbody>
</table>
Defining a Crystal Ball Assumption

With Crystal Ball, a single spreadsheet cell can be defined with a range or set of values according to a probability distribution.
Which input distributions do I use?

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

- 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
What is correlation?

- A measure of association between two independent variables (Crystal Ball Assumptions)

  - Specifies strength and direction of association (range -1 to +1)
  - Positive correlation indicates that the variables tend to increase or decrease together
  - Association is not the same as cause and effect
  - Adding correlation will generally increase the standard deviation of the results
  - Without considering correlation, you run the risk of underestimating / overestimating the variation.

**Correlation = +0.75**

ASSUMPTION #1

ASSUMPTION #2
Correlation dialogs
Simulation Output: Forecast Chart

Explore the range of possible outcomes AND the probability of their occurrence

Number of simulation trials performed

Display range

Certainty (probability) that the forecast lies between the bounds

Number of data points displayed in the chart

Parts within the certainty bounds are shown in blue, parts outside the bounds are shown in red
Sensitivity Analysis: A Critical Tool

Which critical factors contribute most to the variance in the outcome?

- Acts as communication tool to understand what’s driving variation
- Useful in developing strategy for improvement and prioritizing resources
  - Refined estimates
  - Further data collection
  - Risk mitigation efforts (contracts, etc)
- After reducing the variation for these few critical X’s, you can rerun the simulation and examine the effects on the output
Generate a Report

- Use a template or custom report structure.
- Options for location and format.
- Reports are static, not dynamic.
Benefits of Simulation in Cost Estimation

• How does your investment decision change?
  • Single point estimate: Expected NPV $13MM
  • Add range information: Low $-62MM, High $103MM
  • Add certainty information: ~28% chance of NPV < 0
Case Study 1:
Cost Estimation and Contingency
Cost Estimation Objective

• A Cost Estimator must provide an accurate estimate of costs involved in a Construction Project so that a reasonable bid price is set with low likelihood of losing money.

• Breakdown of tasks into categories:
  • Project Management
  • Engineering
  • CENTRC (Capital Equipment Not Related To Construction)
  • Construction
  • Other Project Costs
  • Safety & Environmental
Cost Estimation Approaches

• Single point estimate
  • Represents what appears to be the most-likely total cost
  • No associated probability with the outcome

• Single point estimate plus contingency
  • Past 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 still no probability associated with the likelihood of meeting or not meeting the cost target!
Correlation

- A realistic Monte Carlo simulation must also account for correlation factors (coefficients) between the various assumptions.
- The following Correlation Matrix is enabled:

```
    PROJECT MANAGEMENT (Monte Carlo)  ENGINEERING (Monte Carlo)  CENRTC (Monte Carlo)  CONSTRUCTION (Monte Carlo)  OTHER PROJECT COST (Monte Carlo)  SAFETY & ENVIRONMENTAL (Monte Carlo)
PROJECT MANAGEMENT (Monte Carlo)       1.000                  0.250                 0.500              0.500                      
ENGINEERING (Monte Carlo)              1.000                  0.250                 0.500              0.500                      
CENRTC (Monte Carlo)                   1.000                  0.250                 0.500              0.500                      
CONSTRUCTION (Monte Carlo)             1.000                  0.250                 0.500              0.500                      
OTHER PROJECT COST (Monte Carlo)       1.000                  0.250                 0.500              0.500                      
SAFETY & ENVIRONMENTAL (Monte Carlo)   1.000                  0.250                 0.500              0.500                      
```
Simulation Analysis Goals

- Define Crystal Ball forecast: Total Project Costs

- Determine how often (% of outcomes) the estimated project costs will be exceeded by predicted costs. (Monte Carlo Simulation)

- Which project tasks are driving the variation? (Sensitivity Analysis)
Simulation Results

- Predicted costs will **exceed original cost estimate during 93.6%** of all outcomes.

- Predicted costs **exceed contingency cost estimate in only .39%** of all outcomes.
Simulation Results

• To be more realistic, determine what cost estimate value would capture 90% of the possible cost outcomes.
  • Submit a total cost estimate of $78.47 MM.
Sensitivity Results

- Which project task is driving the overall variation in predicted costs?
- Examine assumptions associated with biggest influence on output variation. (Are they realistic?)
Case Study Conclusions

• Single point estimates on costs can either under predict or over predict the actual costs based on the probabilities associated with Monte Carlo simulations.

• Sensitivity analysis indicates which inputs drive most of the output variation (construction).

• Use forecast results to determine which cost estimate meets acceptable level of risk.
  • Cost estimate of $78.47MM represents 10% chance of overruns.
Modeling Cost Estimate Contingency

Techniques Used

- Auto Extract (DEFINE / DEFINE FORECAST) percentile cost estimates.

- Compute contingency as percent deviation from most likely estimate (EST–ML)/ML.