Teaching (Monte-Carlo) Spreadsheet Simulation

Roger Grinde, roger.grinde@unh.edu
University of New Hampshire
Files: http://pubpages.unh.edu/~rbg/TMS/TMS_Support_Files.html

Simulation in Spreadsheets
- Do you teach simulation?
  - In which courses?
  - With spreadsheets? Add-Ins?
  - Monte Carlo? Discrete Event?
- Do you use simulation to help teach other topics?
- Do other courses (not taught by you) use simulation?

Session Overview
- Learning Goals
- Motivations
- Examples that Work Well
- Examples Posing Difficulties
- Foundations of Simulation
- Concept Coverage Through Examples
- Learning Goals (Revisited)
- Issues to Consider

Learning Goals
- What are your learning goals when teaching simulation?

Concept Coverage Through Examples
- Philosophy: Expose students to a number of application areas, “sneaking” in the concepts along the way.
- Counter to the way many of us were taught.
- Key: We need to clearly understand which concepts we’re trying to convey with each example.

Mapping: Goals to Examples
Motivations

- Two investment alternatives
  - A: Invest $10,000.
    - Probability of a $100,000 gain is 0.10
    - Probability of a $10,000 loss is 0.90
  - B: Invest $10,000
    - Probability of a $500 gain is 1.0
- Which would you choose?
- Why?

Motivations (continued)

- On Average, “A” is twice as good as “B”!
- Do we ever actually receive the average?
- Decisions made based only on the average can be very poor.
- Other examples

Motivations: Simulation and Risk Analysis

- Simulation allows us to evaluate the risk of a particular situation.
- Risk: Typically defined as the uncertainty associated with an undesirable outcome (such as financial loss).
- Risk is not the same as just being uncertain about something, and is not just the possibility of a bad outcome.
- Risk considers the likelihood of an undesirable outcome (e.g., the probability) as well as the magnitude of that outcome.

Simulation Model Schematic

- Same basic schematic throughout course
- Concept of an output “distribution.”

Examples that Work Well

- **Fundamentals:** Dice Roller, Interactive Simulation Tool
- **Personal Decisions:** Car Repair/Purchase Decision, Portfolio (single period, based on CB Model), College Funding (based on Winston & Albright)
- **Capital Project Evaluation:** Truck Rental Company (based on Lawrence & Weatherford), Project Selection/Diversification (CB Model), Product Development & Launch (CB Model)
- **Finance:** Stock Price Models, Option Pricing, Random Walks, Mean Reverting Processes

Examples (continued)

- **Inventory:** DG Winter Coats (NewsVendor), Antarctica (multi-period, based on Lapin & Whisler)
- **Queuing:** QueueSimon (Armonn Ingolfsdonn)
- **Games/ Tournaments:** NCAA Tourney (based on Winston & Albright)
- **Simulation in Teaching Other Topics:** Revenue Management Illustration
- **Crystal Ball Features:** CB Macros, CB Functions
Examples Posing Difficulties for Spreadsheets

- Multi-server queues and queue networks
- Most production systems
- Business process redesign
- However, some add-ins do exist for simple discrete-event models (e.g., SimQuick by David Hartvigsen)

Foundations of Simulation

- Randomness, Uncertainty
- Probability Distributions
- Tools
  - Dice Roller (John Walkenbach: http://www.j-walk.com/ss)
  - Die Roller (modified)
  - Die Roller (modified for investment "game")
  - Interactive Simulation Tool

From “What If” to “Wow”

- Simulation as an Extension of Other Methodologies
  - Spreadsheet Engineering, Base Case
  - What-If Analysis
  - Sensitivity Analysis
  - Scenario Analysis
  - Simulation
- Comparison of Analysis Methodologies

Extending Other Methodologies

- Familiar Example/Case
- Students provided with some probability distribution information
- Develop comfort with mechanics of simulation
- See the “value added” of simulation
- Provides entry point for discussion of important questions

Example: Watson Truck

- Adapted from Lawrence & Weatherford (2001)
- Students have built base-case model, and have done sensitivity analysis
- Examples
  - Base Case
  - Sensitivity Analysis
  - Simulation

Watson Truck: Inputs
Watson Truck: Base Case Model

7/7/2004

Watson Truck: Sensitivity Analysis

7/7/2004

Watson: Simulation

7/7/2004

Learning Goals Addressed (at least partially)

7/7/2004

Sources of Error in Simulation

7/7/2004

Example: Single-Period Portfolio

7/7/2004

- Linkage with other course/functional area
- What inputs should we simulate?
- Useful probability distributions. Choice of parameters.
- Concept of an output distribution
- Simulation in context with other tools
- What results are important?
- Sources of error in simulation
- Simulation mechanics

- Simple example, but helps address a number of learning goals
  - Do we need to simulate?
  - Precision of estimates from simulation
  - Confidence vs. Prediction (certainty) intervals
  - Effect of correlation among input quantities
  - Quantification of risk, multiple decision criteria
  - Optimization concepts within simulation context
**Portfolio Allocation Model**

<table>
<thead>
<tr>
<th>Investments</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Money Market Fund</td>
<td>$0</td>
<td>$50,000</td>
</tr>
<tr>
<td>Income Fund</td>
<td>$10,000</td>
<td>$25,000</td>
</tr>
<tr>
<td>Growth and Income</td>
<td>$0</td>
<td>$80,000</td>
</tr>
<tr>
<td>Aggressive Growth</td>
<td>$10,000</td>
<td>$100,000</td>
</tr>
</tbody>
</table>

**Total amount available** $100,000

**Decision variables**

- Money Market Fund: $25,000
- Income Fund: $25,000
- Growth and Income Fund: $25,000
- Aggressive Growth Fund: $25,000

**Total expected return** $6,500

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**Correlation of Returns**

<table>
<thead>
<tr>
<th>Large Stocks</th>
<th>Large Growth Stocks</th>
<th>Large Value Stocks</th>
<th>Small Stocks</th>
<th>Small Growth Stocks</th>
<th>Small Value Stocks</th>
<th>Foreign Stocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.698411</td>
<td>0.756557</td>
<td>1</td>
<td>0.709758</td>
<td>0.798096</td>
<td>0.391551</td>
</tr>
<tr>
<td>Large Growth Stocks</td>
<td>0.698411</td>
<td>0.749218</td>
<td>0.770546</td>
<td>1</td>
<td>0.827806</td>
<td>0.685912</td>
</tr>
<tr>
<td>Large Value Stocks</td>
<td>0.756557</td>
<td>0.749218</td>
<td>0.770546</td>
<td>1</td>
<td>0.827806</td>
<td>0.685912</td>
</tr>
<tr>
<td>Small Stocks</td>
<td>0.709758</td>
<td>0.770546</td>
<td>1</td>
<td>0.827806</td>
<td>0.685912</td>
<td>0.275857</td>
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<tr>
<td>Small Growth Stocks</td>
<td>0.798096</td>
<td>0.827806</td>
<td>0.685912</td>
<td>1</td>
<td>0.325624</td>
<td>0.140232</td>
</tr>
<tr>
<td>Small Value Stocks</td>
<td>0.685912</td>
<td>0.685912</td>
<td>0.140232</td>
<td>1</td>
<td>0.325624</td>
<td>0.140232</td>
</tr>
<tr>
<td>Foreign Stocks</td>
<td>0.391551</td>
<td>0.325624</td>
<td>0.140232</td>
<td>0.391551</td>
<td>1</td>
<td>0.112763</td>
</tr>
</tbody>
</table>

Based on Standard & Poor Microcap, via Franklin/Templeton Investor Topics Update, Winter 2001

**Results (n=1000)**

- **No Correlation**
  - Mean = $6842
  - Standard Deviation = $5449
  - 5% VaR = ($2165)
- **Positive Correlation**
  - Mean = $6409
  - Standard Deviation = $7386
  - 5% VaR = ($5655)

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**Decision Criteria**

- What criteria are important for making decision as to where to invest?
- Measures of risk.
- Simulation gives us the entire output distribution.
- Entry point for optimization within simulation context
- Alternate scenarios, efficient frontier, OptQuest, RiskOptimizer, etc.

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**Crystal Ball Functions and Simple VBA Control**

- Crystal Ball provides built-in functions
- Distribution Functions (e.g., CB.Normal)
- Functions for Accessing Simulation Results (e.g., CB.GetForeStatFN)
- Control through VBA
  - For some students, can be a “hook.”
  - Allows one to prepare a simulation-based model for someone else who doesn’t know Crystal Ball.

**Example**
Precision of Results: Confidence Intervals

- Students can calculate a confidence interval for the mean?
- Do they know what it means?

Sample Results (Portfolio Problem)

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Value</th>
<th>90% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trials</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>$6,499</td>
<td>$6,499 - $6,531</td>
</tr>
<tr>
<td>Median</td>
<td>$6,531</td>
<td></td>
</tr>
<tr>
<td>Mode</td>
<td>$6,677</td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>$7,386</td>
<td></td>
</tr>
</tbody>
</table>

- What does that confidence interval mean?
- Common (student) error
- What does this imply about an individual outcome?
  For example, from any single year?

Sample Results (cont)

<table>
<thead>
<tr>
<th>Percentile</th>
<th>dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>$6,499 - $6,531</td>
</tr>
<tr>
<td>15%</td>
<td>$6,499 - $6,531</td>
</tr>
<tr>
<td>25%</td>
<td>$6,499 - $6,531</td>
</tr>
<tr>
<td>30%</td>
<td>$6,499 - $6,531</td>
</tr>
<tr>
<td>35%</td>
<td>$6,499 - $6,531</td>
</tr>
<tr>
<td>40%</td>
<td>$6,499 - $6,531</td>
</tr>
<tr>
<td>45%</td>
<td>$6,499 - $6,531</td>
</tr>
<tr>
<td>50%</td>
<td>$6,531 - $6,595</td>
</tr>
<tr>
<td>55%</td>
<td>$6,531 - $6,595</td>
</tr>
<tr>
<td>60%</td>
<td>$6,531 - $6,595</td>
</tr>
<tr>
<td>65%</td>
<td>$6,531 - $6,595</td>
</tr>
<tr>
<td>70%</td>
<td>$6,531 - $6,595</td>
</tr>
<tr>
<td>75%</td>
<td>$6,531 - $6,595</td>
</tr>
<tr>
<td>80%</td>
<td>$6,531 - $6,595</td>
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<tr>
<td>85%</td>
<td>$6,531 - $6,595</td>
</tr>
<tr>
<td>90%</td>
<td>$6,531 - $6,595</td>
</tr>
<tr>
<td>95%</td>
<td>$6,531 - $6,595</td>
</tr>
<tr>
<td>100%</td>
<td>$6,531 - $6,595</td>
</tr>
</tbody>
</table>

- What do these results mean?
- What is the 90% “prediction” (or “certainty”) interval?

Confidence and Prediction Intervals

- 90% Confidence Interval for the Mean
  - ($6,499, $6,531)
- 90% Prediction Interval (centered around median)
  - ($6,531, $6,595)
- Note: Crystal Ball uses the term “certainty”
- Students:
  - Understand the difference?
  - Understand when one is more appropriate than the other?

Precision of Simulation Results

- Since we know the true value of the mean (for the portfolio problem), this can be a good example to look at precision and sample size issues.
- Crystal Ball: Precision control for mean, standard deviation, and percentiles.
- Simulation stops when precision reached
- Confidence interval for proportion or for a given percentile sometimes makes more sense.

Crystal Ball: Precision Control

- Nice way to illustrate effect of sample size.
- Precision Control stops simulation based on user-specified precision on the mean, standard deviation, and/or a percentile.
- Example (Portfolio Allocation)
- Example (Option Pricing)
Learning Objectives (Revisited)

- General
- Probability Distributions
- Statistics
- Relationships Among Variables
- Decision Making

Possible Learning Goals

- General
  - Use simulation as an extension of other analysis tools
  - Apply simulation to a variety of business problems
  - Identify when simulation is and is not needed to analyze a situation
- Probability Distributions
  - Understand and use probability distributions to model phenomena
  - Describe the output distribution, understanding this to be a function of the input distributions
  - Use historical/empirical data and subjective assessments appropriately in choosing distributions and parameters

Possible Learning Goals (cont)

- Statistics
  - Correctly interpret summary statistics, including percentiles/histograms
  - Correctly interpret confidence and prediction (certainty) intervals
  - Identify sources of error in simulation, apply to specific situations
- Relationships Among Variables
  - Include appropriate correlation and/or other relationships when model building
  - Describe the effect of correlation and/or other relationship on simulation results

Possible Learning Goals (cont)

- Decision Making
  - Identify and correctly use different risk measures
  - Use appropriate criteria in making recommendations
  - Use optimization concepts in a simulation application

Difficult Issue (for me)

- Decide which learning goals are the most important, and structure coverage so those goals are attained.
  - Student backgrounds
  - Time constraints
  - Overall course objectives
  - Mapping of learning goals to examples that you will use.

Mapping: Learning Goals to Examples
Mapping: Goals to Examples

<table>
<thead>
<tr>
<th>Learning Goal/Outcome</th>
<th>Inventory (single-period)</th>
<th>Portfolio Allocation</th>
<th>Capital Project NPV</th>
<th>Multiple Project Selection</th>
<th>Stock Price Modeling, Option Pricing</th>
<th>Inventory (multi-period)</th>
<th>Personal Financial Planning</th>
<th>Queuing</th>
<th>Games/Tournaments</th>
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<td></td>
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</tr>
</tbody>
</table>

| Extension of other analysis tools |                  |                      |                     |                           |                                     |                          |                            |         |                  |
|----------------------------------|-------------------|----------------------|---------------------|---------------------------|-------------------------------------|--------------------------|----------------------------|---------|                  |

| Is simulation needed? |              |                      |                     |                           |                                     |                          |                            |         |                  |
|-----------------------|-------------------|----------------------|---------------------|---------------------------|-------------------------------------|--------------------------|----------------------------|---------|                  |

| Variety of probability distributions |                  |                      |                     |                           |                                     |                          |                            |         |                  |
|--------------------------------------|-------------------|----------------------|---------------------|---------------------------|-------------------------------------|--------------------------|----------------------------|---------|                  |

| Model-building issues (where a simulation model would be different than a deterministic model) |                  |                      |                     |                           |                                     |                          |                            |         |                  |
|--------------------------------------------------------------------------------------------|-------------------|----------------------|---------------------|---------------------------|-------------------------------------|--------------------------|----------------------------|---------|                  |

| Output distribution as function of input distributions |                  |                      |                     |                           |                                     |                          |                            |         |                  |
|--------------------------------------------------------|-------------------|----------------------|---------------------|---------------------------|-------------------------------------|--------------------------|----------------------------|---------|                  |

| Historical/empirical data |              |                      |                     |                           |                                     |                          |                            |         |                  |
|--------------------------|-------------------|----------------------|---------------------|---------------------------|-------------------------------------|--------------------------|----------------------------|---------|                  |

| Summary statistics |              |                      |                     |                           |                                     |                          |                            |         |                  |
|--------------------|-------------------|----------------------|---------------------|---------------------------|-------------------------------------|--------------------------|----------------------------|---------|                  |

| Alternate decision criteria & risk measures |                  |                      |                     |                           |                                     |                          |                            |         |                  |
|---------------------------------------------|-------------------|----------------------|---------------------|---------------------------|-------------------------------------|--------------------------|----------------------------|---------|                  |

| Sources of error |              |                      |                     |                           |                                     |                          |                            |         |                  |
|-------------------|-------------------|----------------------|---------------------|---------------------------|-------------------------------------|--------------------------|----------------------------|---------|                  |

| Correlation and/or relationships among input variables |                  |                      |                     |                           |                                     |                          |                            |         |                  |
|--------------------------------------------------------|-------------------|----------------------|---------------------|---------------------------|-------------------------------------|--------------------------|----------------------------|---------|                  |

| Optimization concepts in simulation |                  |                      |                     |                           |                                     |                          |                            |         |                  |
|-------------------------------------|-------------------|----------------------|---------------------|---------------------------|-------------------------------------|--------------------------|----------------------------|---------|                  |

Common Student Errors

- Thinking of simulation as the method of first choice.
- Simulating too many quantities.
- Too much focus on distribution/parameter selection or on the numerical results, not enough on insights/decision.
- Misinterpretation of results, especially confidence intervals
- Modeling: Using same return, lead time, etc. for every time period/order, etc. (difference between deterministic and simulation models)
- Choosing the assumptions, distributions, parameters, etc. that give the "best" numerical results.

Issues to Consider

- Teaching environment (lab setting or not?)
- Role of course in curriculum
- Use add-ins for Monte-Carlo simulation?
- Teach Discrete-Event simulation?
- How much of the "quant" course should be devoted to simulation?

Conclusions, Discussion

Student Project Example (MBA)

- PPT File
- Excel File