Simulation and Lean Six Sigma

Hilary Emmett, 22 August 2007

Crystal Ball®

Improve the quality of your critical business decisions
Agenda

- Simulation and Lean Six Sigma
- What is Monte Carlo Simulation?
- Loan Process Example
- Inventory Optimization Example
Models and Simulation

- Models are an attempt to capture behavior and performance of business processes and products.

- Simulation is the application of models to predict future outcomes with known and uncertain inputs.

MODELS

\[ F = m \times a \]

\[ Y = f(x) \]

SIMULATION

Control Inputs

Noise Variables

Outcome Predictions

\[ Y = f(x) \]
What Is Monte Carlo Simulation?

- A system that uses random numbers to measure the effects of uncertainty.
- The inputs are variable or uncertain X’s represented by probability distributions (assumptions).
- The outputs are responses / Y’s / formulas / effects (forecasts).
- A computer:
  1. Samples input values from the assumptions (PDFs) and puts them in the model
  2. Recalculates model to create a new response, which is recorded
  3. Provides sampling statistics that characterize the output variation (mean, standard deviation, fitted probability distributions, Cpk, PPM, Z-score)
Monte Carlo Simulation and Optimization can be used in many Lean & Six Sigma phases:

- **IDENTIFY VALUE / DEFINE:**
  Project selection, Project financial review

- **VALUE STREAM / MEASURE:**
  Process simulation to include variations, Simulate “As-Is” state

- **IMPROVE FLOW-CUSTOMER PULL / ANALYZE-IMPROVE:**
  Operations decision analysis and optimization, Process or product design modeling and improvement

- **ALL LEAN PHASES:**
  Service Process & OEE
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Inputs: Probability Distributions

- Simulation requires probabilistic inputs.
- Distributions use ranges of values and assign a likelihood of occurrence for values (e.g., a normal distribution could represent variation of the part dimensions).
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Outputs: Charts and Tables

Number of simulation trials

Parts within the spec limits are shown in blue, parts outside spec limits are shown red

Certainty (probability) that the forecast lies between LSL and USL

Upper Spec Limit (USL)

Quality Metrics such as $C_{pk}$, $Z_{st}$, $p(N/C)$, etc....

Certainty: 81.62%
Sensitivity Analysis: A Critical Tool

- Examine which few critical factors (X’s) in your analysis cause the predominance of variation in the response variable of interest (Y)
- Operates during the simulation, calculating the relationships between all X’s and Y’s
- Similar to Pareto Chart in interpretation but is not a Main Effects plot
Sensitivity Analysis: Using the Results

- Acts as communication tool to help team understand what’s driving defects
- Generally see a few factors having strongest impact on forecast variation
- Shows where to focus your energies (and where not to focus them)
- After reducing the variation for these few critical X’s, you can rerun the simulation and examine the effects on the output
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Loan Process Example

Loan Process Example with Delays and Rework

Performance Target: 36

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<tr>
<th>Process Step</th>
<th>Simulate Delayed Cycle</th>
<th>Assumption Parameters</th>
<th>Simulated Delay</th>
<th>Average Delay</th>
<th>Rework Necessary</th>
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Cycle Time: 75
VA Efficiency: 35.72

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Problem Statement

- A financial organization wishes to use Lean Six Sigma techniques on increasing the efficiency and decreasing the variation of their Loan Process.

- Customer: Loan Applicants

- Note: This could really be any simple process or sub-process / cell
Case Study Overview by Phase

**Identify Value**
- Define Problem

**Value Stream**
- Create high-level process map
- Refine process map to include variation (distributions)
- Measure or estimate process step variation
- Monte Carlo Simulation to predict variation
- Determine variation drivers w/ Sensitivity Analysis

**Improve Flow**
- Address drivers and reiterate simulation to improve flow

**Customer Pull**

**Process Perf.**
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Step 1: High-Level Process Map

- Delays and Rework in Loan Process do not add value to customers.
- Use Process Map and Value Stream techniques to identify delays and rework (assuming all identified process execution steps are Value-Added).

Identify Value

Value Stream

Improve Flow

Customer Pull

Process Perf.

1. Customer Inquiry
2. Loan Application
3. Document Verification
4. Loan Underwriting
5. Loan Closing
6. Loan Disburse
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Step 2: Refinement of High-Level Process Map

- Unfortunately, high-level process maps generally do not consider delay times or rework cycles at each process step ("Hidden Factory").
- Using Monte Carlo techniques, we can model the variation in execution & delay times, in addition to defects (reworks) occurring at each high-level process step!
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Refinement of High-Level Process Map

- **Six Steps**
- **Four can be broken into Execution and Delay**
- **Three rework loops**
- **Upper Spec Limit = 96 hours**
Step 3: Measure or Estimate Process Step Variation

As part of the Value Stream Phase, an estimate or measurement of the process step times needs to be captured:

- **Sampling:** Samples of steps 1 and 6 indicate these steps vary lognormally and normally, respectively.

- **Expert opinion:** No reliable measures of Steps 2 through 4 exist so expert opinion is utilized
  
  - Step 2 has a most likely, a minimum, and a maximum estimated process time
  
  - Step 3 has an 80% chance of being anywhere between 16 and 32 hours and a 20% chance of being anywhere between 32 and 48 hours
  
  - Step 4 can be anytime between 1 and 8 hours

- **Collection System:** No data was measured for Step 5 so a measurement collection system was put in place for 100 processed loans.
For Execution inputs, define each step as the appropriate distribution.
Building the Model - 2

For Delay, define each step as an Exponential distribution

For Defects, define each step as a Yes / No (Binomial with 1 trial)
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Building the Model - 3

Now, just calculate Cycle Time (91 hours with delay and no rework)
Cycle Time = Execution steps + Delay steps + Rework when it occurs
Can also calculate VA Efficiency (is it always that high?)
Step 4: Monte Carlo Simulation to Predict Variation

Rather than run single steps, can run thousands of trials quickly.
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Step 4: Monte Carlo Simulation to Predict Variation

Rather than run single steps, can run thousands of trials quickly.
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Step 4: Monte Carlo Simulation to Predict Variation

Rather than run single steps, can run thousands of trials quickly.
Step 4: What Does the Simulation tell us?

After simulating 10,000 loans:

- Mean loan process cycle time is 93 hours (vs. base case of 91 hours)
- Standard deviation = 40 hours!
- ~40% of loans (3,839/10,000) are over USL
- Sigma level is a dismal 0.084
- As-is state has serious problems. What is driving the variation?
Monte Carlo Simulation to Predict Variation

VA Efficiency is reduced by including effect of added Cycle Time due to delay times and rework cycles (non-value-added steps)

- VA Efficiency mean less than 100% (~ 35%)
Step 5: Review Sensitivity Analysis

- Run Sensitivity Analysis to determine major driver of variation.
- Can anything be done to reduce Document Verification Delay times?
  - Assume average delay time can be reduced by 50% in Cell K33.
  - Run simulation.
Step 6: Reiterate Monte Carlo Analysis

- Run Monte Carlo again → less than 20% of process loans are out of specification → Sigma Level of ~ +0.8
- The Loan Process Cycle Time quality has been improved.
Reiterate Monte Carlo Analysis

- By reducing the primary non-value-added Cycle Time variation (Verification Delay), the Value-Added Efficiency mean has also been increased (from ~ 35% to ~ 40%)!
## Comparison of Results

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<tr>
<th>Stage</th>
<th>Mean Cycle Time</th>
<th>Mean VA Efficiency</th>
<th>Standard Deviation</th>
<th>Sigma Level</th>
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<td>To-Be Sim</td>
<td>75 hours</td>
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<td>26 hours</td>
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Analysis is iterative and the model will be adjusted (improved) as the project continues...
Case Study Conclusions

• Quality Levels will be increased by decreasing variation on driving input variables.
  – Monte Carlo analysis predicts quality levels.
  – Sensitivity analysis identified Verification Defect as most influential input variable.

• Knowledge of variation drivers allows one to experiment with the process in the simulation world and determine improvements.
  – Simulations allow the user to determine quality improvements without real-world implementation.
  – Saves time and money while improving the process.
# Inventory Optimization Example

## Inventory Simulation With Lost Sales

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### Total Annual Costs

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## Table

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## Notes

- **Order Quantity**: 250 units
- **Reorder Point**: 250 units
- **Initial Inventory**: 250 units
- **Lead Time**: 2 weeks
- **Order Cost**: $50
- **Holding Cost**: $0.20
- **Lost Sales Cost**: $100
- **Optimize order quantity and reorder point to minimize costs**

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Problem Statement

- The two basic inventory decisions that managers face are: (1) how much additional inventory to order or produce, and (2) when to order or produce it.

- Although it is possible to consider these two decisions separately, they are so closely related that a simultaneous solution is usually necessary.

- Given variable (uncertain) demand over a 52-week period, you need to determine an optimal order quantity and reorder point that results in the lowest possible total annual costs.
Step 1: Create Excel Model

- Determine amounts for inventory and ordering
- Create calculation for whether or not to place order
- Calculate individual weekly costs and roll up to annual costs
- As-is state: $7,090 in Annual costs for order of 250 units and reorder of 250 units

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<th>Beg Rec’d</th>
<th>Order Rec’d</th>
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Optimize order quantity and reorder point to minimize costs.

Total Annual Costs: $1,040 + $1,050 + $5,000 + $7,090
Step 2: Define Key Assumptions

All 52 weeks have same Poisson distribution for demand
Step 3: Run the Simulation

- After 10,000 trials, find that mean annual inventory costs is around $25,500.
- The base case of $7,090 is far from realistic given the uncertainty of demand.
Step 4: Stochastic Optimization

Simulation can help you to understand and reduce variation but does not by itself offer the best solution.

An optimization model answers the question "What's best?" rather than "What happened?" (statistics), "What if?" (simulation) or "What will happen?" (forecasting).

The combination of simulation and optimization lets you make the best (optimal) decisions while accounting for the variability or uncertainty inherent within a process.
Running Simulation with Optimization

- Define objective: minimize mean of annual inventory costs
- Define controllable variables: Order Quantity (200-400 units) and Reorder Point (200-400 units)

<table>
<thead>
<tr>
<th>Optimization (1 = 1000 trials)</th>
<th>Order Quantity</th>
<th>Reorder Point</th>
<th>Minimized Cost (mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250</td>
<td>265</td>
<td>$18,474</td>
</tr>
<tr>
<td>2</td>
<td>345</td>
<td>320</td>
<td>$2,791</td>
</tr>
<tr>
<td>3</td>
<td>325</td>
<td>275</td>
<td>$7,705</td>
</tr>
</tbody>
</table>
Simulation and Lean Six Sigma

Running Simulation with Optimization

- After 10 minutes, optimization has converged on Order Point of 330 and Reorder Point of 325.
- This will minimize the Annual Costs to a mean of ~$2825.
Running Simulation with Optimization

Re-run simulation with new controls and see optimized inventory problem at 10,000 simulation trials.
Case Study Conclusions

• Modeling demand of as-is state can show weaknesses of base case estimations.

• Stochastic optimization lets you run simulations while changing controlled variables for each consecutive simulation.

• By adjusting controlled variables during optimization, you can determine settings that will optimize your output (e.g., minimize costs, maximize profit).

• Final optimization solution results in reduced inventory waste and substantial cost savings.
Examples of Simulation Reducing Waste

Transportation..........................Location of Facilities- Distribution Center
Inventory..........................................................Inventory System
Movement
Waiting...............................................................Workforce with Queing
Over Processing.....................................................Loan Process
.............................................................................Value Stream
Overproduction.....................................................Sales Projection
Defects..............................................................Hidden Factory
Benefits of Simulation in Lean 6σ Projects

- Identify the Current Process Capability
  - Identify the capability of current process, product or service.

- Identify the Primary Inhibitors to Process Flow
  - Immediate insight on the impact to flow of work in queue, batch processing, transportation delays, and rework cycles.
  - Examine alternate process configurations at low cost.

- Establish Optimal Lean Pull
  - Reduce or eliminate non-value-adding activities.
  - Reduce, perform in parallel and/or optimize business-value-adding activities.
When to Use Simulation in Lean $6\sigma$ Projects?

- Mathematical relationship exists
- You have quantified the variation in multiple inputs
- Little or no data for as-is state
- Can represent problem in a spreadsheet (for Crystal Ball)
- Simple process or sub-process (cell) level
- Want quick overview to help project direction
- You have a high cost for implementation
- Want to avoid extended wait for post-improve results
Questions and Answers

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