Simulation and Lean Six Sigma

Hilary Emmett, 22 August 2007

Crystal Ball®

Improve the quality of your critical business decisions

DECISIONEERING

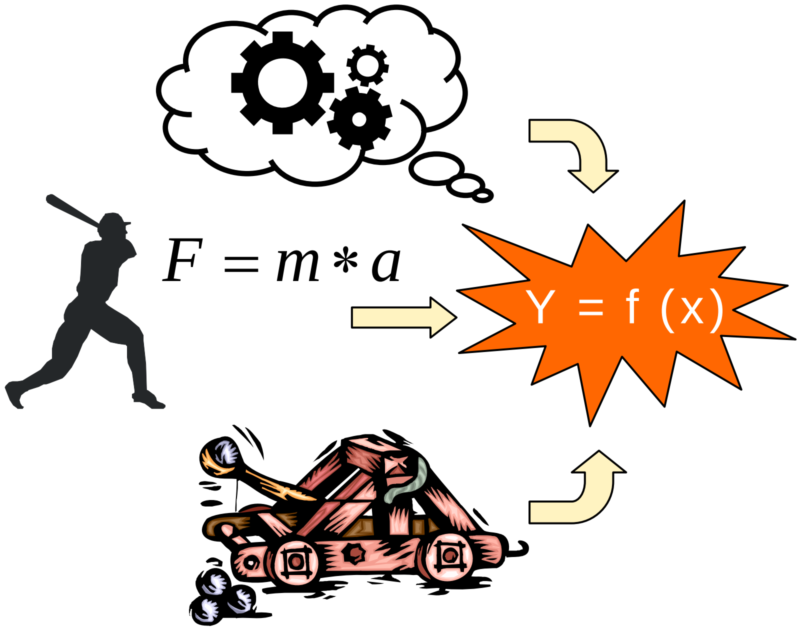
Agenda

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

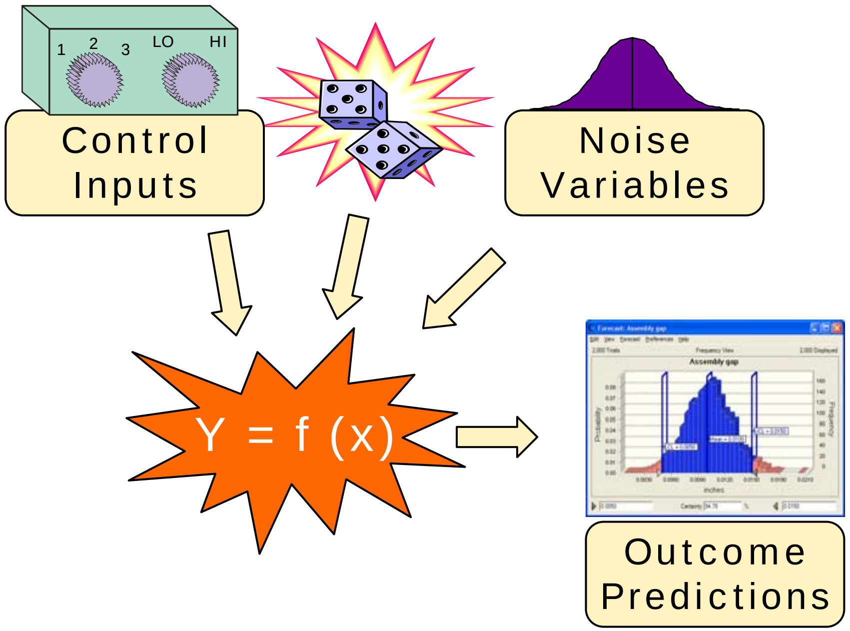
Models and Simulation

- 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



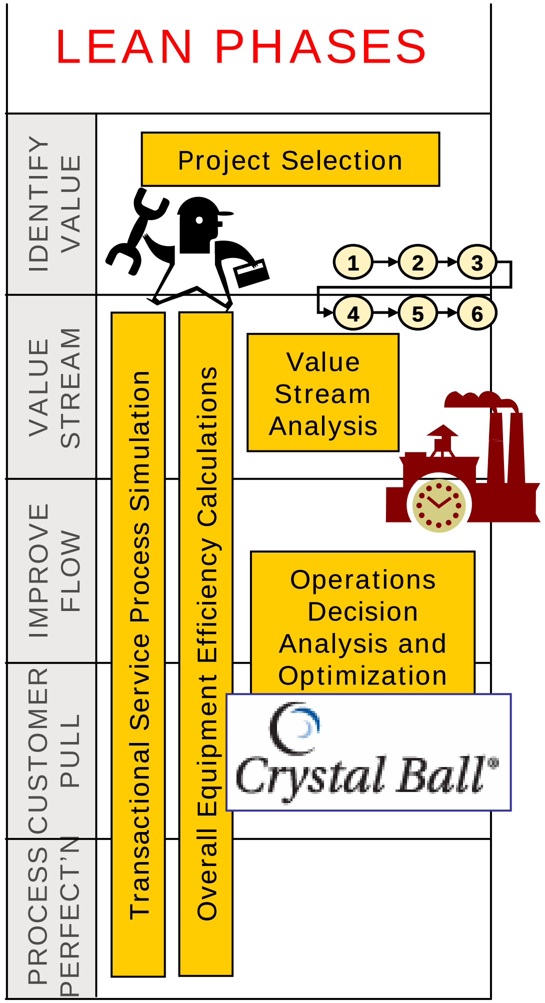
SIMULATION



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)

Typical Simulation Roles in Lean 6σ Projects

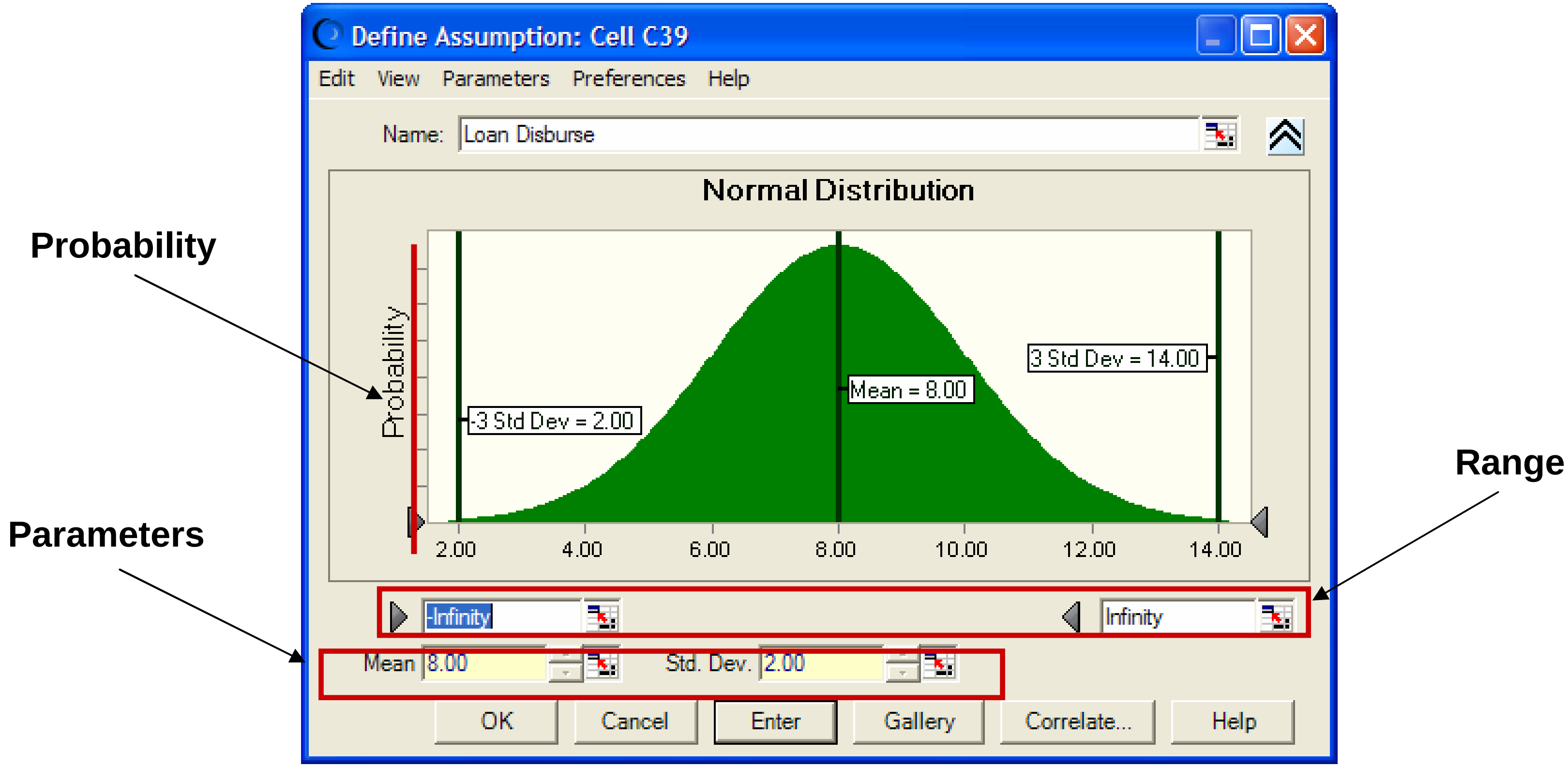


Monte Carlo Simulation and Optimization can be used in many Lean & Six Sigma phases:

- 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

Inputs: Probability Distributions

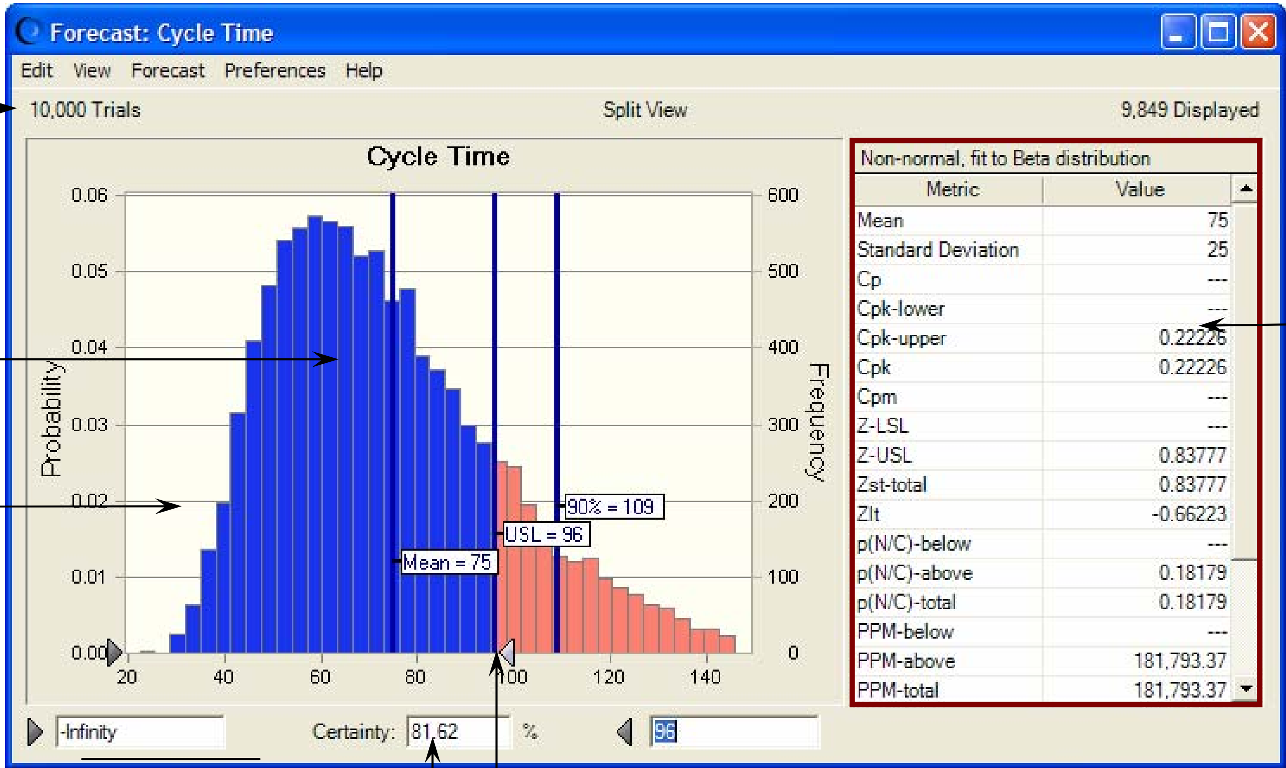
- Simulation requires probabilistic inputs.
- Distributions use ranges of values and assign a likelihood of occurrence for values (e.g., a normal distribution could represent variation of the part dimensions).



Outputs: Charts and Tables

Number of simulation trials

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



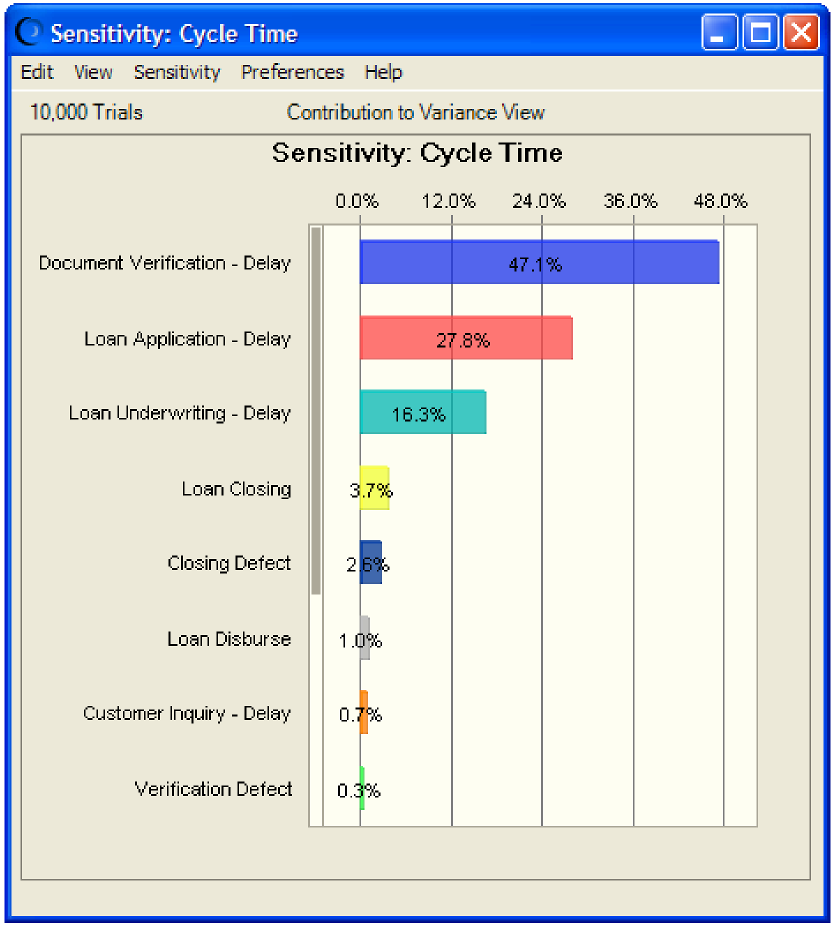
Certainty (probability) that the forecast lies between LSL and USL

Upper Spec Limit (USL)

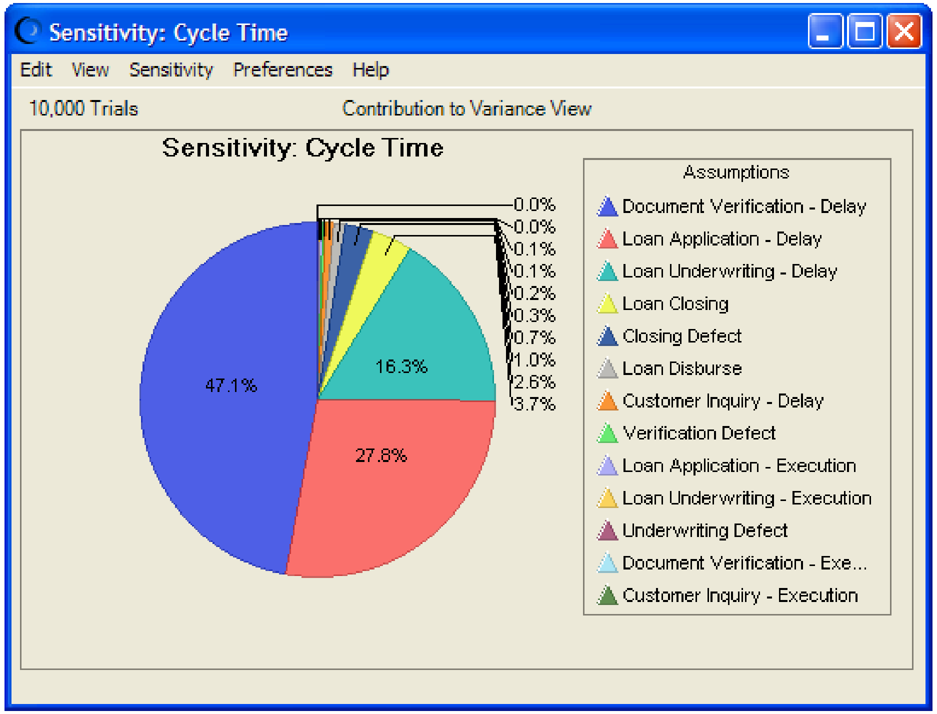
Quality Metrics such as C_{pk}, Z_{ST}, p(N/C), etc....

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



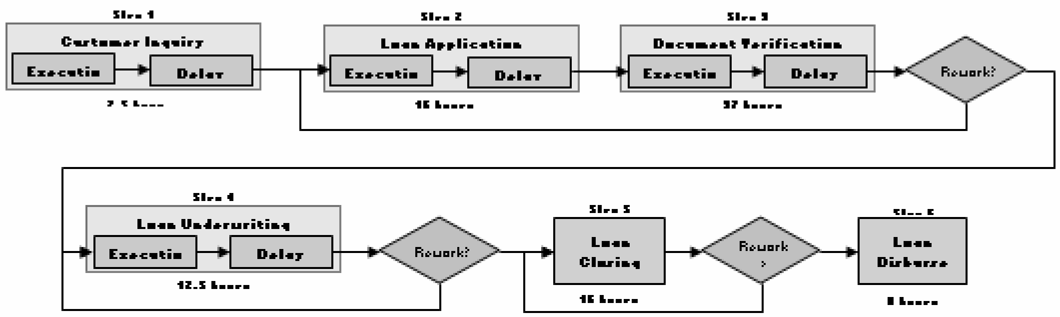
Sensitivity Analysis: Using the Results



- 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

Loan Process Example

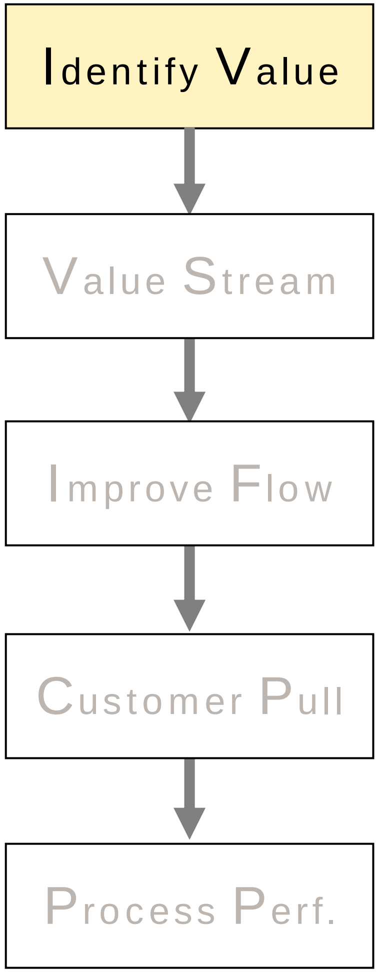
Loan Process Example with Delays and Rework



Performance Target: 96

Process Step	Simulated Cycle	Assumption Parameters				Simulated Delay	Average Delay	Rework Necessary	Probability of
Step 1:	0.5	0.5	0.125		*lognormal(mean,st dev)*	2	2		
Step 2:	2	0.5	1	4	*triangular(min, likely max)*	14	14		
Step 3:	1	0.5	1	80%	*custom (two conditions)*	18	18	0	30%
		1	2	20%					
Step 4:	1.5	1	2		*uniform(min, max)*	10	10	0	20%
Step 5:	16				*(fit to data on Data tab)*			0	5%
Step 6:	8	8	2		*normal(mean,st dev)*				
Cycle Time	73								
VA Efficien	39.7%								

Problem Statement



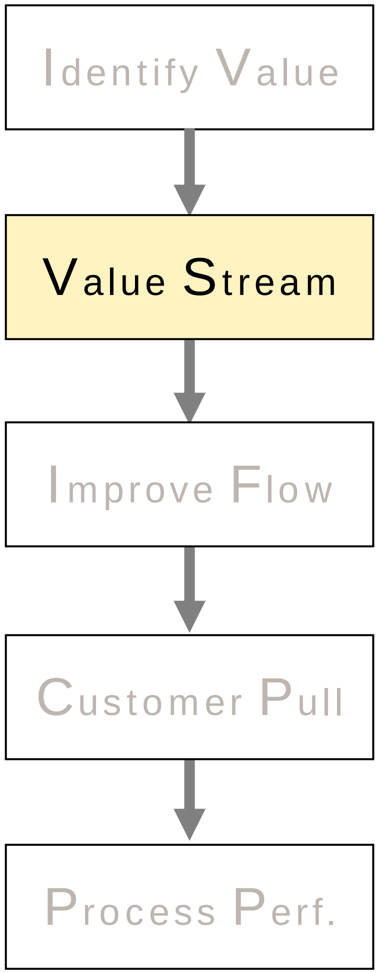
- A financial organization wishes to use Lean Six Sigma techniques on increasing the efficiency and decreasing the variation of their Loan Process.
- Customer: Loan Applicants
- Note: This could really be any simple process or sub-process / cell

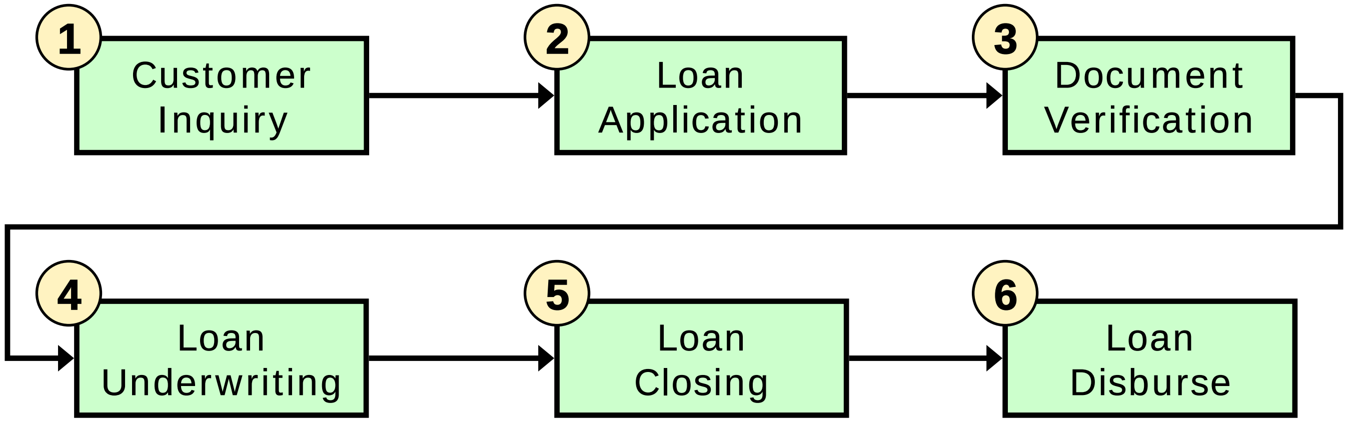
Crystal Ball

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.	

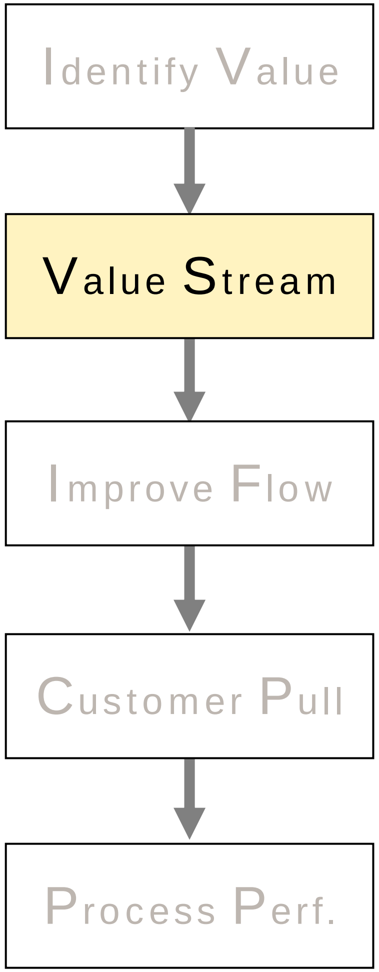
Step 1: High-Level Process Map

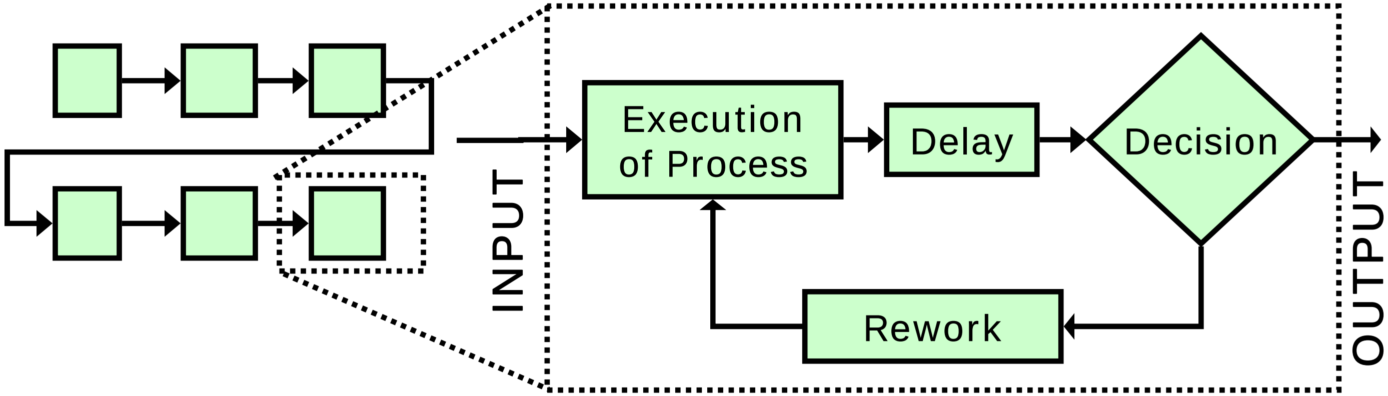




- Delays and Rework in Loan Process do not add value to customers.
- Use Process Map and Value Stream techniques to identify delays and rework (assuming all identified process execution steps are Value-Added).

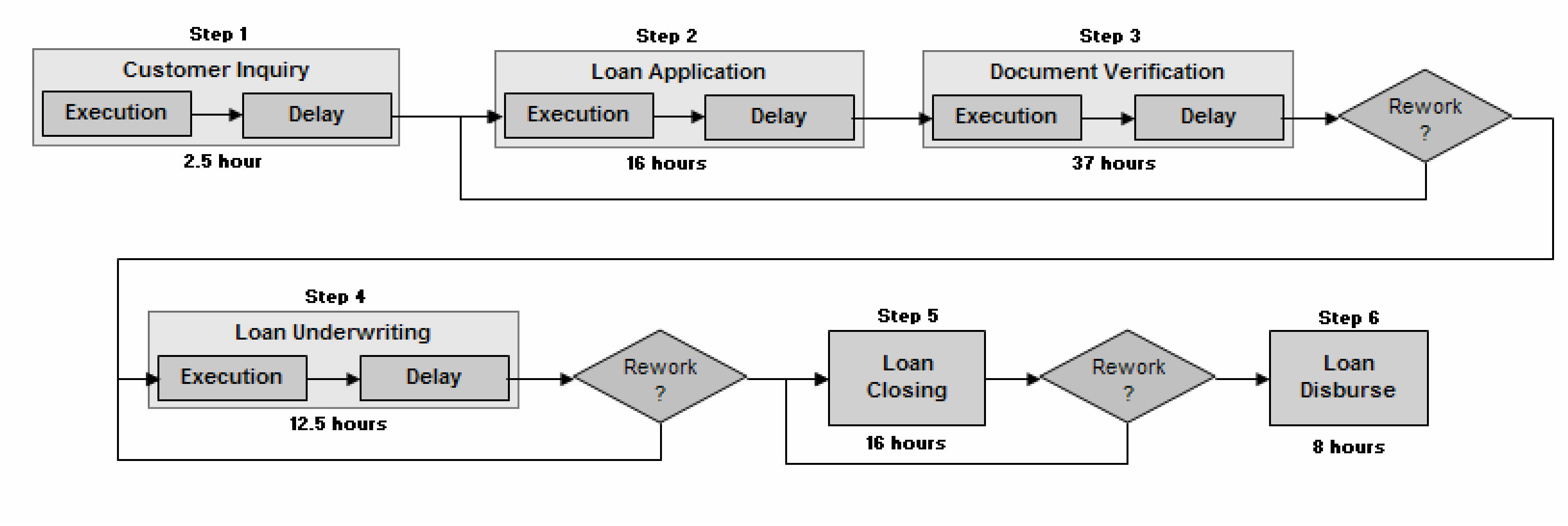
Step 2: Refinement of High-Level Process Map





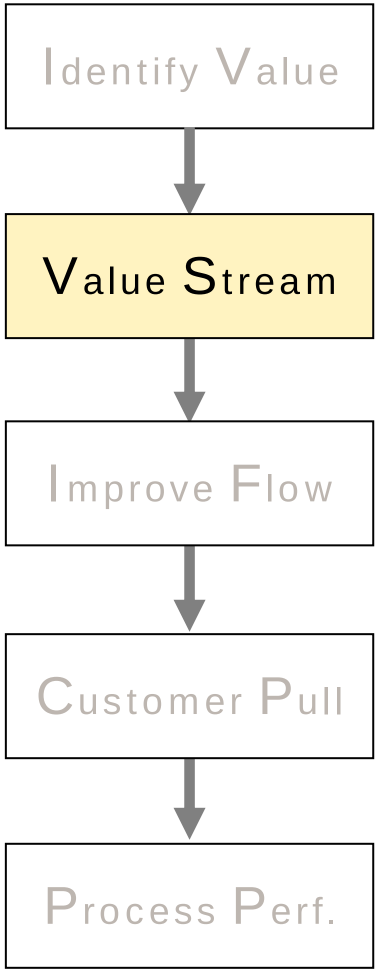
- Unfortunately, high-level process maps generally do not consider delay times or rework cycles at each process step (“Hidden Factory”).
- Using Monte Carlo techniques, we can model the variation in execution & delay times, in addition to defects (reworks) occurring at each high-level process step!

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



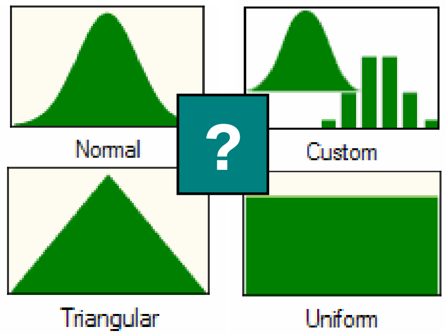
As part of the Value Stream Phase, an estimate or measurement of the process step times needs to be captured:

- **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.

Building the Model - 1

Process Step	Simulated Cycle Time	Assumption Parameters			
Step 1:	0.5	0.5	0.125		*lognormal (mean, st dev)*
Step 2:	2	0.5	1	4	*triangular (min, likely max)*
Step 3:	1	0.5	1	80%	*custom (two conditions)*
		1	2	20%	
Step 4:	1.5	1	2		*uniform (min, max)*
Step 5:	16				*(fit to data on Data tab)*
Step 6:	8	8	2		*normal (mean, st dev)*

For Execution inputs, define each step as the appropriate distribution

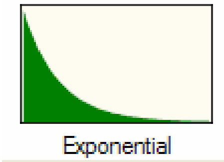


Building the Model - 2

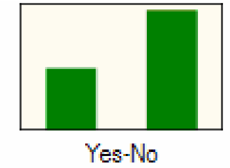
Simulated Delay Time	Average Delay Time
2	2
14	14
18	18
10	10

Rework Necessary?	Probability of Rework
0	30%
0	20%
0	5%

For Delay, define each step as an Exponential distribution



For Defects, define each step as a Yes / No (Binomial with 1 trial)



Building the Model - 3

Performance Target:	96

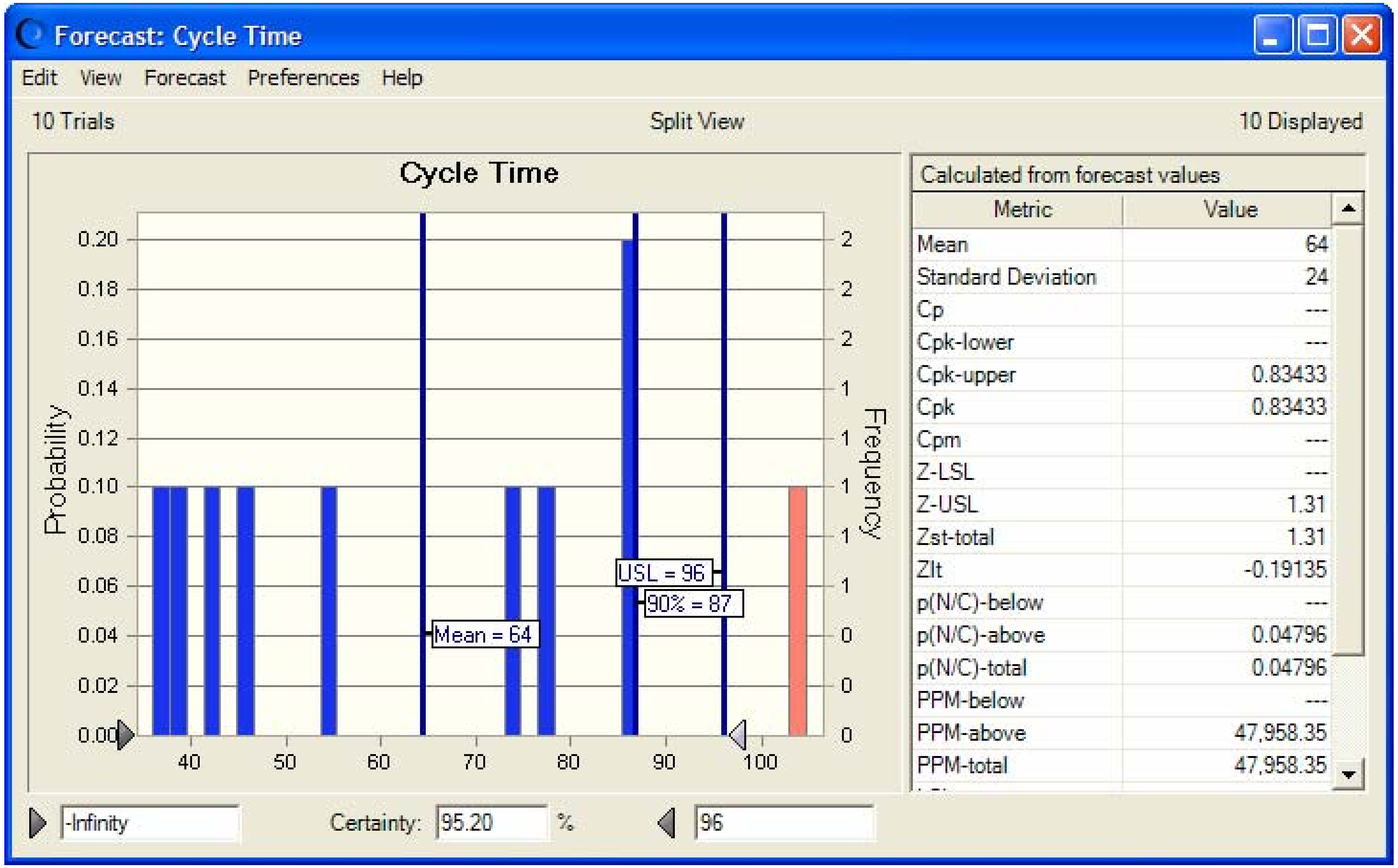
Process Step	Simulated Cycle Time	Assumption Parameters				Simulated Delay Time	Average Delay Time	Rework Necessary?	Probability of Rework
Step 1:	0.5	0.5	0.125		*lognormal (mean, st dev)*	2	2		
Step 2:	2	0.5	1	4	*triangular (min, likely max)*	14	14		
Step 3:	1	0.5	1	80%	*custom (two conditions)*	36	36	0	30%
		1	2	20%					
Step 4:	1.5	1	2		*uniform (min, max)*	10	10	0	20%
Step 5:	16				*(fit to data on Data tab)*			0	5%
Step 6:	8	8	2		*normal (mean, st dev)*				

Cycle Time	91
VA Efficiency	31.9%

- 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?)

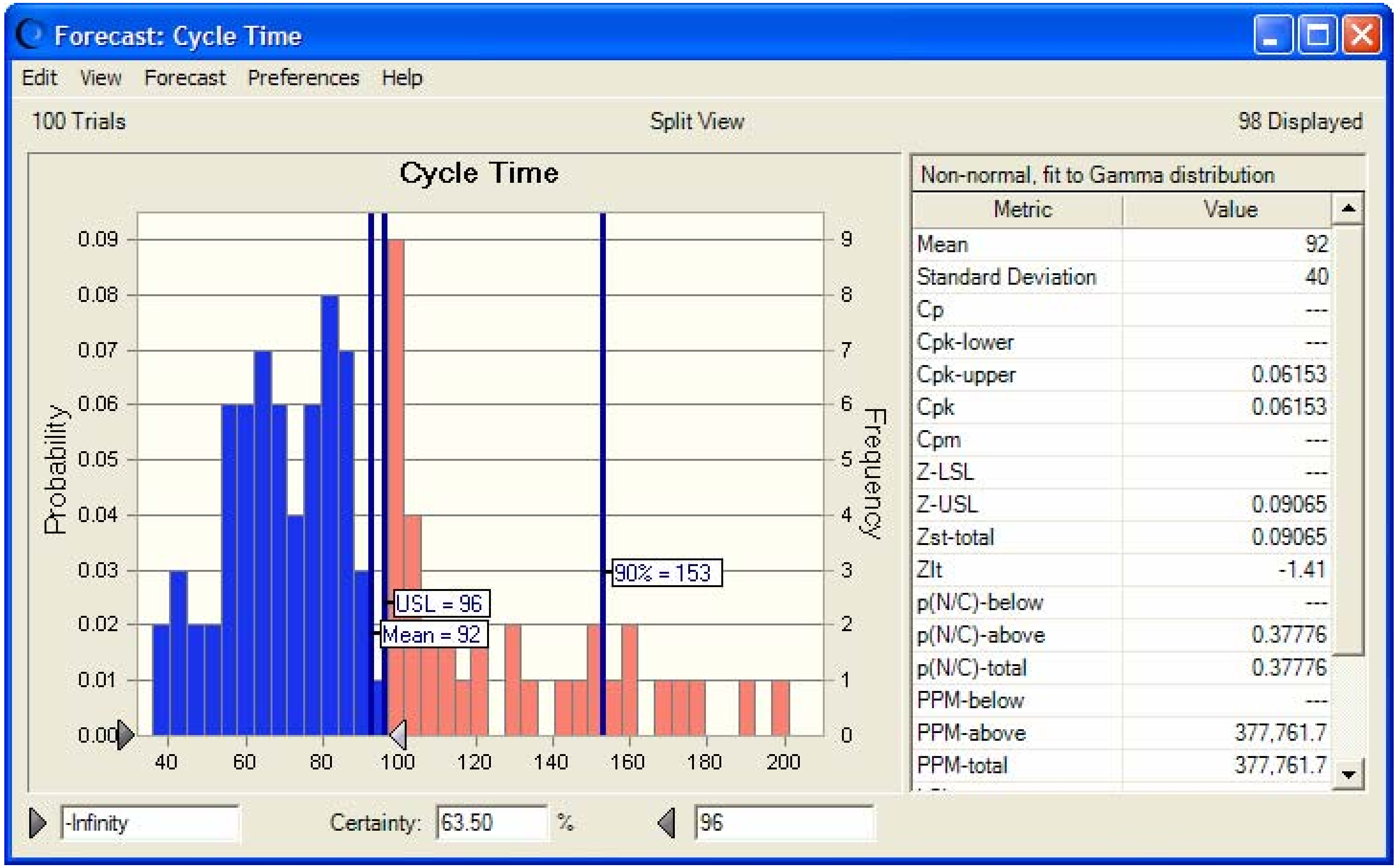
Step 4: Monte Carlo Simulation to Predict Variation

Rather than run single steps, can run thousands of trials quickly.



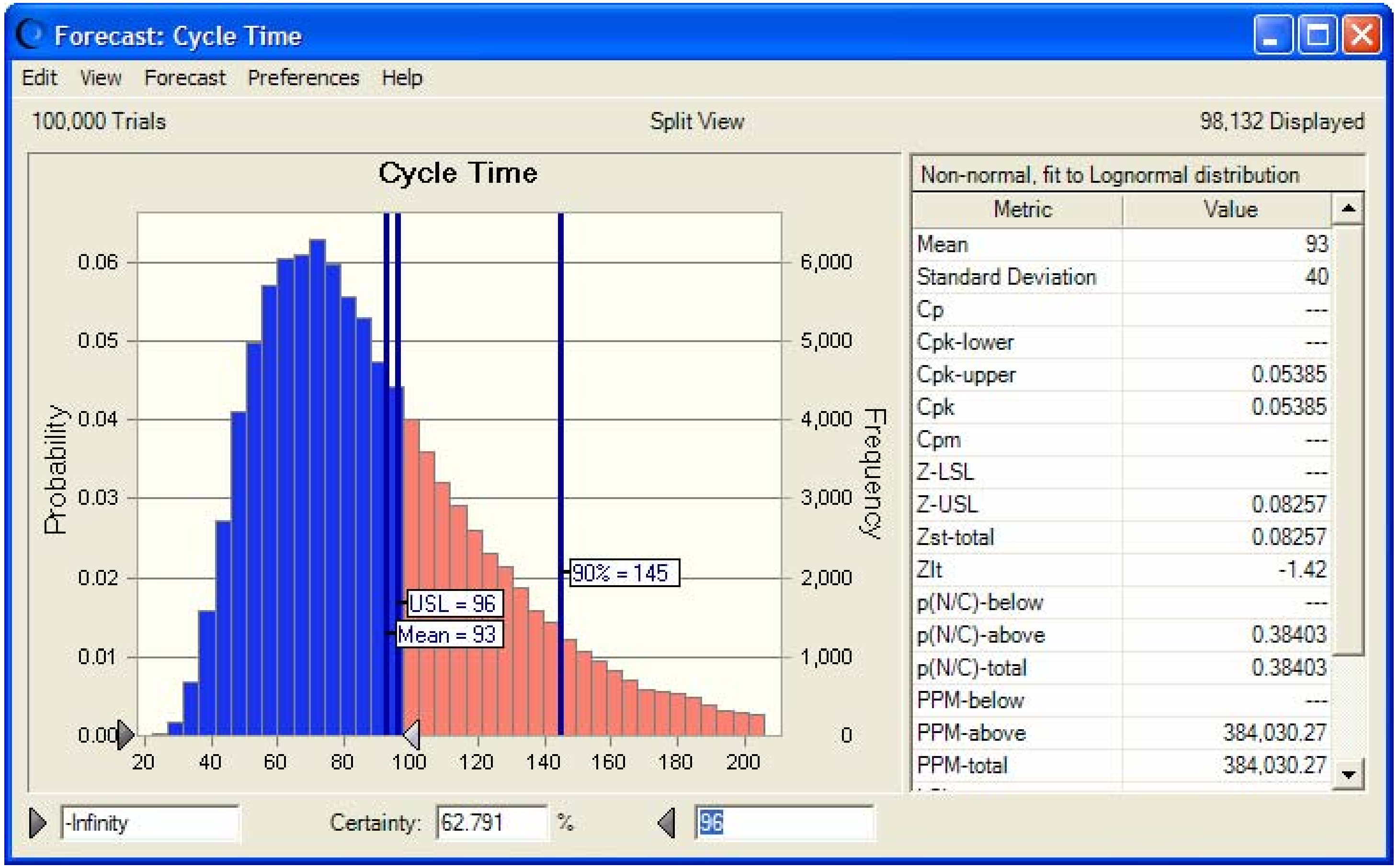
Step 4: Monte Carlo Simulation to Predict Variation

Rather than run single steps, can run thousands of trials quickly.



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?

Forecast: Cycle Time

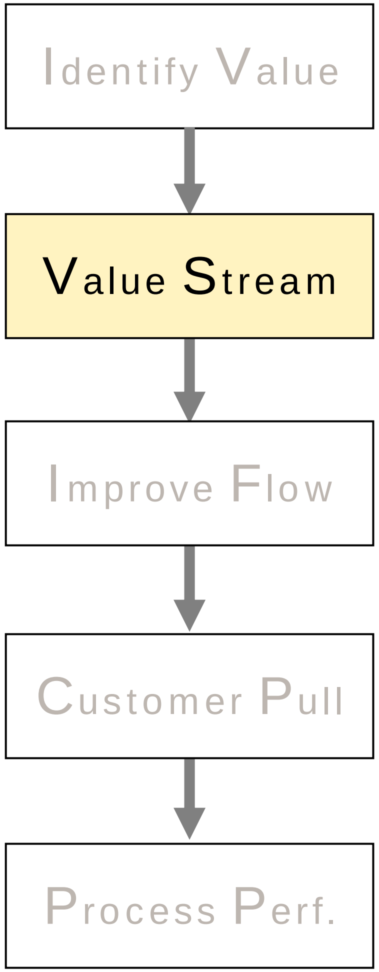
Edit View Forecast Preferences Help

10,000 Trials Capability Metrics View 9,820 Displayed

Non-normal, fit to Lognormal distribution

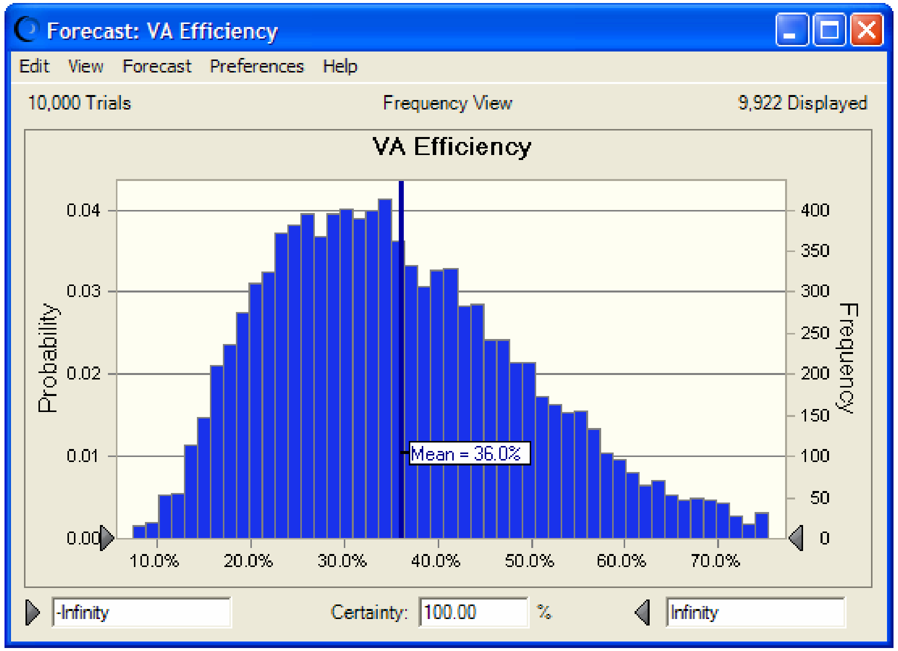
Metric	Value
Mean	93
Standard Deviation	40
Cp	---
Cpk-lower	---
Cpk-upper	0.054
Cpk	0.054
Cpm	---
Z-LSL	---
Z-USL	0.08414
Zst-total	0.08414
Zlt	-1.42
p(N/C)-below	---
p(N/C)-above	0.38389
p(N/C)-total	0.38389
PPM-below	---
PPM-above	383,892.49
PPM-total	383,892.49
LSL	---
USL	96
Target	---
Shift	1.5

Monte Carlo Simulation to Predict Variation

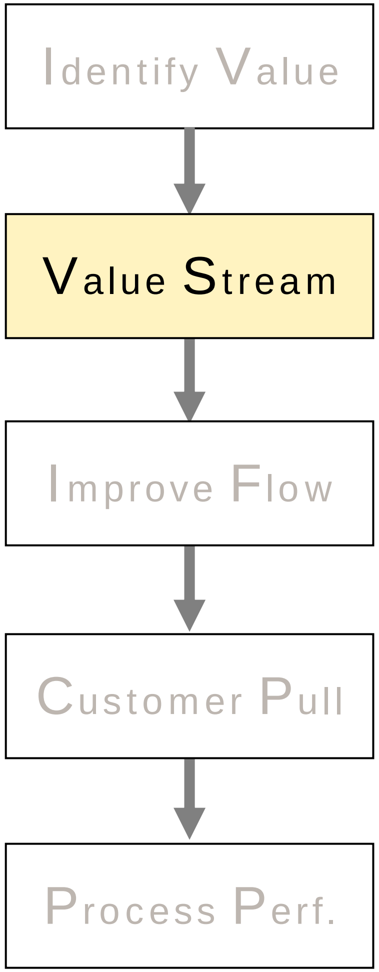


VA Efficiency is reduced by including effect of added Cycle Time due to delay times and rework cycles (non-value-added steps)

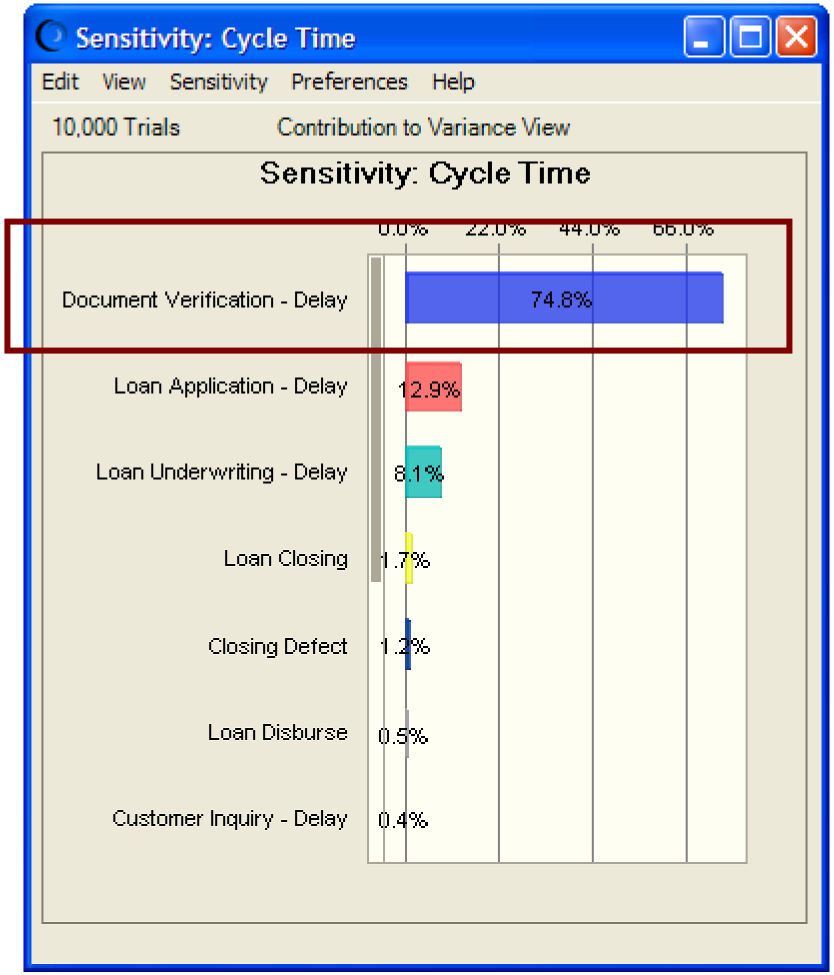
– VA Efficiency mean less than 100% (~ 35%)



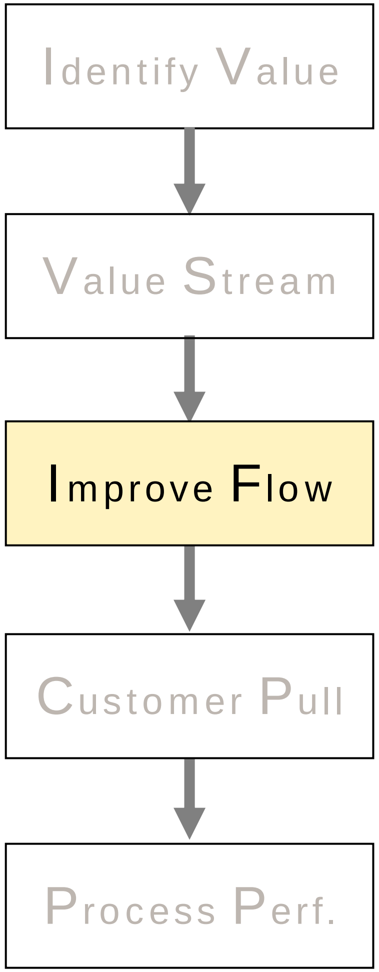
Step 5: Review Sensitivity Analysis



- 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.

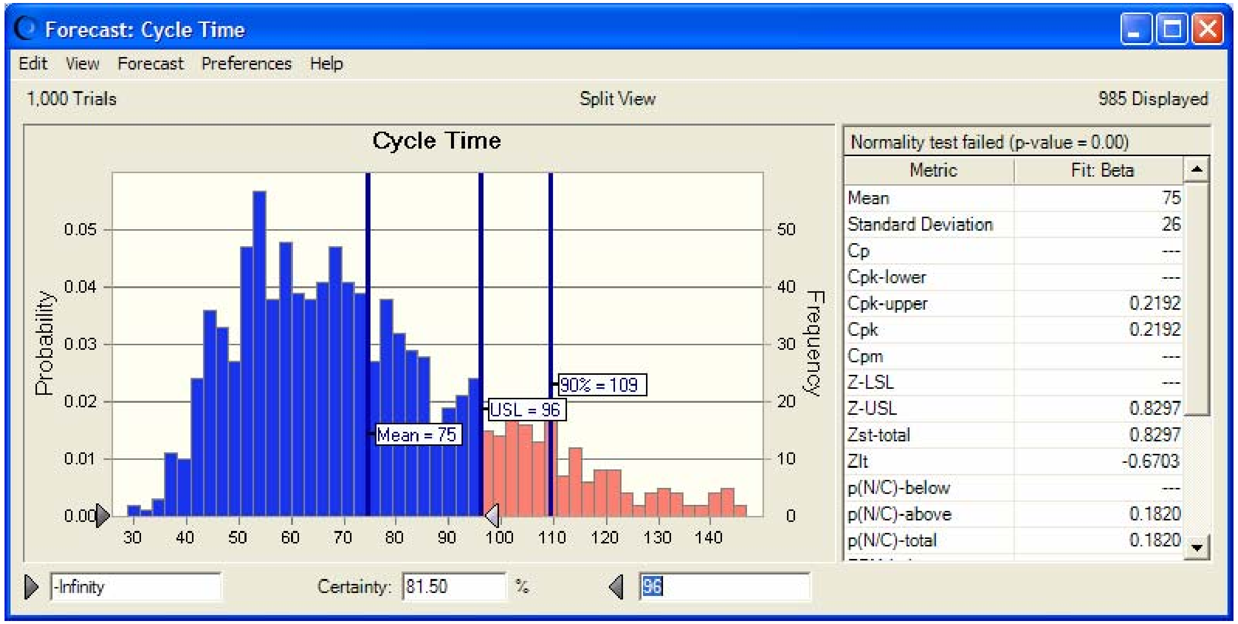


Step 6: Reiterate Monte Carlo Analysis

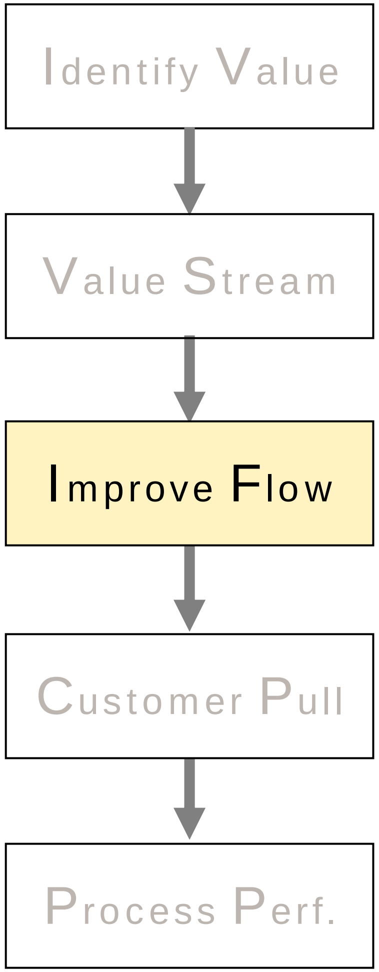


- Run Monte Carlo again → less than 20% of process loans are out of specification → Sigma Level of ~ +0.8

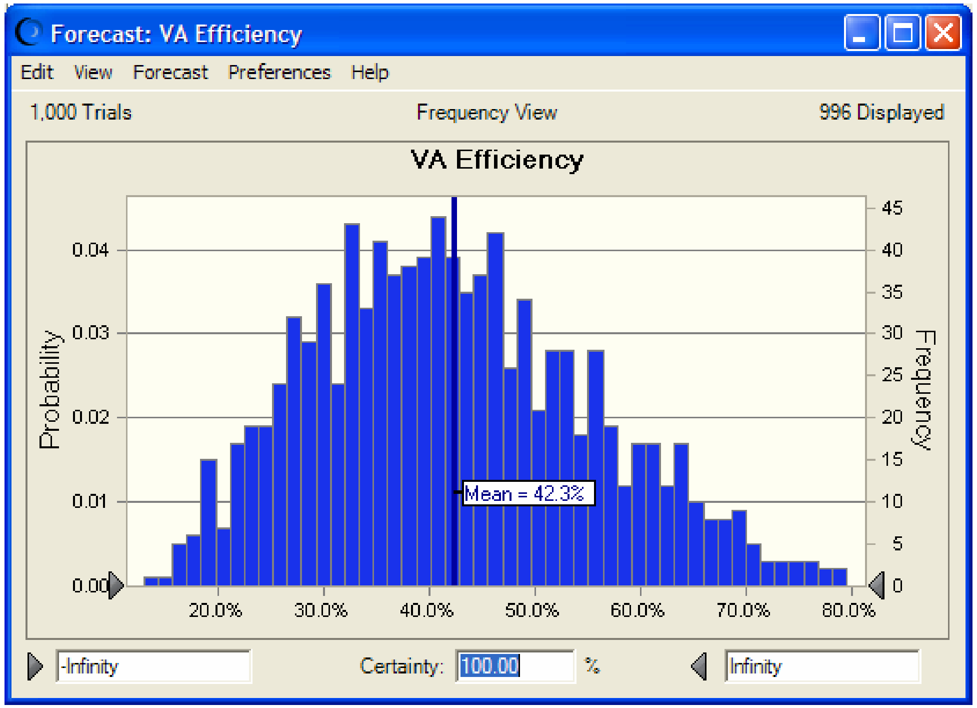
- The Loan Process Cycle Time quality has been improved.



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%)!



Crystal Ball

Comparison of Results

Stage	Mean Cycle Time	Mean VA Efficiency	Standard Deviation	Sigma Level
Base Case	91 hours?	31.5%?	???	???
As-Is Sim	93 hours	~35%	40 hours	.08
To-Be Sim	75 hours	~40%	26 hours	.83

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

Order Quantity	250	units	Order Cost	$ 50	
Reorder Point	250	units	Holding Cost	$ 0.20	
Initial Inventory	250	units	Lost Sales Cost	$ 100	
Lead time	2	weeks			

Optimize order quantity and reorder point to minimize costs

Total Annual Costs			
$1,040	$1,050	$5,000	$ 7,090

Week	Beg Inv Pos	Beg Inv	Order Rec'd	Units Rec'd	Dmd	End Inv	Lost Sales	Order Placed?	Ending Inv Pos	Week Due	Hold Cost	Order Cost	Short Cost	Total Cost
1	250	250		0	100	150	0	TRUE	400	4	$30.00	$ 50	$ -	$ 80
2	400	150		0	100	50	0	FALSE	300		$10.00	$ -	$ -	$ 10
3	300	50	FALSE	0	100	0	50	TRUE	500	6	$ -	$ 50	$5,000	$ 5,050
4	500	0	TRUE	250	100	150	0	FALSE	400		$30.00	$ -	$ -	$ 30
5	400	150	FALSE	0	100	50	0	FALSE	300		$10.00	$ -	$ -	$ 10
6	300	50	TRUE	250	100	200	0	TRUE	450	9	$40.00	$ 50	$ -	$ 90
7	450	200	FALSE	0	100	100	0	FALSE	350		$20.00	$ -	$ -	$ 20
8	350	100	FALSE	0	100	0	0	TRUE	500	11	$ -	$ 50	$ -	$ 50
9	500	0	TRUE	250	100	150	0	FALSE	400		$30.00	$ -	$ -	$ 30
10	400	150	FALSE	0	100	50	0	FALSE	300		$10.00	$ -	$ -	$ 10
11	300	50	TRUE	250	100	200	0	TRUE	450	14	$40.00	$ 50	$ -	$ 90
12	450	200	FALSE	0	100	100	0	FALSE	350		$20.00	$ -	$ -	$ 20
13	350	100	FALSE	0	100	0	0	TRUE	500	16	$ -	$ 50	$ -	$ 50
14	500	0	TRUE	250	100	150	0	FALSE	400		$30.00	$ -	$ -	$ 30
15	400	150	FALSE	0	100	50	0	FALSE	300		$10.00	$ -	$ -	$ 10

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.

Crystal Ball

Step 1: Create Excel Model

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

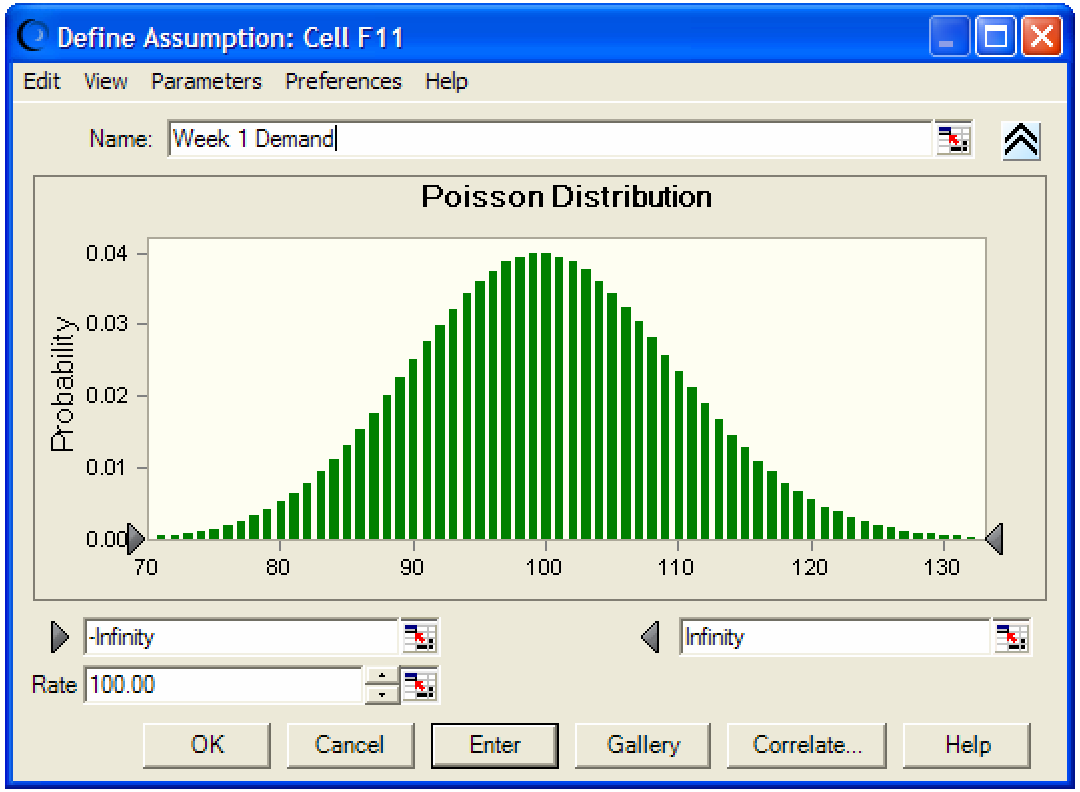
Optimize order quantity and reorder point to minimize costs

Total Annual Costs			
$1,040	$1,050	$5,000	$ 7,090

Week	Beg Inv Pos	Beg Inv	Order Rec'd	Units Rec'd	Dmd	End Inv	Lost Sales	Order Placed?	Ending Inv Pos	Week Due	Hold Cost	Order Cost	Short Cost	Total Cost
1	250	250		0	100	150	0	TRUE	400	4	$30.00	$ 50	$ -	$ 80
2	400	150		0	100	50	0	FALSE	300		$10.00	$ -	$ -	$ 10
3	300	50	FALSE	0	100	0	50	TRUE	500	6	$ -	$ 50	$5,000	$ 5,050
4	500	0	TRUE	250	100	150	0	FALSE	400		$30.00	$ -	$ -	$ 30
5	400	150	FALSE	0	100	50	0	FALSE	300		$10.00	$	$	$ 10

- 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

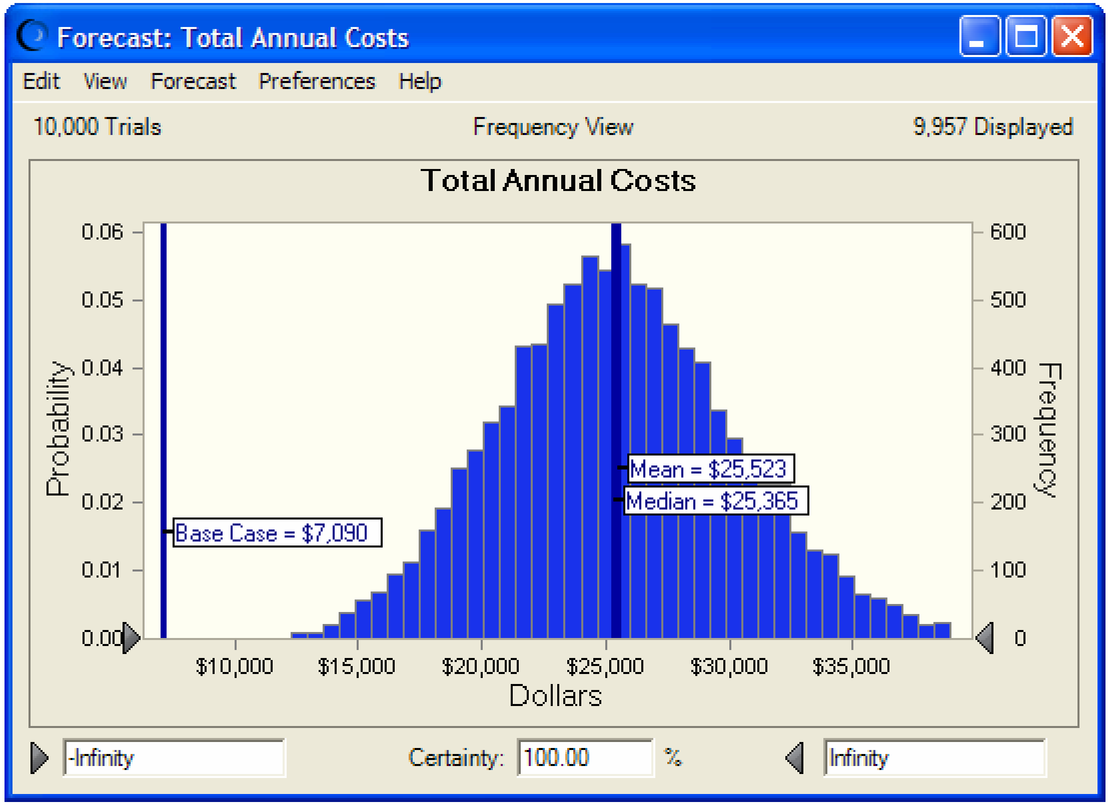
Step 2: Define Key Assumptions



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)

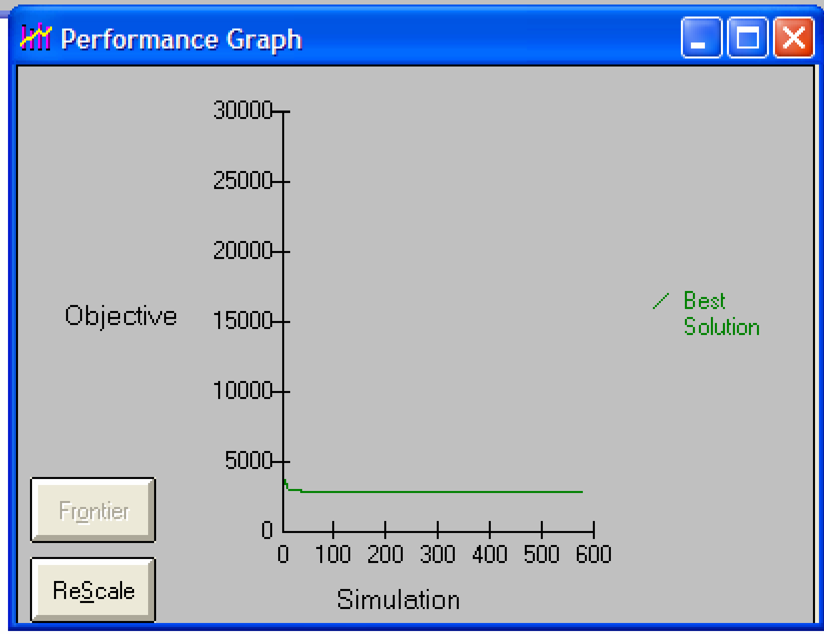
Optimization (1 = 1000 trials)	Order Quantity	Reorder Point	Minimized Cost (mean)
1	250	265	$18,474
2	345	320	$2,791
3	325	275	$7,705

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.

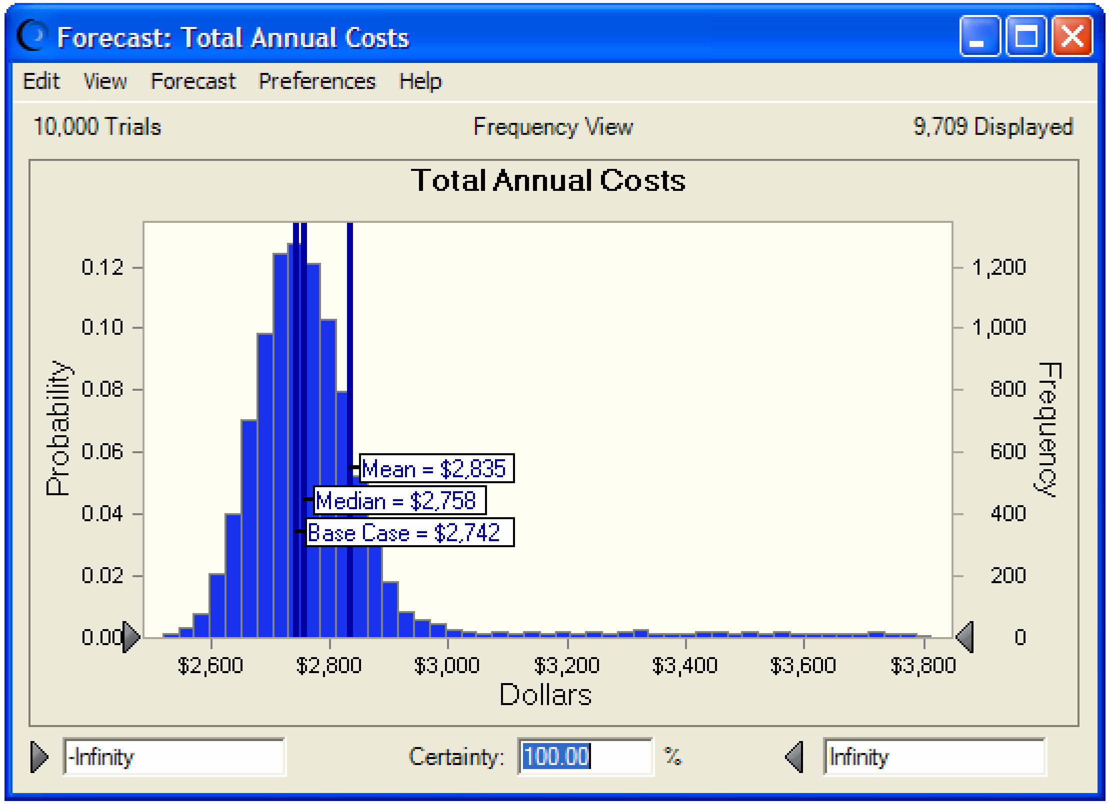
Optimization

Simulation	Minimize Objective Total Annual Costs Mean	Order Quantity	Reorder Point
2	4549.66	300	300
4	3755.89	400	400
7	3452.86	320	385
11	3062.83	350	350
13	3020.66	380	315
18	2964.73	375	325
Best: 36	2824.97	330	325



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

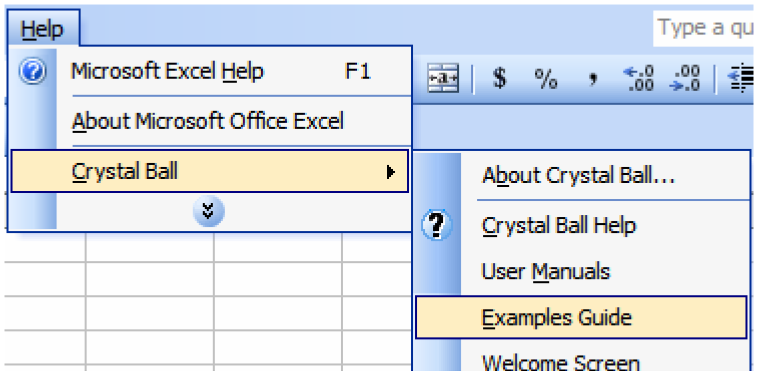
Waiting……………………………………………………………Workforce with Queing

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 6σ 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

Oracle
Crystal Ball Global Business Unit
Phone: +1.303.534.1515
Fax: +1.303.534.4818
HILARY.EMMETT@ORACLE.COM

Crystal Ball®

Improve the quality of your critical business decisions

Special Thanks to Larry Goldman for case study contributions