Monte Carlo Simulation

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The Global Voice of Quality

The Casino Connection

Modern version credited to Stanislaw Ulam and John von Neumann for their work in the 1940's on nuclear weapons research at Los Alamos Scientific Laboratory

The code name "Monte Carlo" was created to refer to their work

Markov Chain Monte Carlo

Based on the Markov process, defined by Andrey Markov

A Markov Chain is a series of process steps, where the outcome of any one step in the process is not dependent on the outcome of the previous steps

- This feature is referred to as “memorylessness”

IID

Independent and Identically Distributed

When can we make that assumption?

Autoregressive Behavior

The last ‘n’ outcomes can be used to predict the next outcome

Demand Forecasting

Can we assume IID

Stability of the mean and variance?

Is there an autoregressive component, or is it memoryless?

Financial Forecasting

Memoryless?

Autoregressive?

IID over time?

Airport Queues

Memoryless?

IID

What about the effect of self-optimization on queue performance?

Queue Time as an Input

With Monte Carlo simulation, time in queue is an input to the model

Any concerns?

Constructing a Monte Carlo model

Identify component inputs

Construct the transfer function

IF's

Generate a binary variable which represents the probability of a single outcome

- Probability of NOT having a pre-printed boarding pass = 63%

B1 = binary with p(1) = .63, p(0) = .37

TC = distribution of delay time at ticket counter

Total Time = …. + TC * B1 + …

OR's

Generate a binary variable which represents the probability of a single outcome

Probability of TSA pre-check = 24%

B2 = binary with p(1) = .24, p(0) = .76

TSEC = distribution of delay time at normal TSA checkpoint

TPRE = distribution of delay time at TSA Pre checkpoint

Total Time = …. + TPRE*B2 + TSEC*(1-B2) + …

Multiple IF's

If B1 and B2 and not B3

Total Delay = …+ D1 * B1 * B2 * (1-B3) + …

Multiple OR's

If B4 or B5 or B6

Total Delay = … +D2*{1-[(1-B4)*(1-B5)*(1-B6)]}

B4	B5	B6	Any One Happen?	(1-B4)*(1-B5)*(1-B6)	1-[(1-B4)*(1-B5)*(1-B6)]
1	1	1	Yes	0	1
1	1	0	Yes	0	1
1	0	1	Yes	0	1
1	0	0	Yes	0	1
0	1	1	Yes	0	1
0	1	0	Yes	0	1
0	0	1	Yes	0	1
0	0	0	No	1	0

Monte Carlo for Demand

Descriptive Statistics for sources of demand

- Mean, variance, shape of the distribution for each source of demand, D1, D2, D3, etc.

Transfer function is a simple additive model

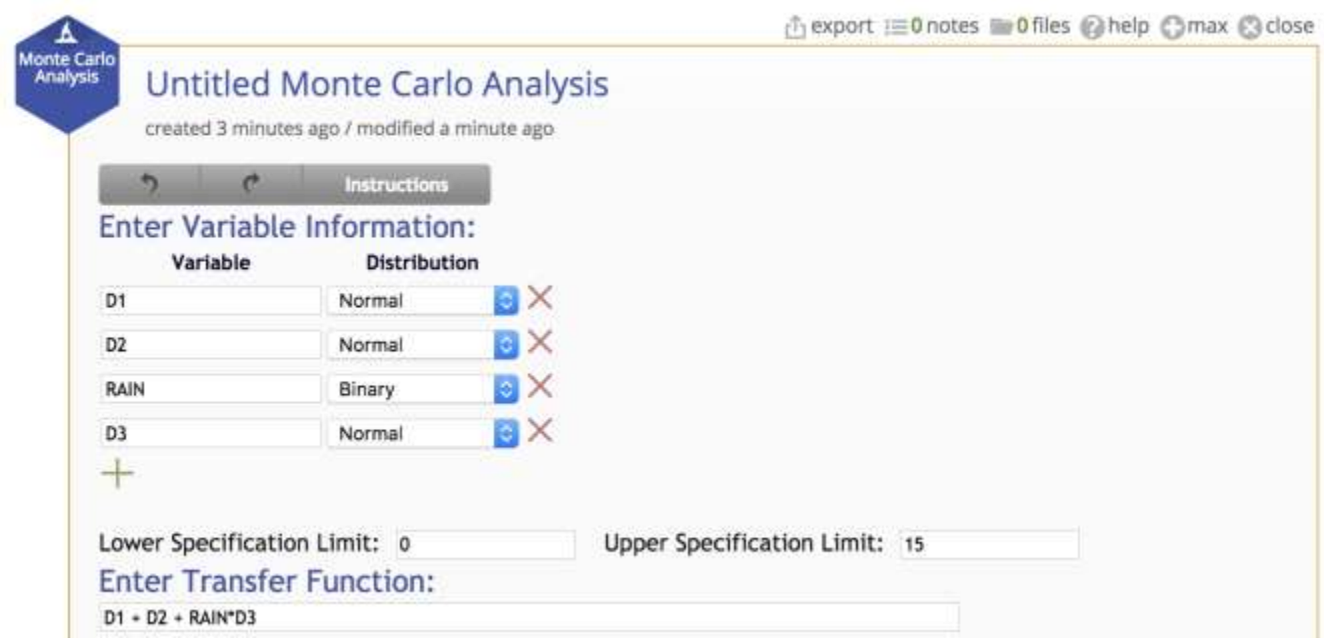
- D1 + D2 + D3 = Total Demand

Anything missing?

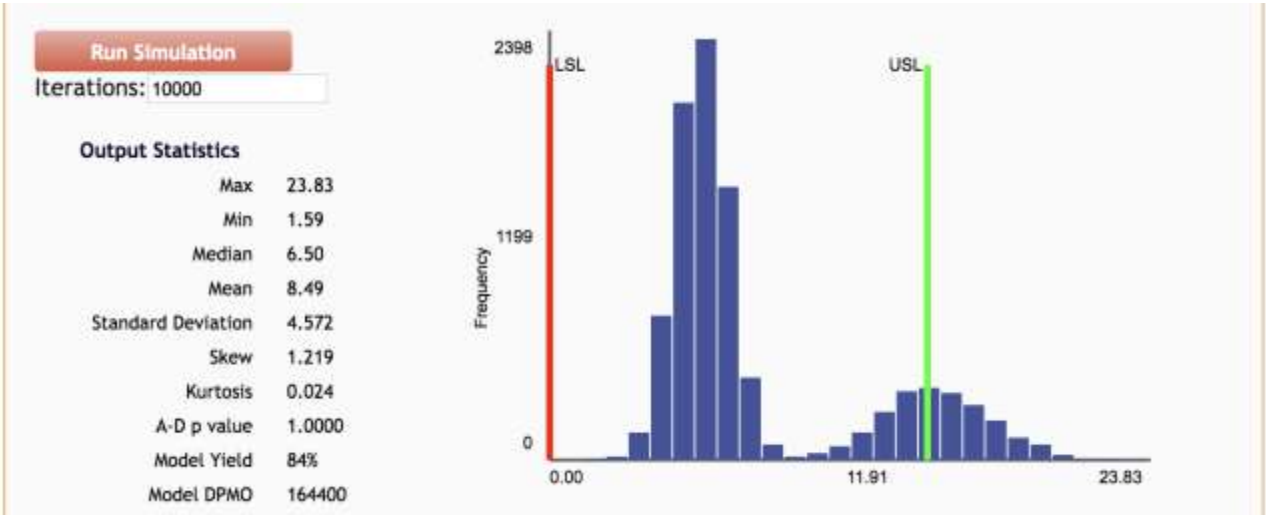
Experiment #1 – Umbrella Demand

Input Factor	Factor Name	Distribution	Mean	Std Dev (if applicable)
Demand Source 1	D1	Normal	4	1
Demand Source 2	D2	Normal	2	.5
Probability Rain	RAIN	Binary	P(RAIN) = .25	P(!RAIN) = .75
Demand Source 3	D3	Normal	10	2

Total Demand =
D1 + D2 + RAIN*D3



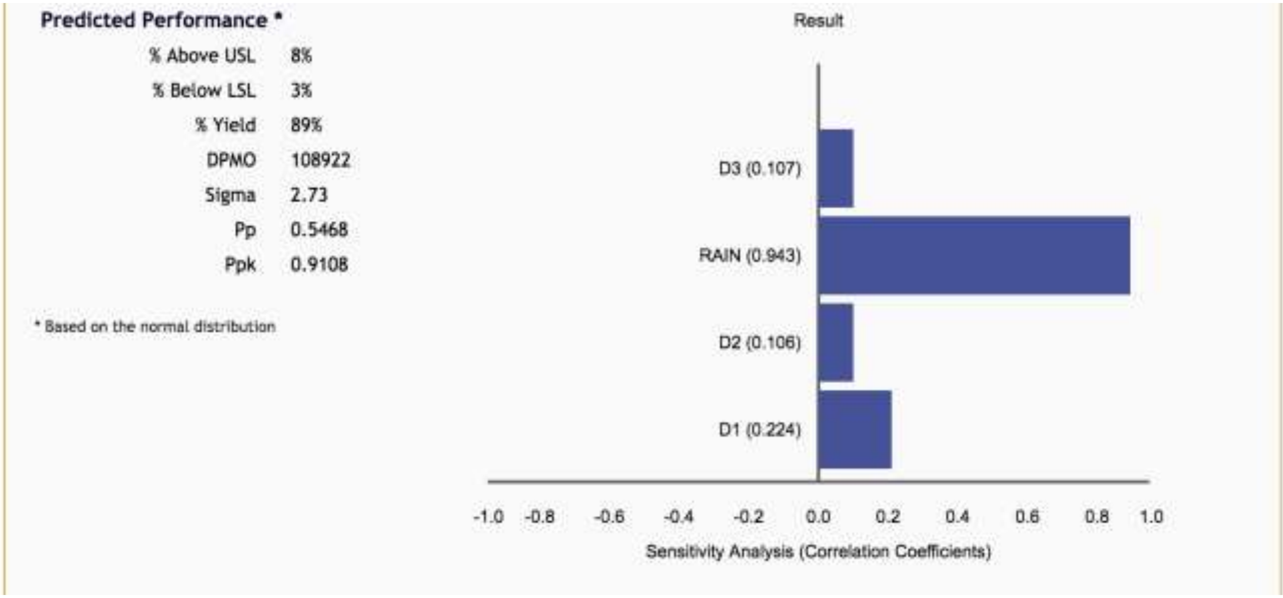
Upper Spec Limit = 15?



Model Yield = 84%

84% of days we will not run out of umbrella stock

Sensitivity Analysis



Rain has the strongest correlation with the output, total demand of umbrellas

Monte Carlo for Financial Forecasting

Descriptive Statistics for expected cash flows

- Initial investment, C0
- Mean, variance, shape of the distribution for expected cash flows of future periods, F1, F2, F3
- The weighted average cost of capital (WACC) for your organization, i

Transfer function is the time value of money formula

- $C0 + (F1/(1+i)) + (F2/(1+i)^2) + (F3/(1+i)^3)$

Anything missing?

Experiment #2 – Financial Returns

Input Factor	Factor Name	Distribution	Mean	Std Dev
Project Cost	COST	Uniform Real	Min = 1000	Max = 1200
Year 1 return	R1	Normal	600	100
Year 2 return	R2	Normal	400	150
Year 3 return	R3	Normal	350	200

WACC (discount rate, interest rate) = 10%

Total Return = -COST + (R1/(1+0.1)) + (R2/(1+0.1)^2 + (R3/(1+0.1)^3)

Is the project worth doing? Might we lose money?

Results

Run Simulation

Iterations: 10000

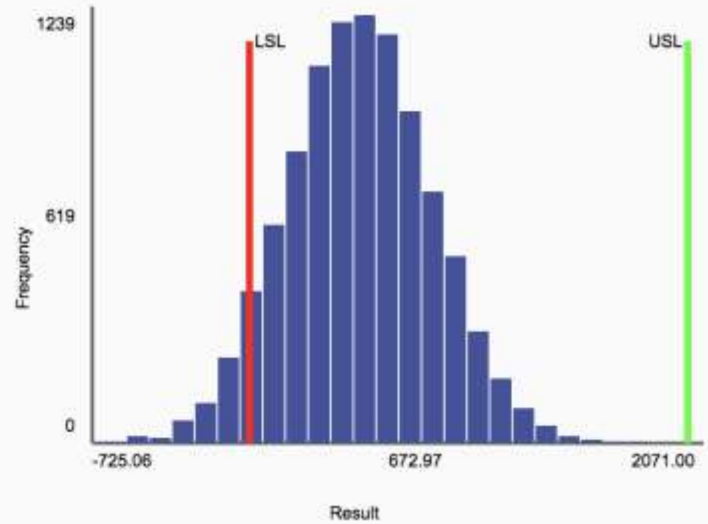
Output Statistics

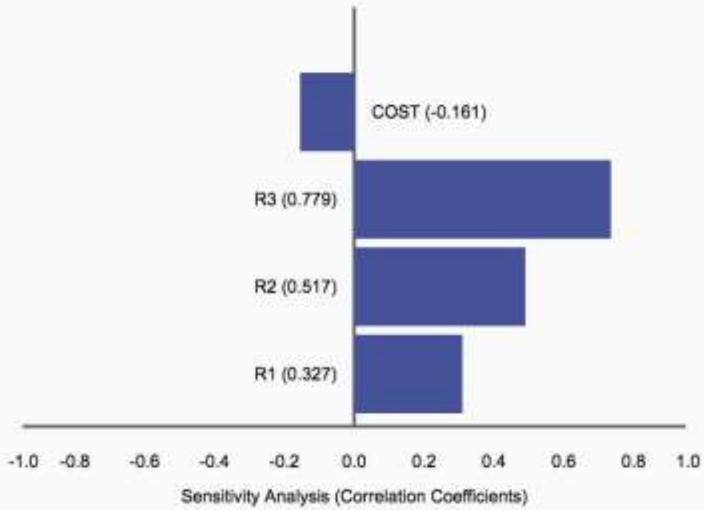
Max	2071.00
Min	-725.06
Median	536.27
Mean	536.96
Standard Deviation	354.980
Skew	0.036
Kurtosis	-0.041
A-D p value	0.6371
Model Yield	94%
Model DPMO	65000

Predicted Performance *

% Above USL	0%
% Below LSL	7%
% Yield	93%
DPMO	65204
Sigma	3.01
Pp	0.9390
Ppk	1.0042

* Based on the normal distribution





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Monte Carlo for Airport Queues

Descriptive Statistics for sources of delay

- Mean, variance, shape of the distribution for each source of delay:
  - Parking, ticket counter, TSA, walk to gate, etc.

What if you pre-print your boarding pass and can skip the counter?

How can we handle “IF’s” and “OR’s” with Monte Carlo

Experiment #3 – Airport Queues

Input Factor	Factor Name	Distribution	Mean (min)	Std Dev (mode)	(max)
Ticket Counter to get boarding pass (including bag check)	GETPASS	Normal	6	2	
Need Ticket	NEEDPASS	Binary	P(NEED) = 0.5		
Bag Check	CHECKBAG	Normal	4	1	
Have Bag?	HAVEBAG	Binary	P(BAG) = 0.25		
TSA Pre?	TSAPRE	Binary	P(PRE) = 0.20		
TSA Queue	TSAQ	Triangular	10	30	40
TSA Check	TSAC	Erlang	1	3	4
TSAPre Queue	TSAPQ	Erlang	0	2	4
TSAPre Check	TSAPC	Erlang	0.5	1	2

Total Time =

NEEDPASS*GETPASS +

HAVEBAG*(1-NEEDPASS)*CHECKBAG +

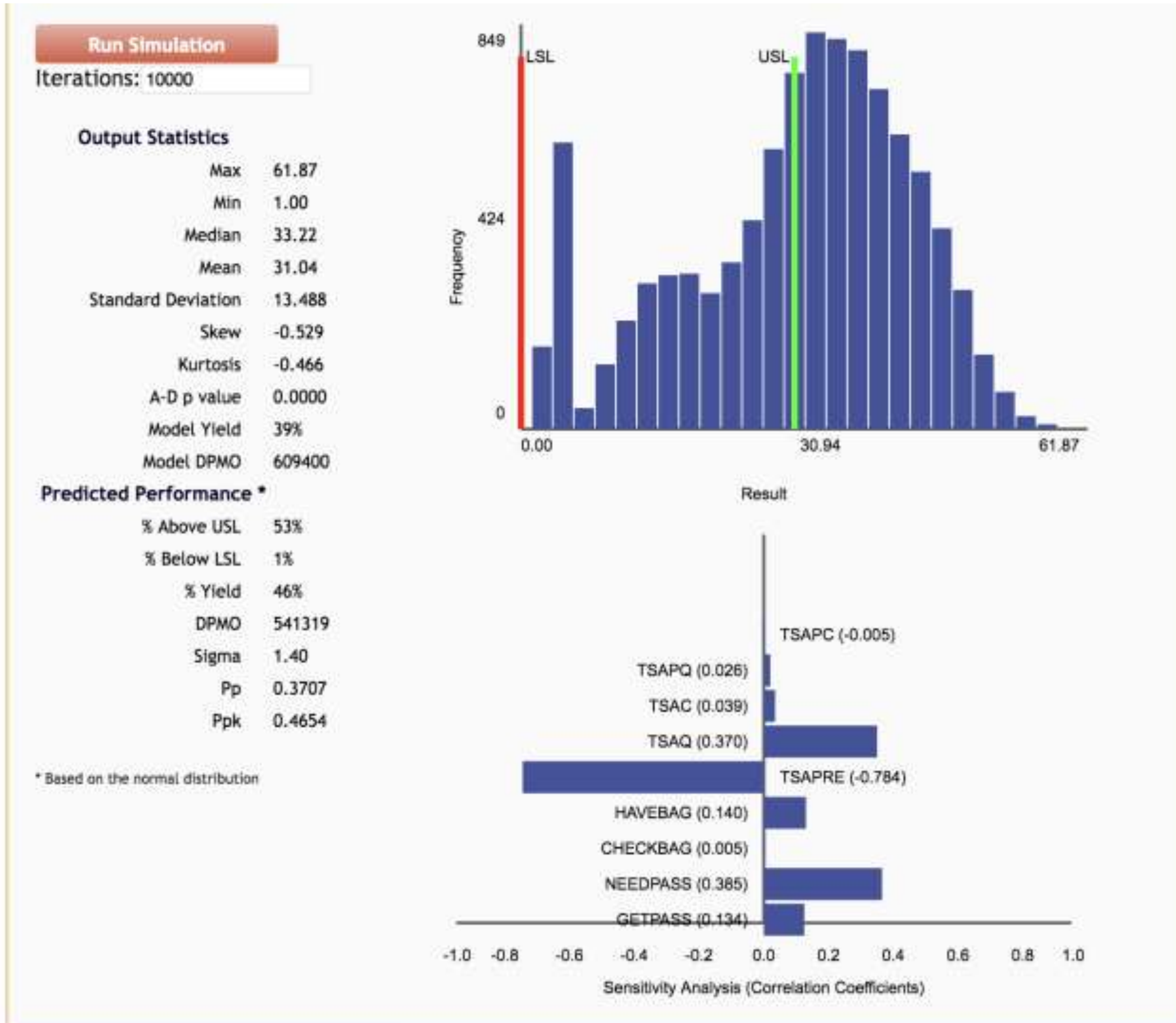
TSAPRE*TSAPQ +

TSAPRE*TSAPC +

(1-TSAPRE)*TSAQ +

(1-TSAPRE)*TSAC

Results


Run Simulation
Iterations: 10000
Output Statistics
Max 61.87
Min 1.00
Median 33.22
Mean 31.04
Standard Deviation 13.488
Skew -0.529
Kurtosis -0.466
A-D p value 0.0000
Model Yield 39%
Model DPMO 609400
Predicted Performance *
% Above USL 53%
% Below LSL 1%
% Yield 46%
DPMO 541319
Sigma 1.40
Pp 0.3707
Ppk 0.4654
* Based on the normal distribution
849
424
0
Frequency
LSL
USL
0.00
30.94
61.87
Result
TSAPC (-0.005)
TSAPQ (0.026)
TSAC (0.039)
TSAQ (0.370)
TSAPRE (-0.784)
HAVEBAG (0.140)
CHECKBAG (0.005)
NEEDPASS (0.385)
GETPASS (0.134)
-1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0
Sensitivity Analysis (Correlation Coefficients)

Queue Time as an Input

With Monte Carlo simulation, queue time is an input

Is queue time truly independent of the other steps in the process?

Another Approach for the Airport Model

Discrete Event Simulation

Model demand changes over time

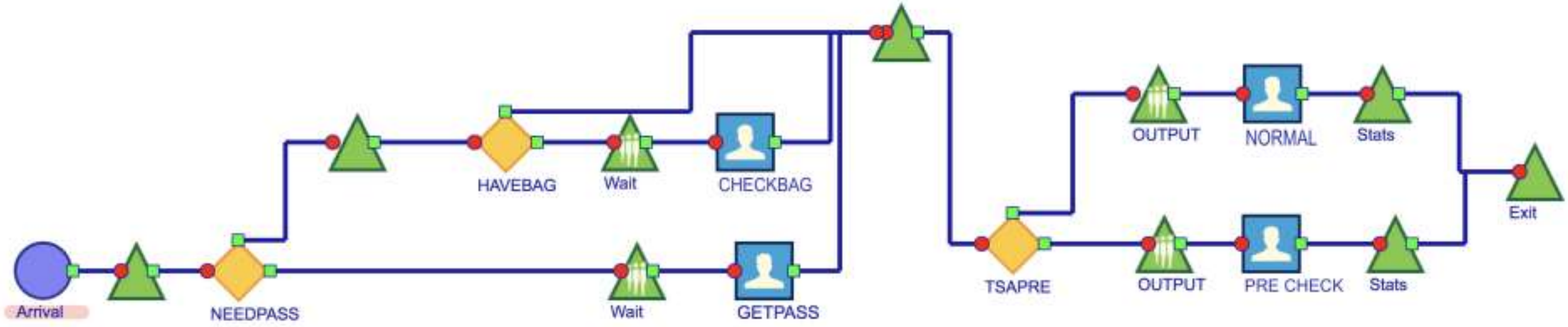
Understand the interaction between activities and queue lengths

Model the impact of rework loops on activities, and the resulting impact on queues

Comparison of Factors for the Airport Model

Factor	Monte Carlo	Discrete Event Simulation
GETPASS	Input	Input/Output
NEEDPASS	Input	Input
CHECKBAG	Input	Input/Output
HAVEBAG	Input	Input
TSAPRE	Input	Input
TSAQ	Input	Output
TSAC	Input	Input
TSAPQ	Input	Output
TSAPC	Input	Input

Experiment #4: Discrete Event Model of Airport Queues



Which to Choose?

George Box, statistician extraordinaire:
"All models are wrong, some are useful"

Are the steps of the process truly independent?

Are the steps of the process truly memoryless?

Are any of the inputs actually outputs?

Does the process change over time?

Will you be conducting experiments to improve the process?

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Questions?

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