MoreSteam.com *MBB Webcast Series*

Monte Carlo Simulation: Don’t Gamble Away Your Project Success

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Agenda

- Welcome
- Introduction of MBB Webcast Series
  - Larry Goldman, MoreSteam.com
- Monte Carlo Simulation
  - Maurice Klaus, MoreSteam.com
- Open Discussion and Questions

MoreSteam.com – Company Background

- Founded 2000
- Over 330,000 Lean Six Sigma professionals trained
- Serving over 50% of the Fortune 500
- First firm to offer the complete Black Belt curriculum online
- Courses reviewed and approved by ASQ
- Registered education provider of Project Management Institute (PMI)

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Today's Presenter

Maurice Klaus

BB and Product Architect, MoreSteam.com

- Product Architect for EngineRoom®
- MoreSteam course content developer
- Over 16 years of management consulting experience and has worked with more than 75 private sector organizations
- M.S. and B.S. in Mechanical Engineering from The University of Michigan

Objectives

An understanding of Monte Carlo simulation

- Background: what, why, when
- Technique: how
- Examples
- Using web-based EngineRoom®

☆ I want you to want to try this out when it makes sense

What is Monte Carlo simulation?

- **An analysis technique**
  - Variation of inputs (x) on the output (Y)
- **Defines**
  - The "*f*" in Y = *f*(x), transfer function
  - Probability distribution of Xs
- **Produces**
  - Probability distribution of the Y
  - Sensitivity of Y to changes in X

☆ Models a situation and characterizes the output

Why use Monte Carlo simulation

- Accounts for **variation of inputs**
- Characterizes output **prior** to committing resources
- Provides a **model** for on-going assessment

☆ Better informed decision making

When to use Monte Carlo simulation?

- A **decision** needs to be made
- Inputs (Xs) can be characterized with a **probability distribution**
- Transfer function, f in $Y=f(X)$, can be expressed as an **explicit** formula

☆ A powerful decision-making support tool

When to use Monte Carlo simulation?

To answer questions…

Will the components of this product assembly together?

What is likelihood of achieving our profitability goal in this project?

What is the potential for this process to meet the customer specifications?

☆ *Before* building the product, selecting the project, improving the process

Technique

1. Process parameters
2. Characterize Xs
3. Transfer function
4. Results

☆ Straightforward and powerful process

Example 1

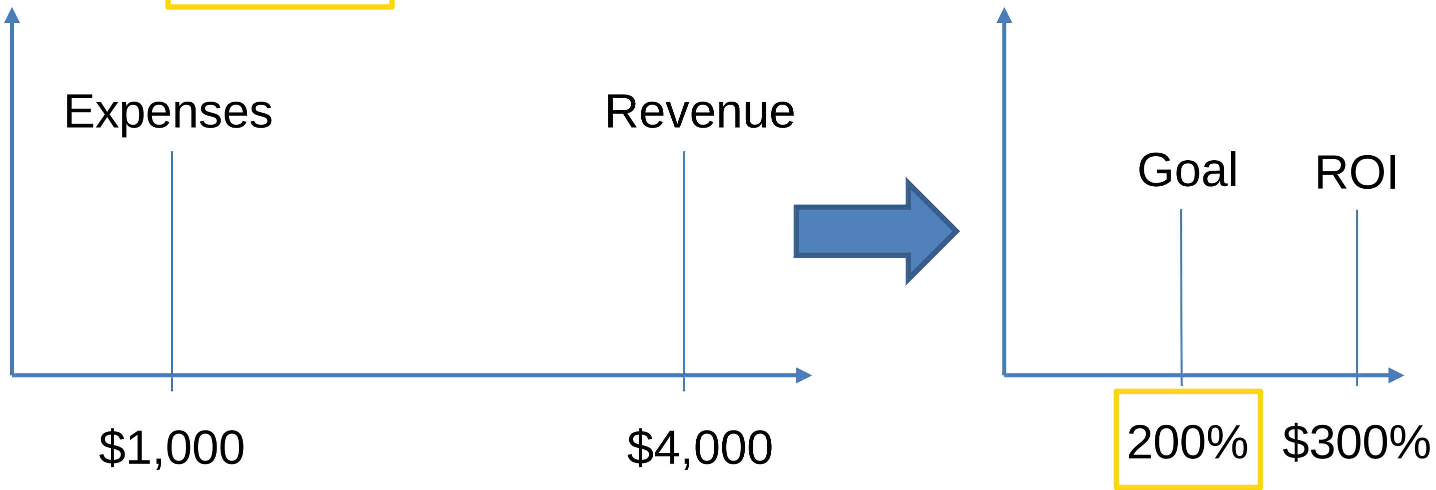
- Project prioritization and selection:
  - Return on Investment (ROI)

    = 100*(Revenue – Expenses)/Expenses

- Y=*f*(X)
  - Y: ROI
  - Xs: X_1 Revenue, X_2Expenses
  - *f:* 100*(Revenue – Expenses)/Expenses
  - $Y = f(X) = (X_1 - X_2)/X_2$
  - Y = ROI = 100*(Revenue – Expenses)/Expenses

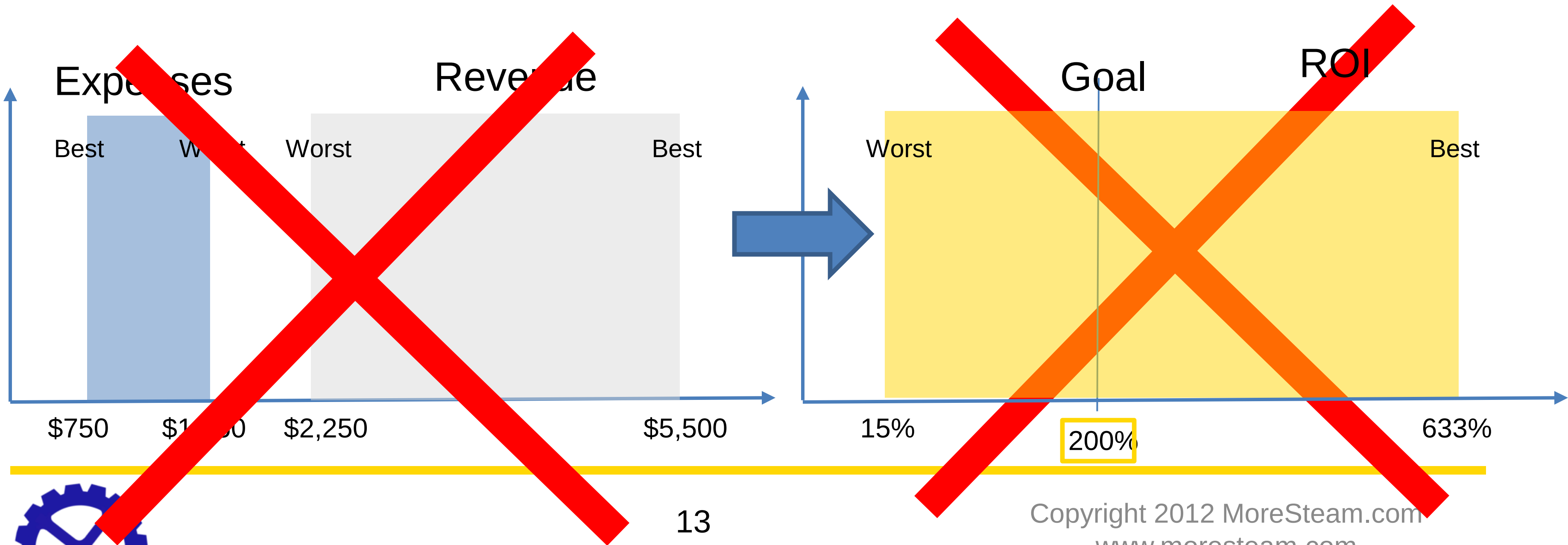
Example 1 – no variation

- Simple equation: ROI = (Revenue – Expenses)/Expenses
- Let Revenue = $4,000
- Let Expenses = $1,000
- ROI = 100*($4,000 - $1,000)/$1,000 = 300%
- Goal = 200% minimum



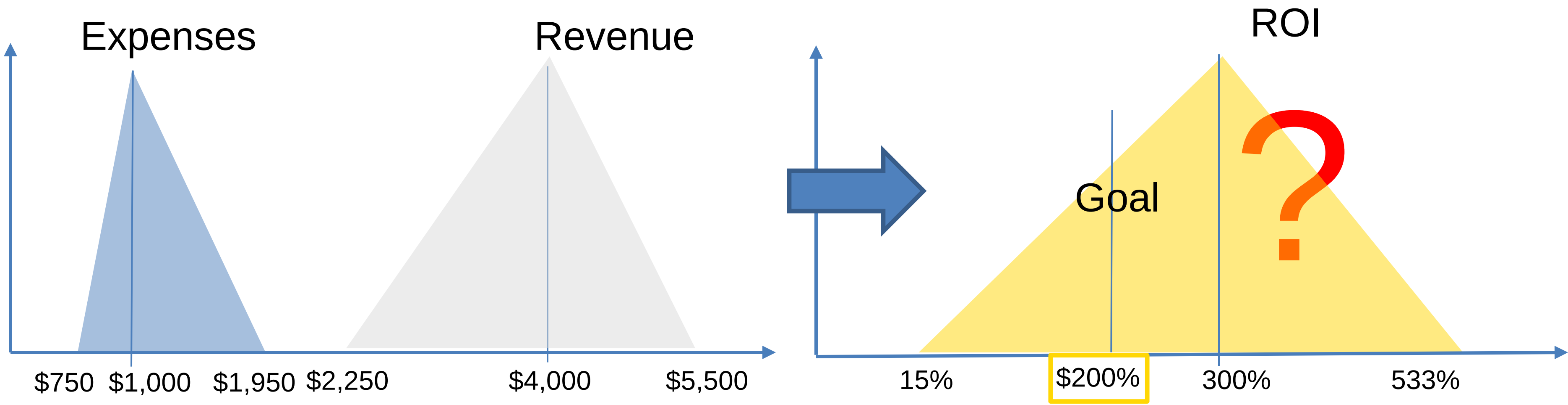
Example 1…with variation

- Best case:
  - Revenue = $5,500, Expenses = $750, ROI = 633%
- Worst case
  - Revenue = $2,250, Expenses = $1,950, ROI = 15%



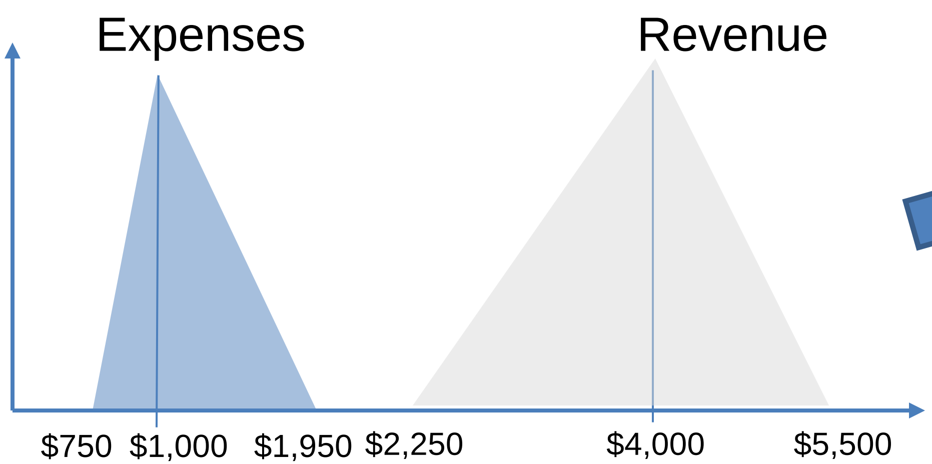
Example 1…with variation

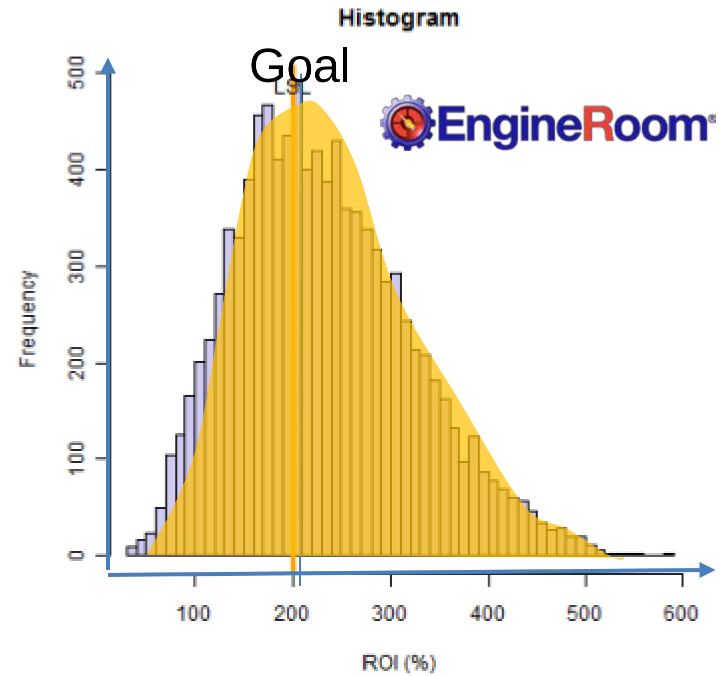
- Best case:
  - Revenue = $5,500, Expenses = $750, ROI = 633%
- Worst case
  - Revenue = $2,250, Expenses = $1,950, ROI = 15%
- Likely case
  - Revenue = $4,000, Expenses = $1,000, ROI = 300%



Example 1…Monte Carlo random sampling

- Revenue, triangular distribution
  - Min = $2,250, Max = $5,500, Mode = $4,000
- Expenses, triangular distribution
  - Min = $750, Max = $1,950 , Mode = $1,000

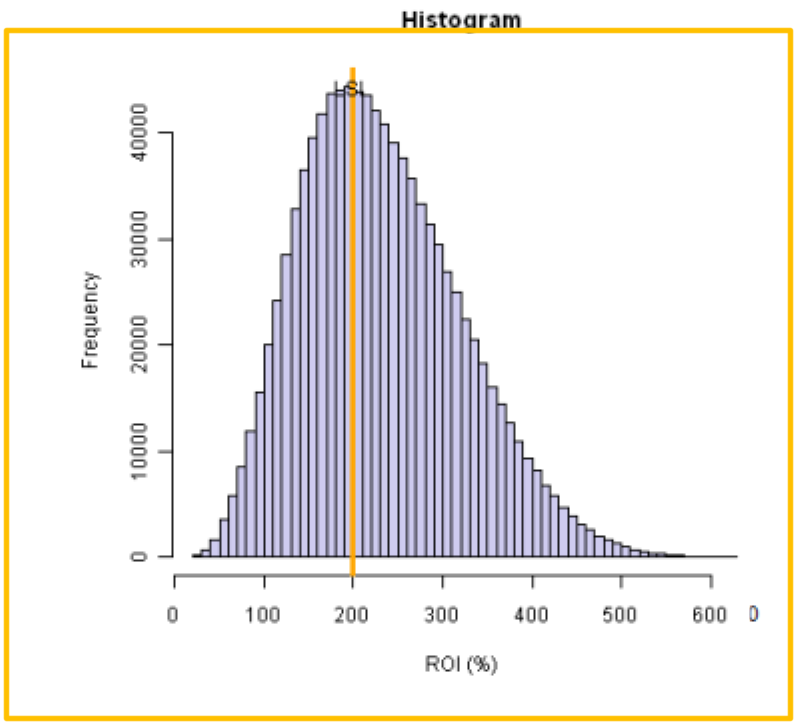




Example 1…The technique applied

1. Process parameters
   - Output: ROI, Units: %
   - Lower spec = 200%, Upper spec = none
2. Characterize Xs
   - Revenue: triangular distribution
     - Min = $2,250, Max = $5,500, Mode = $4,000
   - Expenses: triangular distribution
     - Min = $750, Max = $1,950 , Mode = $1,000
3. Transfer function
   - Y = ROI = 100*(Revenue – Expenses)/Expenses
4. Results

Example 1 – Results…distribution of Y (ROI)



Output Statistics

Trials	10,000 →	1,000,000
Max	588.4	614
Min	27.15	19.42
Median	222	222.1
Average	231.7	231.4
Std Dev	89.61	88.88
Skew	0.4800	0.4757
Kurtosis	-0.1155	-0.1009
Anderson-Darling (normality) p-value	0.0000	0.0000
Model Yield	59.60%	59.70%
Model DPMO	404,000	402,983

If p is low, H_o must go

Predicted Performance*

[illegible]ve USL	N/A
% Be[illegible]	[illegible]
Yield	63.82%
DPMO	361,796
Sigma Level	1.85
Pp	0.3720
Ppk	[illegible]

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☆ There is a 40% chance of missing the ROI target

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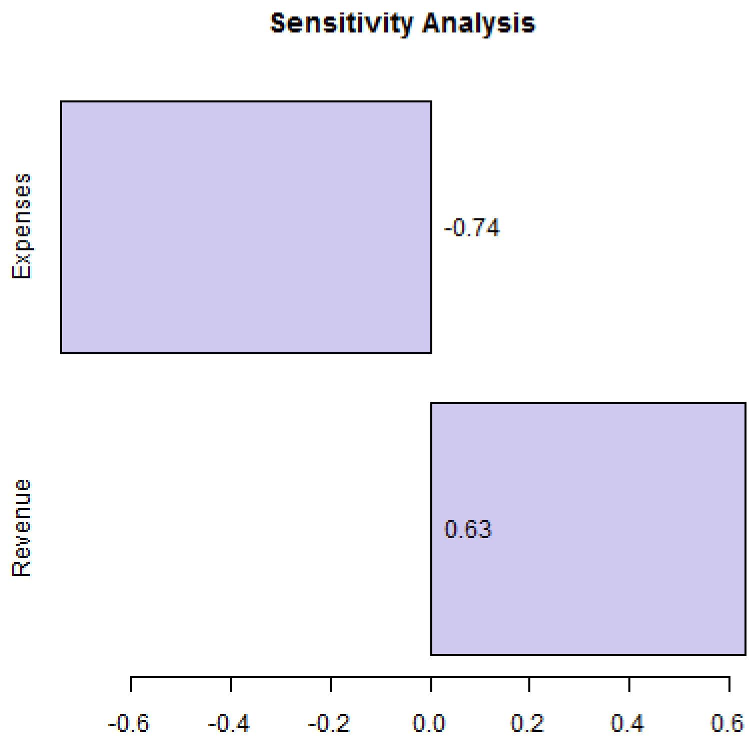
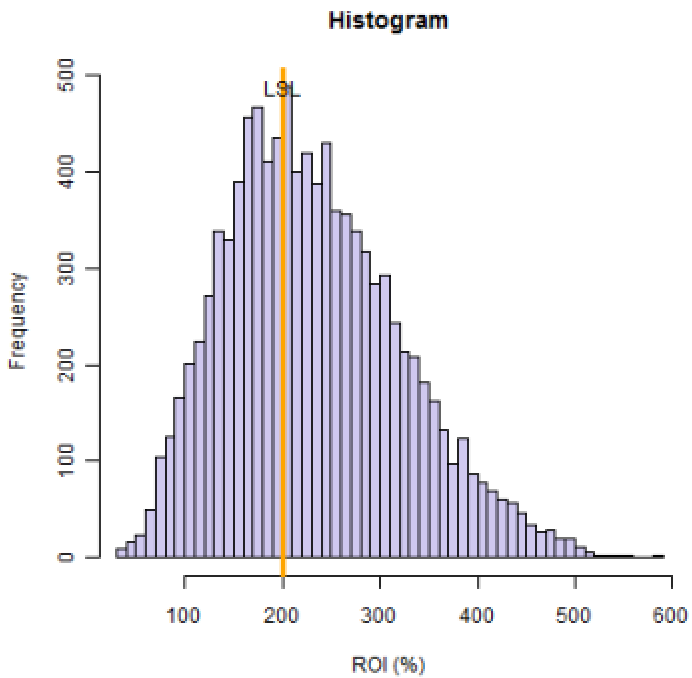
Example 1 – Results…sensitivity

- Changes in which X have the most impact on Y?





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☆ Work on the highest sensitivity Xs to reduce variation in Y

Example 1…Practical significance

- Our project ROI is 300%, it is well above our 200% hurdle so we recommend moving forward.

- The most likely project ROI is 232%, which is above our 200% hurdle. However, there is a 40% likelihood of missing the ROI hurdle. We recommend tabling this project while we review possibilities for reducing the potential variation in expenses which contribute more to the variation of ROI than revenue.

Example 1…Conclusion, next steps

- Review the output
- 40% chance of missing the ROI target
- Make a better informed decision amongst the possible projects
- Focus on reducing the variation in expenses if opportunity to revisit the project is given

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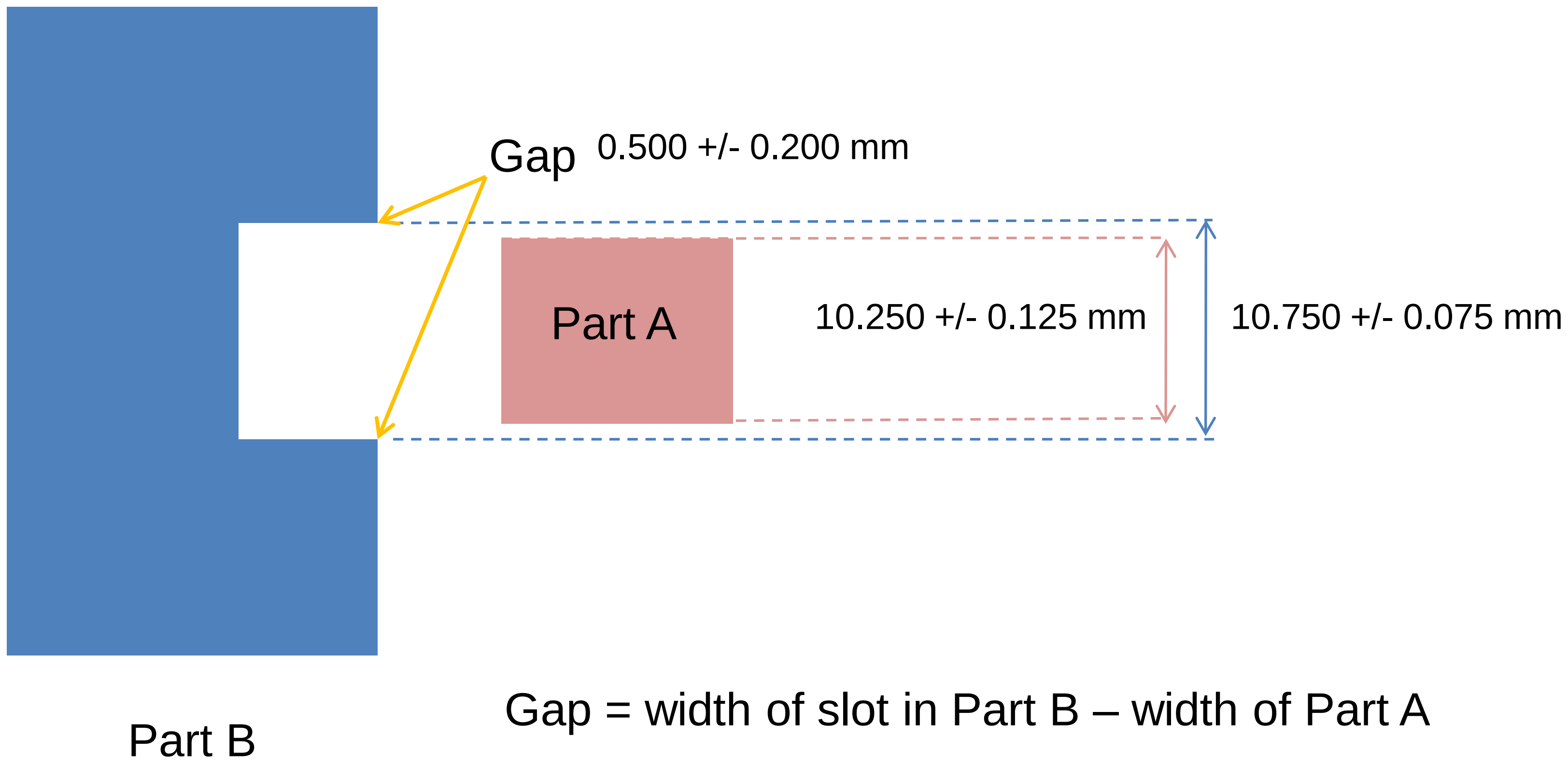
How are you doing?

Example 2 – Product design



Gap = width of slot in Part B – width of Part A

☆ Tolerances specified in this manner are, in effect, uniform distributions

Example 2 – Product design

- No-fit conditions unacceptable
- Acceptable gap range 0.250 – 0.750 mm
  - Example:
    - Gap of 0.200 mm is a no-fit condition, $0.200 < 0.250$
    - Gap of 0.800 mm is a no-fit condition, $0.800 > 0.750$
    - Gap of 0.280 mm is acceptable, $0.250 < 0.280 < 0.750$

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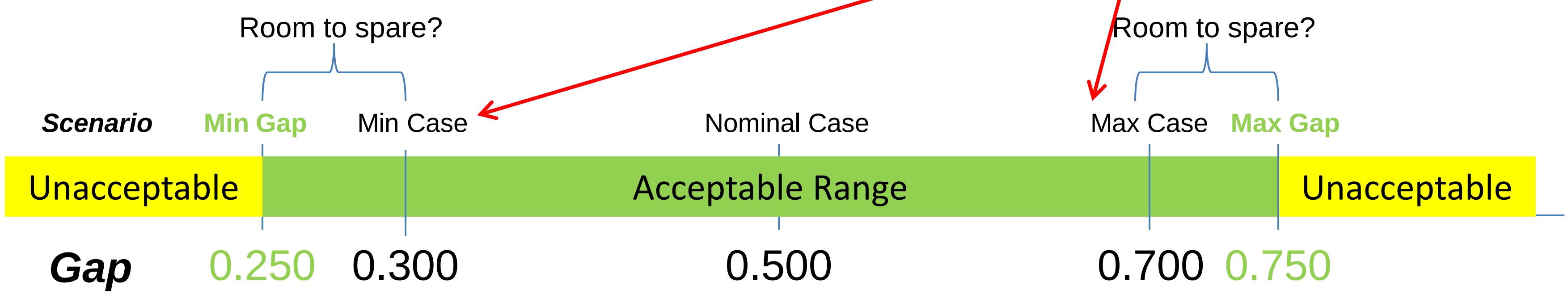
Example 2 – non Monte Carlo approach

- Maximum and minimum material conditions
- Calculate gap

Scenario	Part A (mm)	Part B (mm)	Gap (mm)	Fit?
Nominal	10.250	10.750	0.500	Yes
Tolerance	+/- 0.125	+/- 0.075	n/a	n/a
Maximum	10.125	10.825	0.700	Yes
Minimum	10.375	10.675	0.300	Yes

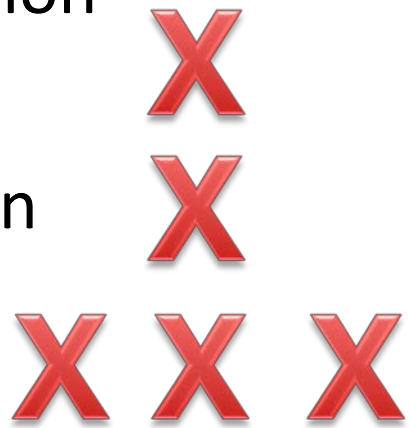


☆ Will the *actual* gap be within that range?

Example 2 – distribution of Xs

- Maximum and minimum material conditions approach is same as the uniform distribution

- Real-life is typically the normal distribution

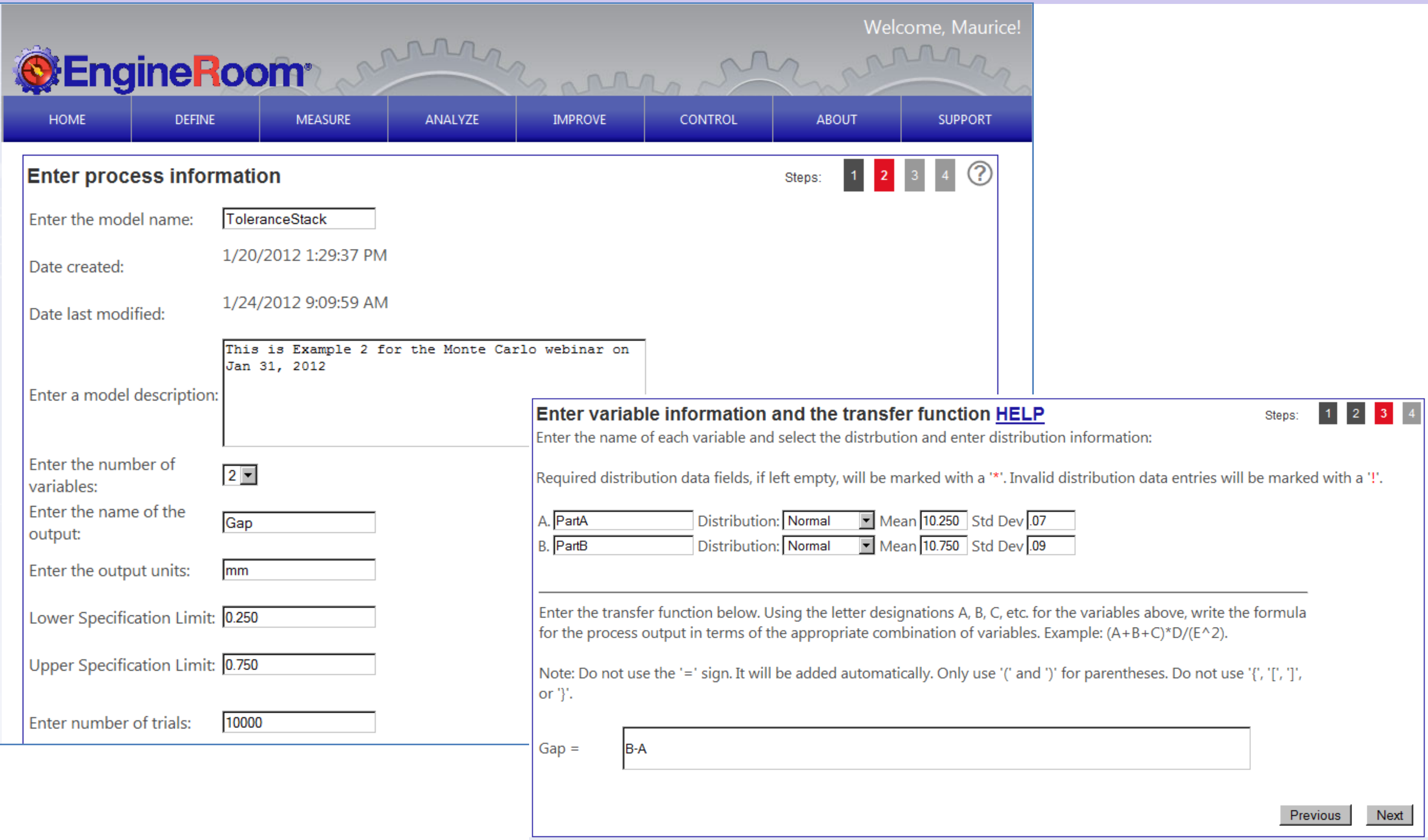


- Approach to characterizing Xs:
  1. Get real data if components exist
  2. Get surrogate data if possible
  3. Use a triangular distribution when no surrogate data are available

Example 2 – Monte Carlo simulation

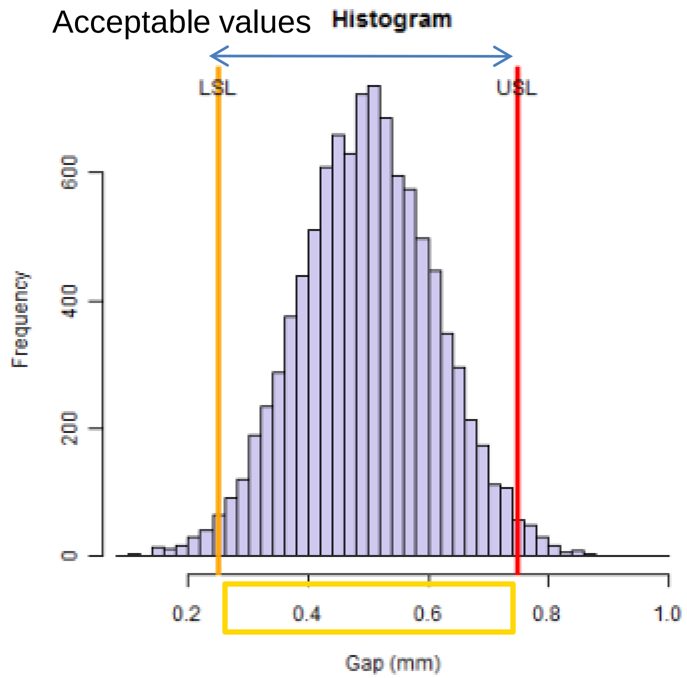
1. **Process parameters**
   – Output: Gap (mm)
   – Lower Specification Limit: 0.250 mm
   – Upper Specification Limit: 0.750 mm
2. **Characterize Xs based on historical data**
   – Part A: Normal distribution
     • Mean: 10.250 mm, Standard Deviation: 0.070 mm
   – Part B: Normal distribution
     • Mean: 10.750 mm, Standard Deviation: 0.090 mm
3. **Transfer function**
   – Y = Gap = B - A

Example 2 – EngineRoom®



Example 2 – Distribution of Y (Gap)

Normal distributions for Xs based on historical data



Output Statistics

Trials	10,000
Max	0.9913
Min	0.0918
Median	0.4986
Average	0.4985
Std Dev	0.1134
Skew	0.0088
Kurtosis	0.0230
Anderson-Darling (normality) p-value	0.8521
Model Yield	97.19%
Model DPMO	28100

Predicted Performance*

% Above USL	1.33%
% Below LSL	1.42%
Yield	97.25%
DPMO	27526
Sigma Level	3.4
Pp	0.7347
Ppk	0.7304

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☆ There will be a no-fit condition 2.75% of the time

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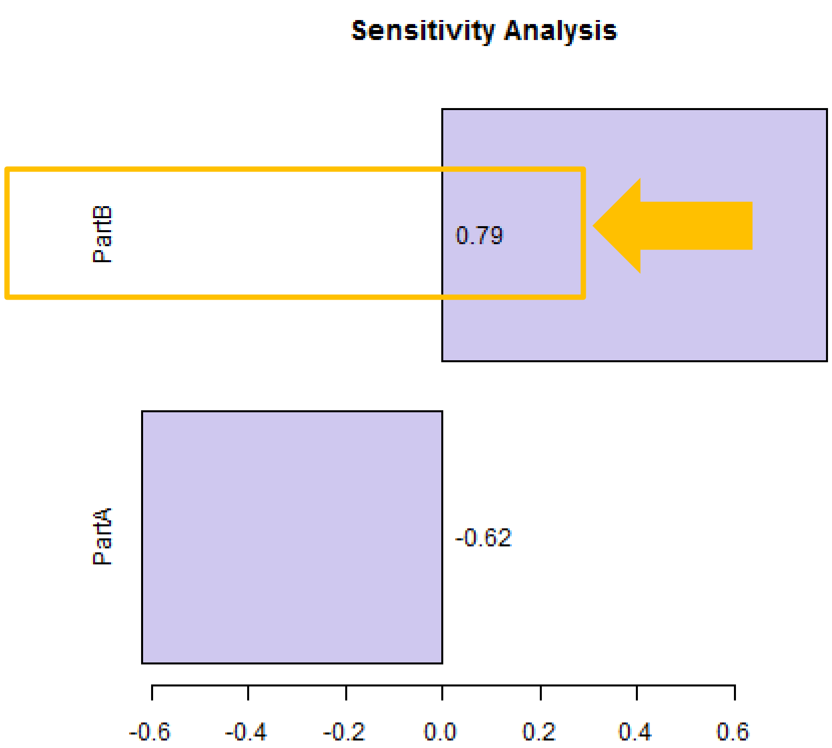
Example 2 – Sensitivity analysis



Example 2 - Conclusion

- Use historical data to characterize Xs
- Determine the likelihood of a no-fit condition
  - 2.75%
- Compare to desired likelihood
  - 2.75% > 0.00%
- Part B contributes more to variation in the Gap than Part A, focus on Part B if 2.75% is unacceptable

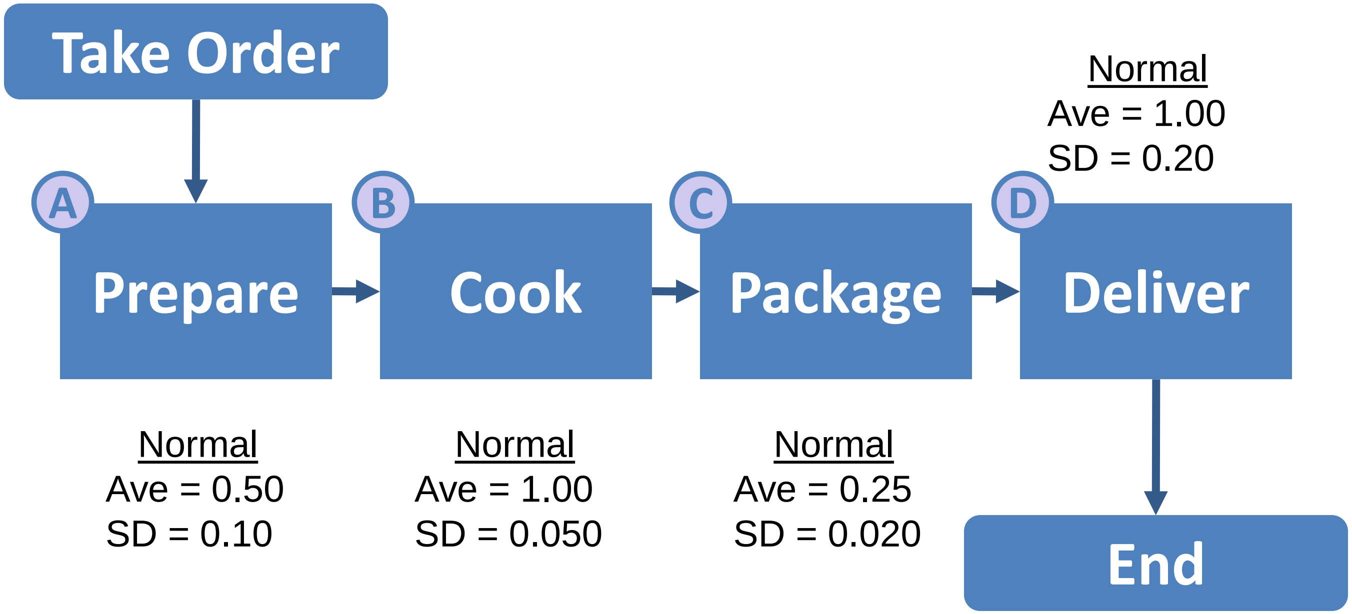
☆ Make a better informed decision

Example 3 – Process improvement

- Simple example – DFSS course
- Burger Kwik drive-through
- VOC = 3 minutes max wait time
- Current performance:
  - 3 minutes or less < 90% of time
  - Customers are complaining

Example 3 – Process improvement

As-Is Process



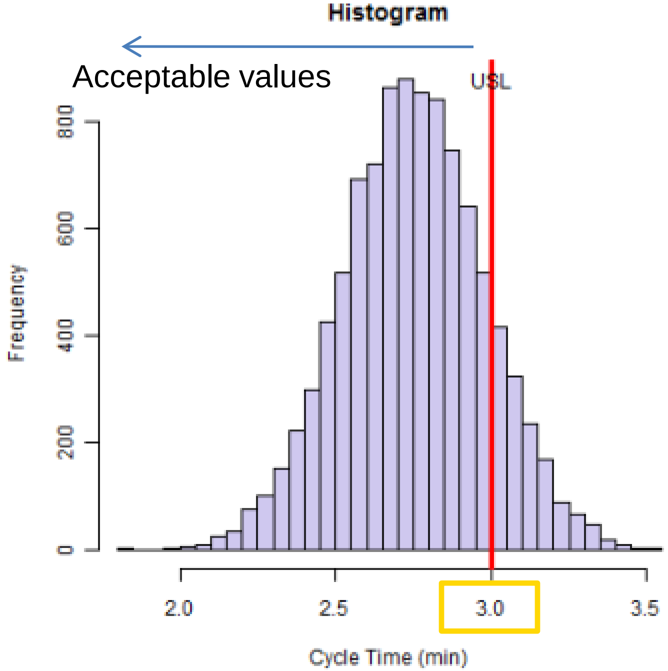
Transfer Function:
Y = Cycle Time = A + B + C + D

☆ Use a triangular distribution if historical and surrogate data are not available

Example 2…The technique applied

1. Process parameters
   - Output: Cycle Time, Units: minutes
   - Lower spec = none, Upper spec = 3 minutes
2. Characterize Xs
   - All 4 steps: normal distribution
     - Step A, mean = 1.0 min, standard deviation = 0.20 min
     - Step B, mean = 0.50 min, standard deviation = 0.10 min
     - Step C, mean = 1.0 min, standard deviation = 0.05 min
     - Step D, mean = 0.25 min, standard deviation = 0.02 min
3. Transfer function
   - $Y = \text{Cycle Time} = A_{\text{cycle time}} + B_{\text{cycle time}} + C_{\text{cycle time}} + D_{\text{cycle time}}$
4. Results

Example 3 – Distribution of Y (Cycle Time)



Output Statistics

Trials	10,000
Max	3.5395
Min	1.8066
Median	2.7489
Average	2.7498
Std Dev	0.2291
Skew	-0.0210
Kurtosis	0.0374
Anderson-Darling (normality) p-value	0.6515
Model Yield	86.18%
Model DPMO	138200

Predicted Performance*

% Above USL	13.75%
% Below LSL	N/A
Yield	86.25%
DPMO	137466
Sigma Level	2.6
Pp	2.1822
Ppk	0.3639

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☆ The Monte Carlo model matches well to real-life

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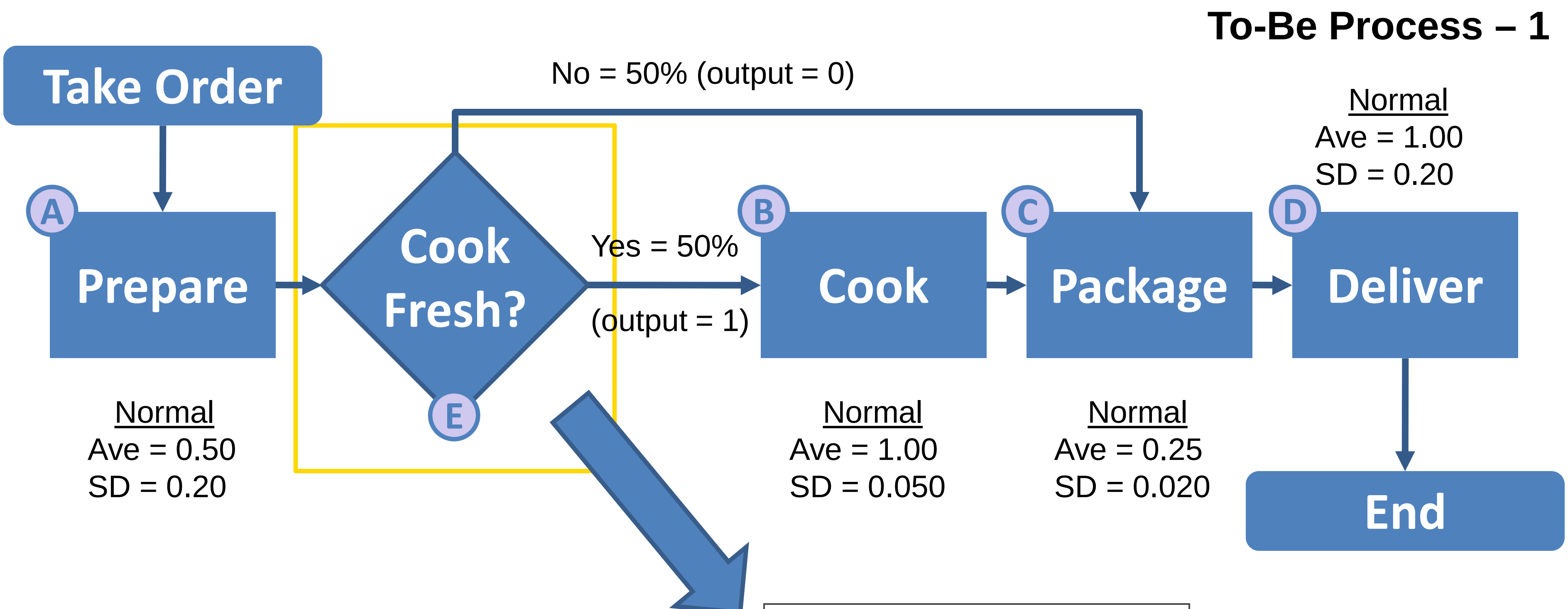
Example 3 – Improvement iteration "1"

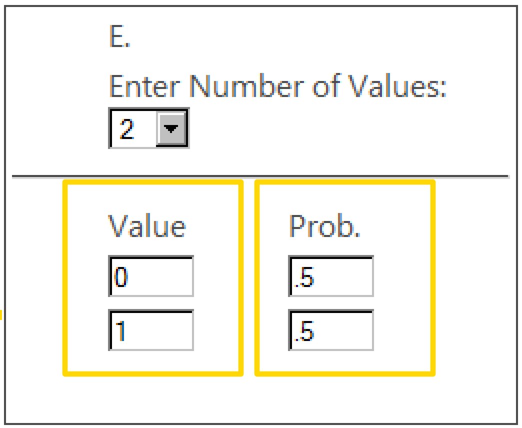
- VOC indicates drive-through cycle time #1
- Freshly cooked not as important
- Pre-cook burgers, off critical path
- 50% of burgers pre-cooked, available in warmer

Example 3 – Improvement iteration "1"

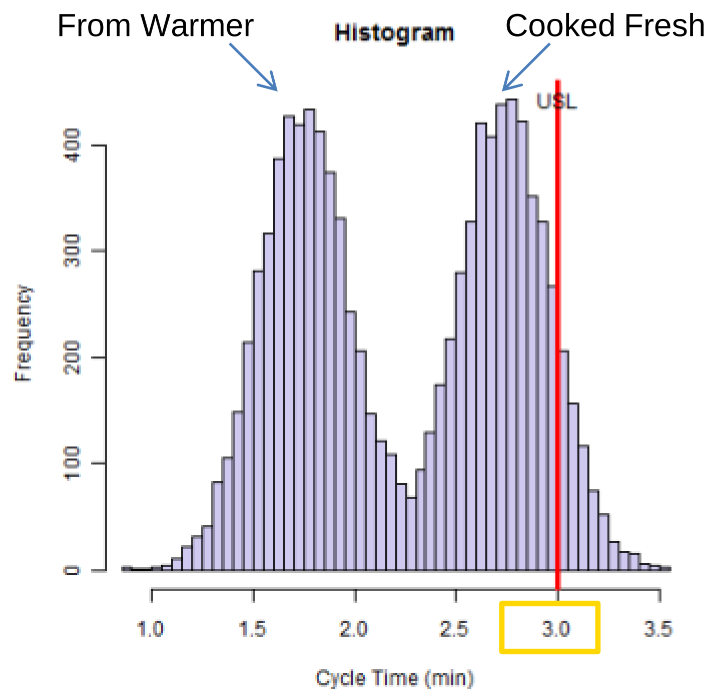


Transfer Function:

Y = Cycle Time = A + E*B + C + D



Example 3 – Distribution of Y (Cycle Time)



Output Statistics

Trials	10,000
Max	3.5327
Min	0.8727
Median	2.2782
Average	2.2523
Std Dev	0.5500
Skew	-0.0138
Kurtosis	-1.3590
Anderson-Darling (normality) p-value	0.0000
Model Yield	93.21%
Model DPMO	67900

Predicted Performance*

[illegible]ove USL	8.70%
% Be[illegible]	[illegible]
Yield	91.30%
DPMO	86977
Sigma Level	2.9
Pp	[illegible].9091
Ppk	0.[illegible]

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☆ Bi-modal distribution as expected; improvement good, but not enough

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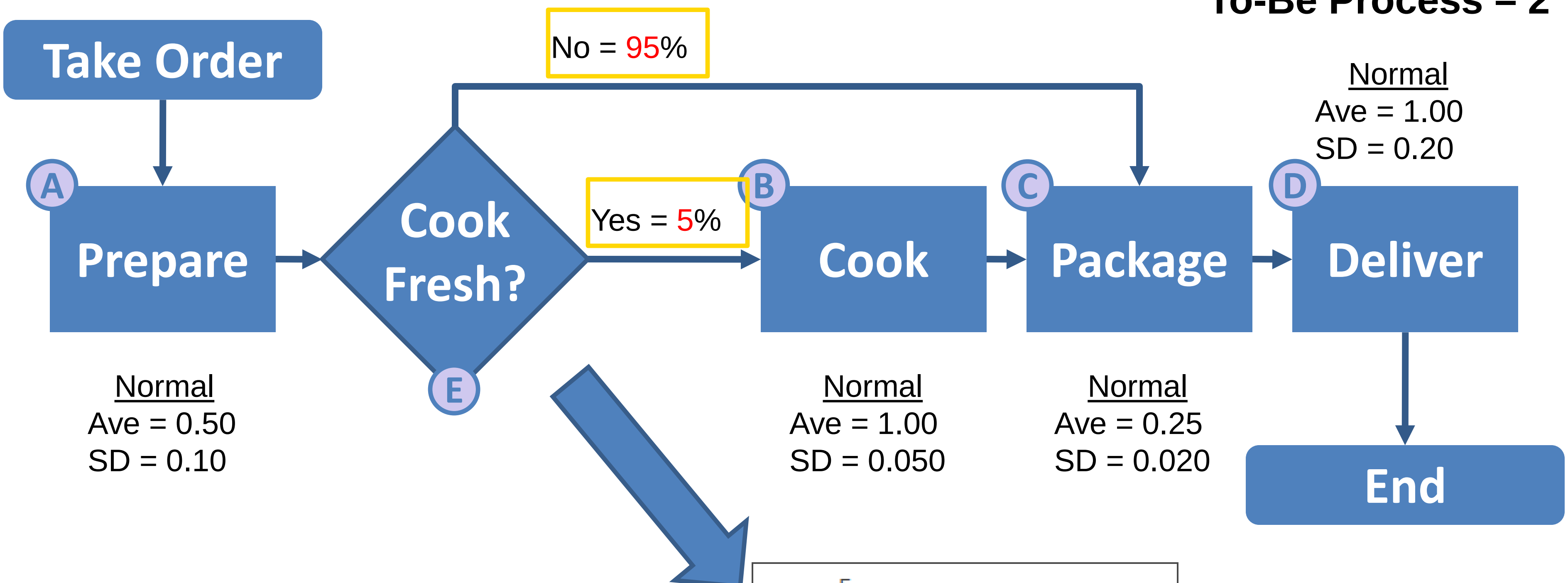
Example 3 – Improvement iteration "2"

- Can adjust to 95% pre-cooked
- 5 minutes maximum in warmer
- No impact to staffing
- Does not affect customer perception of taste or freshness

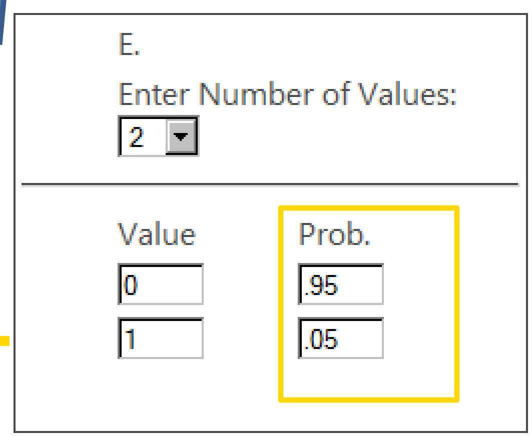
Example 3 – Improvement iteration "2"

To-Be Process – 2

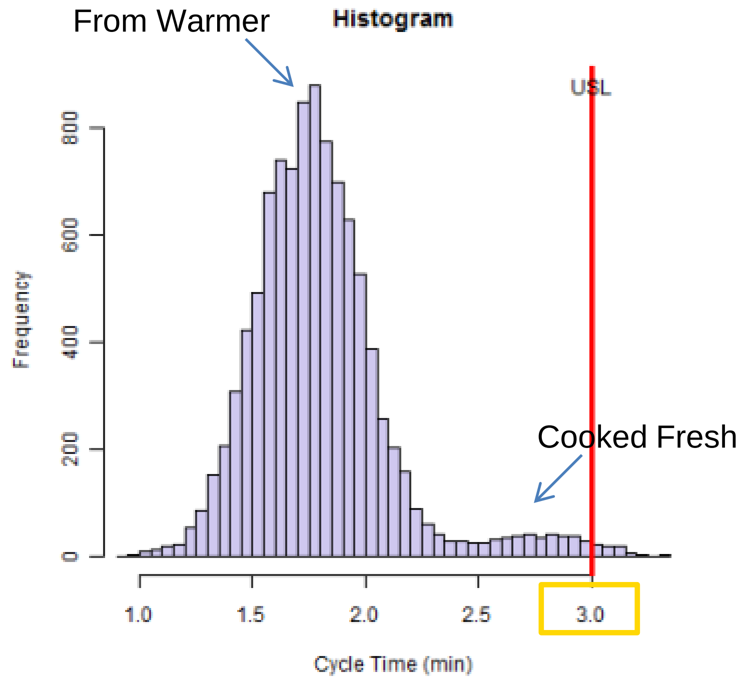


Transfer Function:

Y = Cycle Time = A + E*B + C + D



Example 3 – Distribution of Y (Cycle Time)



Output Statistics

Trials	10,000
Max	3.3224
Min	0.9336
Median	1.7621
Average	1.7963
Std Dev	0.3117
Skew	1.4125
Kurtosis	3.6138
Anderson-Darling (normality) p-value	0.0000
Model Yield	99.30%
Model DPMO	7000

Predicted Performance*

[illegible]bove USL	0.01%
% Be[illegible]SL	[illegible]
Yield	[illegible]9.99%
DPMO	56
Sigma Level	5.4
Pp	1.6041
Ppk	[illegible]

[illegible]Based on the normal distribution

Example 3 - Conclusion

- Review results
- Compare the yield of 99.3% to the goal of 90%
- Decide whether or not to proceed with the improvement

☆ Make a better informed decision

Thank you for joining us

Master Black Belt Program

- Offered in partnership with Fisher College of Business at The Ohio State University
- Employs a Blended Learning model with world-class instruction delivered in both the classroom and online
- Covers the MBB Body of Knowledge, topics ranging from advanced *DOE* to *Leading Change* to *Finance for MBBs*

Resource Links and Contacts

Questions? Comments? We'd love to hear from you.

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Additional Resources

Archived presentation, slides and other materials:
http://www.moresteam.com/presentations/

Master Black Belt Program: http://www.moresteam.com/master-black-belt.cfm