DoE in Action
(How to Use Different DoE Techniques to Improve Processes)

Kenneth Quiros
Continuous Improvement Manager & Lean Six Sigma Master Black Belt Bridgestone Americas
Learning Objectives

At the end of this session, attendees should be able to:

• Understand how Minitab and Qeystone are being used to support Bridgestone Six Sigma Deployment and Strategy.

• Familiarize themselves with DoE techniques.

• Get introduced to a framework that helps you choose the best DoE approach for your specific situation.

• See the framework in action, real life examples.
Agenda

i. Bridgestone Company.


iii. DoE Theory.

iv. DMAIC Practical Problem- Yield Improving using a Binary Logistic Regression.
   i. Attribute DoE

v. DMAIC Practical Problem- Optimizing a Mixing Process using a Mixture DoE
   i. Formulation and Mixing Design.

vi. DMAIC Practical Problem- Increase the productivity in Mixing Area using a DSD
   i. Definitive Screening Design

vii. Summary and Questions
Bridgestone Company

Corporate Name: Bridgestone Corporation

Headquarters: 1-1, Kyobashi 3- Chome, Chuo- ku, Tokyo 104-8340, Japan

Established: March 1, 1931

Founder: Shojiro Ishibashi

CEO and Representative Board Member: Masaaki Tsuya

Concurrently Chairman of the Board: Masaaki Tsuya

COO and Representative Board Member: Kazuhisa Nishigai

Financial Data:

As of December 31, 2015

Consolidated Sales \3,790.2 billion
Consolidated Net Income \284.2 billion
Paid-in Capital \126.3 billion
Consolidated No. of Employees 144,303

Non-consolidated Sales \912.6 billion
Non-consolidated Net Income \171.0 billion
No. of Employees 13,843

As of 1931

Paid-in Capital \1 million
No. of employees 144
Products and Operations

Tires

- Tires for passenger cars
- Tires for trucks and buses
- Retreading materials and services
- Off the road tires for construction and mining vehicles
- Tires for aircraft (agricultural machinery, motorcycles)

Diversified Products

- Bicycles
- Sporting goods
- Seismic isolation rubber
- Conveyor belts
- Roofing material
- Seat pads for automobiles (polyurethane foam)
- High pressure hose
Group Global Facilities

Plants: 171 plants in 26 nations
Technical Centers: 6 facilities in 5 nations
Proving Grounds: 10 facilities in 8 nations
(As of April 1, 2015) * Facilities under construction are not included in the number of facilities above.
Bridgestone Six Sigma Deployment and Strategy using Qeystone & Minitab.
Strategy includes no mandates, but projects are required and application is critical.

- 6 Black Belts Trained by PACCAR
- Creation of IQS / 6σ Department
- 1st In-House Black Belt Training
- MS Best Practice in C-bus (9/07)
- 1st Green Belt Class
- Switch to “Blended” Model using Moresteam
- Expansion into FSBP
- 400+ Belts Trained
- Significant Savings Reported
- 384 Certified Belts
- 970 Belts Trained
- 1st DFSS Black Belt Class
- Master Black Belt LA

Carefully Planned Implementation

Strategy includes no mandates, but projects are required and application is critical.

Model relies on a minimal # of full time belts.
Bridgestone Six Sigma Deployment and Strategy using Qeystone & Minitab.

六西格玛

D→M→A→I→C

Define
Measure
Analyze
Improve
Control

Cuernavaca Tire Plant
Bandag

San Jose Tire Plant
SSC
FSIP

Valencia Tire Plant

Bahia Tire Plant

Santo Andre Tire Plant

Buenos Aires Tire Plant

Cuernavaca Tire Plant

San Jose Tire Plant

Valencia Tire Plant

Bahia Tire Plant

Santo Andre Tire Plant

Buenos Aires Tire Plant

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Bridgestone Six Sigma Deployment and Strategy using Qeystone & Minitab.

Master Black Belts Provide 4 levels of DMAIC Training

- **Black Belt**
  - 2 full weeks training with e-learning
  - Large training project
  - Supports other belts and projects
  - Design for Six Sigma (DFSS) option available

- **Green Belt**
  - Two 3-day week training with e-learning
  - Focused training project
  - Supports yellow belt projects
  - Transactional version available

- **Yellow Belt**
  - 1 week kaizen event
  - Focused training project
  - Can be taught by BB
  - e-learning version available

- **White Belt**
  - 1-2 day awareness
  - Exposure to DMAIC process and tools
  - Basic problem solving

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Bridgestone Six Sigma Deployment and Strategy using Qeystone & Minitab.

<table>
<thead>
<tr>
<th>Nashville Blended Model Schedule: Six Sigma Black Belt</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>JUL</strong></td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>Nomination Forms Due</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td><strong>AUG</strong></td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>Kickoff &amp; Champions</td>
</tr>
<tr>
<td>28</td>
</tr>
<tr>
<td><strong>SEP</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Classroom Week 1: Nashville</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td><strong>OCT</strong></td>
</tr>
<tr>
<td>29</td>
</tr>
<tr>
<td>Hypo Test Study Hall</td>
</tr>
<tr>
<td>13</td>
</tr>
<tr>
<td>Project Update</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td><strong>NOV</strong></td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>Classroom Week 2: Nashville</td>
</tr>
<tr>
<td>17</td>
</tr>
<tr>
<td><strong>DEC</strong></td>
</tr>
<tr>
<td>1</td>
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<tr>
<td><strong>Minitab Study Hall</strong></td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>E-Learning Sessions 1 &amp; 2</td>
</tr>
<tr>
<td>27</td>
</tr>
<tr>
<td><strong>CLASSROOM WEEK 1: NASHVILLE</strong></td>
</tr>
<tr>
<td>22</td>
</tr>
</tbody>
</table>
What is Qeystone?

Qeystone is an enterprise system that consists of Qeystone Tools, a desktop application, and Qeystone.com, a cloud-based Dashboard and repository.
Bridgestone Six Sigma Deployment and Strategy using Qeystone & Minitab.

Why are we using Qeystone?

Where is the final version of the project?

Is there any template available?

Is there a visual standard that reminds me the steps to do the analysis?

Belts

How can I access to others projects?
Bridgestone Six Sigma Deployment and Strategy using Qeystone & Minitab.
Bridgestone Six Sigma Deployment and Strategy using Qeystone & Minitab.

1. To add customer requirements, pause your cursor above the row in the table below, click 🔍, and choose **Create New Customer Requirements**...

2. For each customer requirement, rate its importance relative to all other customer requirements. Use the following scale:

   - 1: Least important
   - 2: Of little importance
   - 3: Somewhat important
   - 4: Important
   - 5: Most important

3. To add product characteristics, pause your cursor above the column in the table below, click 🔍, and choose **Create New Product Characteristics**...

4. Beside **Direction of Improvement**, choose one of the following symbols for each product characteristic:

   - Higher is better
   - Lower is better
   - Specific target
Bridgestone Six Sigma Deployment and Strategy using Qeystone & Minitab.

DMAIC Transactional (Six Sigma) Project - Qeystone

Project Manager
- Define-Measure
  - Pareto Chart
  - Graphing Y vs Categorical X
  - Value Stream Map Current State
  - High Level Map
  - IPO Map
  - Compare Process to Standard
  - C&E Matrix
  - Generic MSA
  - Attribute Agreement Analysis
  - Baseline Capability (Normal)
  - Baseline Capability (Nonnormal)
  - FMEA

- Analyze
  - Value Stream Map (Future State)
  - Waste Analysis
  - Funnel Report
  - Hypothesis Testing Guide
  - Multi-Vari Chart
  - Graphing Y vs Categorical X
  - 1-Sample t (Normal Data)
  - 1-Sample Wilcoxon (Non-normal Data)
  - 2-Sample t (Normal Data)
  - One-Way ANOVA
  - Kruskal-Wallis
  - Chi-Square Test of Independence
  - Simple Regression

- Improve
  - 2K Factorial DOE
  - Value Stream Map (Improvements)

- Control

Customer Demand
- 3 pieces per day
- (Takt Time 1,6667 hours)

Six steps were eliminated

Cycle Time 10 min

Open Excel file and run macro

Go to Am 15.2 and release

Cycle Time 23,553 min

20 min

10 min

47,126 min

23,563 min

Total Cycle Time = 33,563 min
Total VA Cycle Time = 33,563 min
Total NVA Cycle Time =

Lead Time = 1,6782 hr
WIP Time = 1,3448 hr
Total Distance =
Bridgestone Six Sigma Deployment and Strategy using Qeystone & Minitab.

Why are we using Qeystone?

- It takes a lot of time.
- Inaccurate Information.
- Sometimes it is not on time.
- There is no clear visibility.
- The tracking is difficult.

MBB
Number of Projects in Dashboard by Status & Region

<table>
<thead>
<tr>
<th>Region</th>
<th>Not Started</th>
<th>In Progress</th>
<th>Completed</th>
<th>On Hold</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latin America</td>
<td>1</td>
<td>38</td>
<td>142</td>
<td>3</td>
<td>184</td>
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<tr>
<td>North America</td>
<td>0</td>
<td>24</td>
<td>299</td>
<td>1</td>
<td>324</td>
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<tr>
<td>Europe</td>
<td>0</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Middle East</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>South Africa</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Number of Projects in Dashboard

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Green Belt</th>
<th>Black Belt</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Six Sigma</td>
<td>286</td>
<td>234</td>
<td>520</td>
</tr>
<tr>
<td>DFSS</td>
<td>1</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Status</th>
<th>Start</th>
<th>Current Phase</th>
<th>Completion</th>
<th>Health</th>
<th>Belt Level</th>
<th>Project Leader</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce lead time of the process</td>
<td>Completed</td>
<td>7/13/2015</td>
<td>DMAIC</td>
<td>1/18/2016</td>
<td>Green Belt</td>
<td>Felipe Jara Aven</td>
<td></td>
</tr>
<tr>
<td>Reduce 16Z Foreign Material Scrap</td>
<td>Completed</td>
<td></td>
<td>DMAIC</td>
<td>5/19/2007</td>
<td>Black Belt</td>
<td>Steve Stillman</td>
<td></td>
</tr>
<tr>
<td>Reduce Inspection Error Rate/Beta</td>
<td>Completed</td>
<td></td>
<td>DMAIC</td>
<td>10/6/2006</td>
<td>Black Belt</td>
<td>Chris Welch</td>
<td></td>
</tr>
</tbody>
</table>
Familiarize with DoE techniques.
DoE Theory.

• In DOE, we purposefully manipulate KPIV’s to test their effects on Y. There are four main purposes of DOE:

Where to set KPIV’s to center the Y on target
Where to set KPIV’s to minimize variation in Y
Where to set KPIV’s to minimize effect of uncontrollable X’s
To determine which KPIV’s have the greatest impact on Y

\[ Y = f(x_1, x_2, x_3, \ldots, x_k) \]
1. Define the Process and identify potential KPIV's
2. Measure the baseline performance
3. Analyze the Process to funnel KPIV's
4. Improve the Process

Eliminate or Optimize the KPIV's for best Y Ctr / Spread?

DMAIC – P Diagram View
Types of DoEs

- Balanced ANOVA...
- General Linear Model
- Fully Nested ANOVA...

Create Factorial Design

Type of Design
- 2-level factorial (default generators) (2 to 15 factors)
- 2-level factorial (specify generators) (2 to 15 factors)
- 2-level split-plot (hard-to-change factors) (2 to 7 factors)
- Plackett-Burman design (2 to 47 factors)
- General full factorial design (2 to 15 factors)

Create Mixture Design

Type of Design
- Simplex centroid (2 to 10 components)
- Simplex lattice (2 to 20 components)
- Extreme vertices (2 to 10 components)

Taguchi Design

Type of Design
- 2-Level Design (2 to 31 factors)
- 3-Level Design (2 to 13 factors)
- 4-Level Design (2 to 5 factors)
- 5-Level Design (2 to 6 factors)
- Mixed Level Design (2 to 26 factors)
DMAIC Practical Problem- Yield Improving using a Binary Logistic Regression.
**Problem Statement**

Improve the yield metric from 93% to 96% in Tire Production.

**MSA**

*Attribute Agreement Analysis for Criteria Summary Report*

- Is the overall % accuracy acceptable?
  - No
  - Yes

The appraisals of the test items correctly matched the standard 95.0% of the time.

**Pareto**

- Percentage vs. USD
  - Percentage: 0, 20,000
  - USD: 0, 10,000, 20,000

**IPO Map**

- **Process Map - Activity**
  - High Level Map - Process A
  - High Level Map - Process B
  - High Level Map - Process C
- **Type**
  - Controllable
  - Non-Controllable
- **Output (Y Variable)**
  - Y1
  - Y2
  - Y3
  - Y4

**Possible KPIVs**

- **Variables**
  - X1
  - X2
  - X3
  - X4
  - X5
  - X6
- **Is nonconformity a KPIV?**
  - A
  - B
  - N/A
- **Confirmed with**
  - Chi-square
  - Logistic regression
  - Logistic regression/DoE
  - DoE

**FUNNEL**

- Chart showing data flow and possible KPIVs.
Binary Logistic Regression Analysis

Limitation of using a traditional regression analysis:
- The response is bounded between 0 and 1.
- The response should theoretically range between $-\infty$ and $+\infty$.

The original response has limits of 0 and 1.

Creation of an “odds ratio” extends the upper limit of the response to $+\infty$.

$Y_2 = f(x_1, x_2, x_3, \ldots, x_k)$

How Binary Logistic Regression handles the limitation?

$P(Y) = \frac{e^{\alpha + \beta X}}{1 + e^{\alpha + \beta X}}

0 \leq p \leq 1

0 \leq \frac{p}{1-p} < \infty$
• What is a binary logistic regression?
Evaluates success/fail data by using the binomial distribution with a link function to model the probability of the event.

• When to use a binary logistic regression?
Experiment designed to study the effect of the process input variables on a binary response.

• Why use binary logistic regression?
If the distribution of the response is binomial, the normality and constant variance are violated in the ANOVA Analysis. BLG however recognize the boundaries of the proportion and is designed to handle binomial responses.
Binary Logistic Regression Analysis

Analizing a Binary Logistic Regression

1. Choose **Stat>Regression>Binary Logistic Regression**

2. Complete the dialog box as shown below.

   ![Binary Logistic Regression dialog box](image)

   - **Factors**: x1 and x2
   - **Response event**: OK/NG

   ![Data table](image)

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3-T</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>2.0</td>
<td>650</td>
<td>NG</td>
</tr>
<tr>
<td>65</td>
<td>2.0</td>
<td>650</td>
<td>NG</td>
</tr>
<tr>
<td>66</td>
<td>2.0</td>
<td>650</td>
<td>NG</td>
</tr>
<tr>
<td>67</td>
<td>2.0</td>
<td>650</td>
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</tr>
<tr>
<td>68</td>
<td>2.0</td>
<td>650</td>
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<tr>
<td>69</td>
<td>2.0</td>
<td>650</td>
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</tr>
<tr>
<td>70</td>
<td>2.0</td>
<td>650</td>
<td>OK</td>
</tr>
<tr>
<td>71</td>
<td>2.0</td>
<td>650</td>
<td>OK</td>
</tr>
<tr>
<td>72</td>
<td>2.0</td>
<td>650</td>
<td>OK</td>
</tr>
</tbody>
</table>

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Binary Logistic Regression Analysis

Highlights of the Session Window:

Link Function: Logit
Logistic Regression Table

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>Z</th>
<th>P</th>
<th>Odds</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-8.07</td>
<td>2.49</td>
<td>-3.23</td>
<td>0.001</td>
<td>0.00</td>
<td>3.28</td>
</tr>
<tr>
<td>X1</td>
<td>2.39</td>
<td>0.61</td>
<td>3.91</td>
<td>0.001</td>
<td>10.87</td>
<td>3.28</td>
</tr>
<tr>
<td>X2</td>
<td>0.01</td>
<td>0.0037</td>
<td>3.43</td>
<td>0.001</td>
<td>1.01</td>
<td>1.01</td>
</tr>
</tbody>
</table>

\[ \ln(\text{odds ratio}) = m_1x_1 + m_2x_2 + \beta \]

\[ P = \frac{e^{2.3865(x_1)+0.012(x_2)−8.07}}{1 + e^{2.3865(x_1)+0.012(x_2)−8.07}} \]

Which factor is more important?

What is the model?
Design of Experiments with attribute data

Factors: 3  Base Design: 3, 8  Runs: 16  Replicates: 2

Factors and Their Uncoded Levels

<table>
<thead>
<tr>
<th>Factor</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>600</td>
<td>700</td>
</tr>
<tr>
<td>X3</td>
<td>23.5</td>
<td>24.125</td>
</tr>
<tr>
<td>X4</td>
<td>26</td>
<td>29</td>
</tr>
</tbody>
</table>

Why do I need to transform the data?

Freeman- Tukey Transformation

\[ Y = \frac{\sin^{-1}\left(\sqrt{\frac{Np}{N+1}}\right) + \sin^{-1}\left(\sqrt{\frac{Np+1}{N+1}}\right)}{2} \]

Sample Size (N)  50

<table>
<thead>
<tr>
<th>Proportion Defective</th>
<th>Standard Transform</th>
<th>Freeman-Tukey</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.26</td>
<td>0.5351</td>
<td>0.5404</td>
</tr>
</tbody>
</table>

mean = np  \( \sigma = \sqrt{np(1-p)} \)

The Binomial \( \sigma \) depends on sample size and success rate \( p \). \( \sigma \) is largest when \( p = 0.5 \) and smallest as \( p \) approaches 0 or 1. For \( n=10 \) and:

- \( p = 0.5 \)  \( \Rightarrow \sigma = \sqrt{10 \times 0.5 \times (1-0.5)} = 1.58 \)
- \( p = 0.1 \)  \( \Rightarrow \sigma = \sqrt{10 \times 0.1 \times (1-0.1)} = 0.95 \)
- \( p = 0.9 \)  \( \Rightarrow \sigma = \sqrt{10 \times 0.9 \times (1-0.9)} = 0.95 \)

Binomial \( \sigma \) depends on success rate, we’d have non-constant variance which violates DOE model assumptions.
Design of Experiments with attribute data

• How to do it

Performs the Freeman Tukey transformation to **stabilize variance** for binomial data. **Trials** must be a positive integer, and **success** must be an integer between 0 and the number of trials, inclusive.

**Transformation Freeman- Tukey**

1. Choose **Stat>C Calc > Calculator**

2. Complete the dialog box as shown below.

![Image of Minitab interface showing transformation formula and data table]
Binary Logistic Regression Analysis

Interaction Plot

Control Chart

Yield (Comparison Before vs After Improvements)

LCS = 0.9789
X = 0.9708
LCI = 0.9404

Results

Profitability Benefits | Type Cost | Dollar Savings
--- | --- | ---
Improve Yield | Hard Cost | 14,524.57
Spec optimization | | 16,322.00
| | 45,362.74
| | 24,500.00
| | **100,710.01**

Total Project Savings = $100,710.00

Financial Project Signoff: [Signature]
DMAIC Practical Problem- Optimizing a Mixing Process using a Mixture DoE.
Optimizing a Mixing Process using a Mixture DoE

A + B + C + D + E = 100%

<table>
<thead>
<tr>
<th>Linear Constraint</th>
<th>Component Boundaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ≤ A ≤ 30,00</td>
<td>A: 0 - 30</td>
</tr>
<tr>
<td>0 ≤ B ≤ 17,34</td>
<td>B: 0 - 17.74</td>
</tr>
<tr>
<td>60 ≤ C ≤ 82,66</td>
<td>C: 0 - 82.66</td>
</tr>
<tr>
<td>0 ≤ D ≤ 28,6</td>
<td>D: 0 - 82.66</td>
</tr>
<tr>
<td>C + D ≤ 82,66</td>
<td>E: 0 - 25.06</td>
</tr>
<tr>
<td>11,47 ≤ E ≤ 25,06</td>
<td></td>
</tr>
</tbody>
</table>

Type of design: Simplex Centroid, Simplex Lattice, Extreme Vertices
• **What is a Mixture Design**

Mixture Experiments are a class of response surface experiments that investigate products containing several components (Ingredients).

  - In Factorial and RSM designs, the response depends on the levels of each factor and usually they have some properties like orthogonality.

• **What is orthogonality?**

\[
\sum_{i=1}^{q} x_i = x_1 + x_2 + \ldots + x_q = 1
\]

Orthogonality guarantees that the effect of one factor or interaction can be estimated separately from the effect of any other factor or interaction in the model.
Creating a Mixture Design

1. Choose Stat>DOE>Mixture>Create Mixture Design

2. Complete the dialog box as shown below.

Use this design when the design has either upper and lower bounds or linear constraints, which results in a design space that is no longer simplex.
Creating a Mixture Design

3. Complete the dialog box as shown below.

4. Click Components.

A, B, C, D, and E are physical properties.

What does that mean?

Quadratic Model

= A + B + C + D + E

0 ≤ A ≤ 30, 00
0 ≤ B ≤ 17, 34
60 ≤ C ≤ 82, 66
0 ≤ D ≤ 28, 6
C + D ≤ 82, 66
11, 47 ≤ E ≤ 25, 06
### Bounds of Mixture Components

<table>
<thead>
<tr>
<th>Comp</th>
<th>Lower</th>
<th>Upper</th>
<th>Lower Proportion</th>
<th>Upper Proportion</th>
<th>Lower Pseudo Component</th>
<th>Upper Pseudo Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.000</td>
<td>28.530</td>
<td>0.00000</td>
<td>0.28530</td>
<td>0.00000</td>
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<td>B</td>
<td>0.000</td>
<td>17.340</td>
<td>0.00000</td>
<td>0.17340</td>
<td>0.00000</td>
<td>0.60778</td>
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<tr>
<td>C</td>
<td>60.000</td>
<td>82.660</td>
<td>0.60000</td>
<td>0.82660</td>
<td>0.00000</td>
<td>0.79425</td>
</tr>
<tr>
<td>D</td>
<td>0.000</td>
<td>22.660</td>
<td>0.00000</td>
<td>0.22660</td>
<td>0.00000</td>
<td>0.79425</td>
</tr>
<tr>
<td>E</td>
<td>11.470</td>
<td>25.060</td>
<td>0.11470</td>
<td>0.25060</td>
<td>0.00000</td>
<td>0.47634</td>
</tr>
</tbody>
</table>

*NOTE* Bounds were adjusted to accommodate specified constraints.
Optimizing a Mixing Process using a Mixture DoE

Fitting a Model

1. Choose Stat>DOE>Mixture>Analyze Mixture Design

2. Complete the dialog box as shown below.

<table>
<thead>
<tr>
<th>Term</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>11.772</td>
<td>0.5019</td>
<td>*</td>
<td>*</td>
<td>1.760</td>
</tr>
<tr>
<td>B</td>
<td>11.832</td>
<td>0.9017</td>
<td>*</td>
<td>*</td>
<td>1.782</td>
</tr>
<tr>
<td>C</td>
<td>11.811</td>
<td>0.2169</td>
<td>*</td>
<td>*</td>
<td>1.789</td>
</tr>
<tr>
<td>D</td>
<td>12.026</td>
<td>0.2169</td>
<td>*</td>
<td>*</td>
<td>1.789</td>
</tr>
<tr>
<td>E</td>
<td>-2.849</td>
<td>0.6082</td>
<td>*</td>
<td>*</td>
<td>1.864</td>
</tr>
<tr>
<td>C*D</td>
<td>3.510</td>
<td>1.6009</td>
<td>2.19</td>
<td>0.033</td>
<td>1.201</td>
</tr>
</tbody>
</table>

S = 0.560783  PRESS = 20.3450
R-Sq = 90.09%  R-Sq(pred)=87.67%  R-Sq(adj)=89.13%

A, B, C, D, and E are physical properties.

High p-values suggest that these terms are not important and can be removed.

There is not p-value for the individual component effects because these ingredients are in the mixture and must remain in the model.

Minitab Insights 2016
### Highlights of the Session Window:

**Analysis of Variance for Tensilex (component proportions)**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>5</td>
<td>148.606</td>
<td>148.606</td>
<td>29.7212</td>
<td>94.51</td>
<td>0.000</td>
</tr>
<tr>
<td>Linear</td>
<td>4</td>
<td>147.094</td>
<td>143.841</td>
<td>35.9604</td>
<td>114.35</td>
<td>0.000</td>
</tr>
<tr>
<td>Quadratic</td>
<td>1</td>
<td>1.512</td>
<td>1.512</td>
<td>1.512</td>
<td>4.81</td>
<td>0.033</td>
</tr>
<tr>
<td>C*D</td>
<td>1</td>
<td>1.512</td>
<td>1.512</td>
<td>1.512</td>
<td>4.81</td>
<td>0.033</td>
</tr>
<tr>
<td>Residual Error</td>
<td>52</td>
<td>16.353</td>
<td>16.353</td>
<td>0.3145</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>57</td>
<td>164.959</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What is the p value telling us?

A, B, C, D, and E are physical properties.
Optimizing a Mixing Process using a Mixture DoE

A, B, C, D, and E are physical properties

1. Choose
   Stat>DOE>Mixture>
   Surface plots

2. Complete the dialog box as shown below.

How about the cost?
Optimizing a Mixing Process using a Mixture DoE

A, B, C, D, and E are physical properties

<table>
<thead>
<tr>
<th>Optimal D: 0.7917</th>
<th>[ ]:A</th>
<th>[ ]:B</th>
<th>[ ]:C</th>
<th>[ ]:D</th>
<th>[ ]:E</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Cur Low</td>
<td>30.0</td>
<td>17.340</td>
<td>82.660</td>
<td>70.2989</td>
<td>25.060</td>
</tr>
<tr>
<td></td>
<td>[30.0]</td>
<td>[16.1501]</td>
<td>[41.6184]</td>
<td>[0.0]</td>
<td>[12.2315]</td>
</tr>
</tbody>
</table>
Optimizing a Mixing Process using a Mixture DoE

**Results**

<table>
<thead>
<tr>
<th>Financial Data Annualized Totals</th>
<th>Estimate</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annualized Hard Savings</td>
<td>$9,000</td>
<td>$12,000</td>
</tr>
<tr>
<td>Annualized Soft Savings</td>
<td>$0</td>
<td>$0</td>
</tr>
</tbody>
</table>

A,B,C,D, and E are physical properties
DMAIC Practical Problem- Increase the productivity in Mixing Area using a DSD
Increase the productivity in Mixing Area using a DSD

**Problem Statement**
Increase Kg/min in BB#3 from 120 Kg/min to 126 Kg/min

**Pareto**

![Pareto Chart]

**MSA**

Can you adequately assess process performance?

The measurement system variation equals 3.0% of the process variation. The process variation is estimated from the parts in the study.

**IPO Map**

![IPO Map]

**Funnel**

Possible KPIVs

<table>
<thead>
<tr>
<th>X Variable Name</th>
<th>Analysis/Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>x1</td>
<td>DOE</td>
</tr>
<tr>
<td>x2</td>
<td>DOE</td>
</tr>
<tr>
<td>x3</td>
<td>DOE</td>
</tr>
<tr>
<td>x4</td>
<td>DOE</td>
</tr>
<tr>
<td>x5</td>
<td>DOE</td>
</tr>
<tr>
<td>x6</td>
<td>DOE</td>
</tr>
</tbody>
</table>
What is a Definitive Screening Design?

Is it possible to optimize the Y condition using more than 5 factors with just one design?
What is a Definitive Screening Design?

- Orthogonal main effects.
- Main effects uncorrelated with two-factor interactions and quadratic effects.
- Estimable quadratic effects – three-level design.
- Small number of runs – order of the number of factors.
- Two-factor interactions not confounded with each other.

Normal Approach

![Create Factorial Design: Display Available Designs](image)

Resolution

When one factor effect is aliased with another effect

Resolution: III  
Alias Structure: A + BD

Resolution: IV  
Alias Structure: AB + CD

Resolution: V  
Alias Structure: A + BCDE

Increase the productivity in Mixing Area using a DSD
Increase the productivity in Mixing Area using a DSD

Definitive Screening Design

Where is the DSD in Minitab?

You need to run a Macro!

DSD Macro

1. Choose **Tools > Options**
2. Complete the dialog box as shown below.
Increase the productivity in Mixing Area using a DSD

DSD Macro

1. Go to Edit > Command Line Editor
2. Write the script below

```
%defscreening 6;
store c5-c10;
design c1 c2 c3 c4.
```

Definitive Screening Design for 6 Factors

Factors: 6   Runs: 13
Analyze the design using Stat > DOE > Response Surface > Analyze Response Surface Design

Minitab Insights 2016
Increase the productivity in Mixing Area using a DSD

**DSD Analysis**

1. Choose Stat>DOE>Response Surface > Analyze Response Surface
2. Complete de dialog box as shown below.

3. Choose **Terms**
4. Complete de dialog box as shown below

```
Include the following terms: Full quadratic
```

5. Choose **Stepwise**
6. Complete de dialog box as shown below

```
Method: Stepwise
Alpha to enter: 0.01
Alpha to remove: 0.01
```

7. Choose **Graphs>Residual Plots>For in one**
8. **Ok**
**DSD Analysis**

**Stepwise Selection of Terms**

\( \alpha \) to enter = 0.01, \( \alpha \) to remove = 0.01  
The stepwise procedure added terms during the procedure in order to maintain a hierarchical model at each step.

**Analysis of Variance**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>5</td>
<td>9409.1</td>
<td>1881.82</td>
<td>103.80</td>
<td>0.000</td>
</tr>
<tr>
<td>x1</td>
<td>1</td>
<td>2766.0</td>
<td>2766.01</td>
<td>152.58</td>
<td>0.000</td>
</tr>
<tr>
<td>x2</td>
<td>1</td>
<td>1145.7</td>
<td>1145.65</td>
<td>63.20</td>
<td>0.000</td>
</tr>
<tr>
<td>x3</td>
<td>1</td>
<td>2245.3</td>
<td>2245.26</td>
<td>123.85</td>
<td>0.000</td>
</tr>
<tr>
<td>x4</td>
<td>1</td>
<td>468.8</td>
<td>468.81</td>
<td>25.86</td>
<td>0.000</td>
</tr>
<tr>
<td>x2*x2</td>
<td>1</td>
<td>121.0</td>
<td>1121.03</td>
<td>61.84</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>48</td>
<td>870.2</td>
<td>18.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack-of-Fit</td>
<td>45</td>
<td>821.4</td>
<td>18.25</td>
<td>1.12</td>
<td>0.546</td>
</tr>
<tr>
<td>Pure Error</td>
<td>3</td>
<td>48.7</td>
<td>16.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>10279.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Model Summary**

<table>
<thead>
<tr>
<th>S</th>
<th>R-sq</th>
<th>R-sq(adj)</th>
<th>R-sq(pred)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.25777</td>
<td>91.53%</td>
<td>90.65%</td>
<td>89.21%</td>
</tr>
</tbody>
</table>
Increase the productivity in Mixing Area using a DSD

Surface Plot of Kg/min vs X2, X1

Main Effects Plot for Kg/min

Contour Plot of Kg/min vs x2, x1

- x1 = 95.7799
- x2 = 224.577
- Kg/min = 161.984

Hold Values
- x3 = 32.5

Minitab Insights 2016
Optimizing a Mixing Process using a Mixture DoE

RSM Chart
Surface Plot of Kg/min vs X2, X1

Optimizer
Optimal
D: 1.000
High
Cur
Low
Predict
x1
105.0
95.0
x2
231.0
216.0
x3
35.0
30.0
x4
10.0
0.0

Kg/min
Maximum
y = 172.0379
d = 1.0000

Capability Analysis
Process Capability Report for Final Condition
Calculations Based on Weibull Distribution Model

Results

Financial Data Synopsis

Financial Analyst

Financial Review Status
- Unreviewed
- Estimates Approved
- Actuals Approved
- Audit Required
- Needs Further Review

Savings Start Date
- April 2016

Financial Data Annualized Totals

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annualized Hard Savings</td>
<td>$12,000</td>
<td>$20,000</td>
</tr>
<tr>
<td>Annualized Soft Savings</td>
<td>$0</td>
<td>$0</td>
</tr>
</tbody>
</table>
To use the statistical approach in designing and analyzing an experiment. It is necessary for everyone involved in the experiment to have a clear idea in advance of the following:

- What is to be studied?
- How the data are to be collected?
- How the data are to be analyzed?

Minitab is a powerful tool to analyze DoE's, but the analysis is going to be as good as the planification of the design.
Questions?