Who We Are

This month's webinar presented by:
Wayne Adams

With the Stat-Ease, Inc. consulting team

Pat Whitcomb

Mark Anderson

Shari Kraber

DOE—What's In It For Me 1

Webinar Rules
Increasing Signal

Due to time constraints, please hold questions until the Q&A breaks or after the presentation.

All participants will be muted during the presentation except for breaks. (Not everyone has a nice quiet room)

DOE—What's In It For Me 2

Real-World DOE Headlines

A very small sample*

John Deere Saves $500K Annually with DOE
- *Scitech Journal*

DOE Saves Kodak Thousands
- *Metal Forming*

DOE Package Optimizes Coverwrap Process
- *Industrial Engineering Solutions*

Using DOE to Prevent Solvent Pop
- *Paint & Coatings Industry*

DOE Helps Clear Wafer Transport Jams
- *Micro*

DOE Attracts 3.5X More to Crayola Website
- *Harvard Business Review*

DOE—What's In It For Me 3

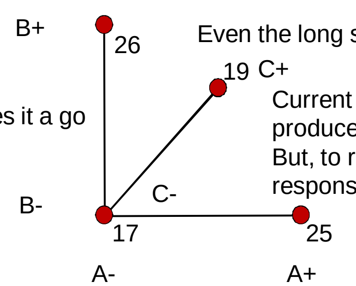
Topic for Today

OFAT vs. DOE

No meaningful improvements found with a one factor at a time experiment.

Even the long shot Team C tries

Team B Gives it a go



Current Operating conditions produce a response of 17 units. But, to remain in business, the response needs to at least double.

Team A works on their factor but cannot double the response

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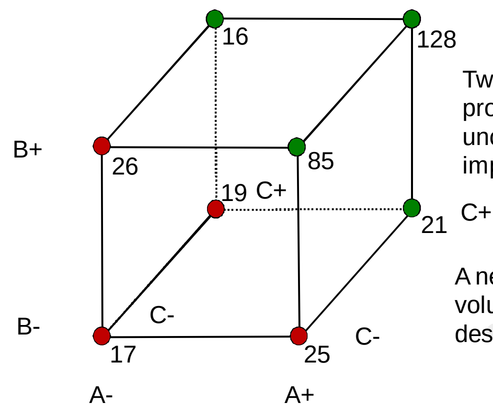
Topic for Today
OFAT vs. DOE



Two solutions to the problem found by uncovering the important interactions

A new hire engineer volunteers to do a designed experiment

Topic for Today
Grand finale

The last example was based on a real occurrence at SKF.

Ultimately SKF improved their actual bearing life from 41 million revolutions on average (already better than any competitors), to 400 million revs* – nearly a ten-fold improvement!

*(“Breaking the Boundaries,” *Design Engineering*, Feb 2000, pp 37-38.)

Reasons to Hire Scientists

Engineers, Chemists, etc.

Fix problems happening now.

Improve quality to improve market share.

Reduce costs w/o sacrificing quality

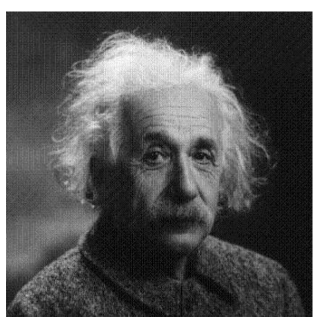
~~PUT OUT FIRES!~~

Make the company more profitable

DOE—What's In It For Me 7

Build a Better Scientist

A few scientists already know the answers



There are more problems than scientists.

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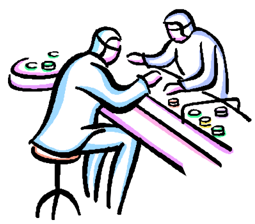
Build a Better Scientist

Most scientists can make very good guesses.

All scientists can conduct experiments and draw conclusions from the results.



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Build a Better Scientist

- Best guesses and even certain knowledge require confirmation work.
- Experiments produce data
  - data confirms guesstimates.
  - through statistical analysis, data can be interpreted to find solutions.
  - interpreted data leverages knowledge to solve problems in the future.
- Experiments do NOT replace subject matter experts

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Build a Better Scientist

"I do not feel obliged to believe that the same God who has endowed us with sense, reason, and intellect has intended us to forgo their use."

- Galileo Galilei

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Questions?

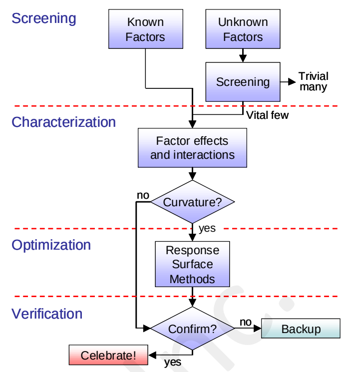
Please Do

- Use the Raise-Hand button
- Un-mute your phone if asking the question
- Mute your phone if some one else is asking a question.

DOE—What's In It For Me 12

Agenda Transition

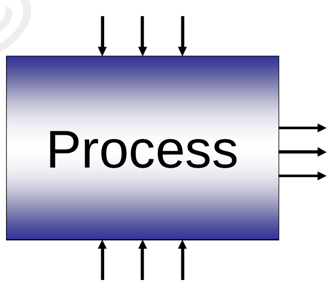
- **DOE – Process and design construction**
  Introduce the process for designing factorial experiments and motivate their use.
- Advantage over one-factor-at-a-time (OFAT)



DOE—What's In It For Me 13

Design of Experiments

Controllable Factors "x"



Noise Factors "z"

Responses "y"

DOE (Design of Experiments) is:

"A systematic series of tests, in which purposeful changes are made to input factors,

so that you may identify causes for significant changes in the output responses."

Have a Plan

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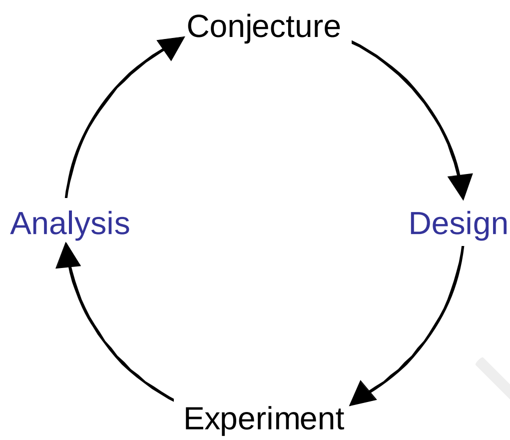
Iterative Experimentation



Expend no more than 25% of budget on the 1st cycle.

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DOE Process *(1 of 2)*
Ask the Scientist

1. Identify the opportunity and define the objective.
   - *Before talking to the scientist.*
2. State objective in terms of measurable responses.
   a. Define the change (Δy) that is important to detect for each response. (Δy = signal)
   b. Estimate experimental error (σ) for each response. (σ = noise)
   c. Use the ratio ($\Delta y/\sigma$) to estimate power.
3. Select the input factors to study. (*Remember that the factor levels chosen determine the size of Δy.*)

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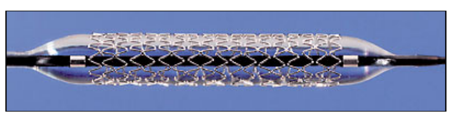
DOE Process *(2 of 2)*
Ask the Statistician

4. Select a design and:
   - Evaluate aliases
   - Evaluate power.
5. Examine the design layout to ensure all the factor combinations are safe to run and are likely to result in meaningful information (no disasters).
   - *Ask the scientist again*

An Example: DOE process
Stent Delivery System

A stent is a wire mesh tube used to prop open an artery that's recently been cleared using angioplasty. The stent is collapsed to a small diameter over a balloon catheter. It's then moved into the area of the blockage.



When the balloon is inflated, the stent expands, locks in place and forms a scaffold. This holds the artery open. The stent stays in the artery permanently, holding it open to improve blood flow to the heart muscle.

An Example: DOE process
Stent Delivery System

1. Identify opportunity and define objective.
   Improve stent safety to avoid a recall. Improve the quality of the manufacturing process.
2. State objective in terms of measurable responses.
   Safety is quantified by Burst pressure.
   a. Define the change (Δy) that is important to detect for each response. We must find process settings that improve burst by 6 psig.
   b. Estimate error (σ): $\sigma_{Burst} = 8$ psig;
   c. Calculate signal to noise: $\Delta/\sigma = 6/8 = 0.75$

0.75 Used in step 4 to calculate power.

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An Example: DOE process
Stent Delivery System

3. Select the input factors to study. Typical factors include:
   - Lengths and diameters of various components, e.g. tip, balloon, catheter, etc.
   - Materials used for the components.
   - Assembly parameters, e.g. weld locations, how the balloon is folded, etc.
   - Stent geometry, wall thickness, how it is crimped on the balloon, etc.

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An Example: DOE process
Stent Delivery System

4. Select a design: Minimum Run Resolution V (MR5)
   - Evaluate aliases (clean through the main-effects, and two-factor interactions)
   - Evaluate power (> 80% for effects of interest)
   - Examine the experiment plan (design) to ensure the factor combinations are likely to result in meaningful information.

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An Example: DOE process
Stent Delivery System

4b. Because designed experiments have a plan before anything is done…
   - An engineer was able to look at the plan and detect a problem. One of the factor combinations produced a gap between two parts that was too large to form a weld.
   - After this combination was adjusted, the experiment continued without a hitch.

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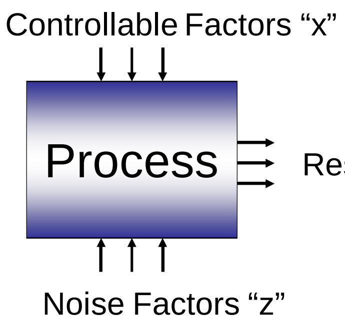
Design of Experiments



Let's brainstorm.

What process might you experiment on for best payback?

How will you measure the response(s)

What factors can you control?

Write it down.

Questions?

Please Do

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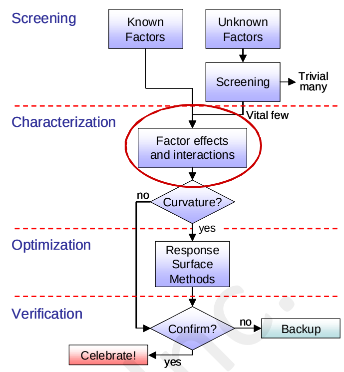
Agenda Transition

- DOE – Process and design construction
- **Advantage over one-factor-at-a-time (OFAT)**
  Summarize the benefits factorial design has over one-factor-at-a-time experimentation.



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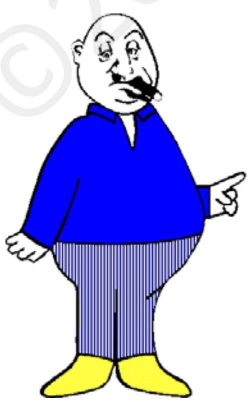
Excuses to Avoid DOE
OFAT is What We've "Always Done"



"It's too early to use statistical methods."

"We'll worry about the statistics after we've run the experiment."

"My data are too variable to use statistics."

"Lets just vary one thing at a time so we don't get confused."

"I'll investigate that factor next."

"There aren't any interactions."

"A statistical experiment would be too large."

"We need results now, not after some experiment."

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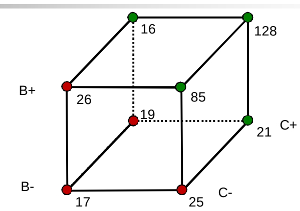
Why OFAT Seems To Work

- OFAT approach confirmed a correct guess.
- There are only main effects active in the process.
- Sometimes it is better to be lucky.
  
  - The experiment path happened to include the optimum factor combinations.
- The current operating conditions were poorly chosen.
  - Changing anything results in improvements.

Why OFAT Fails



- There are interactions.
- The current conditions are stable but not optimal.
- The scientist guessed incorrectly and the OFAT experiment never approaches optimal settings.

Why OFAT Fails

OFAT has problems when multiple responses relate differently to the factors.

OFAT takes more time than DOE to reach the same conclusions.

Time is money!

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Motivation for Factorial Design

- Want to understand how factors interact.
- Want to estimate each factor effect independent of the existence of other factor effects.
- Want to estimate factor effects well; this implies estimating effects from averages.
- Want to obtain the most information in the fewest number of runs.
- Want a **plan** to achieve goals rather than hoping to achieve goals.
- Want to keep it simple.

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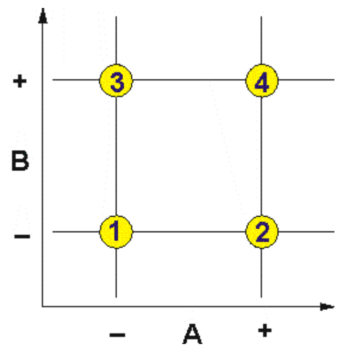
Two-Level Full Factorial Design
Keeping it Simple

Run all high/low combinations of 2 (or more) factors

Use statistics to identify the critical factors



2^2 Full Factorial

What could be simpler?

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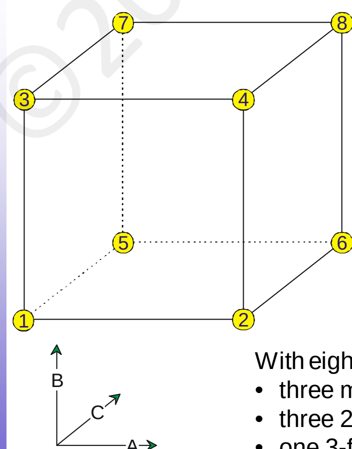
Design Construction
Understanding Interactions

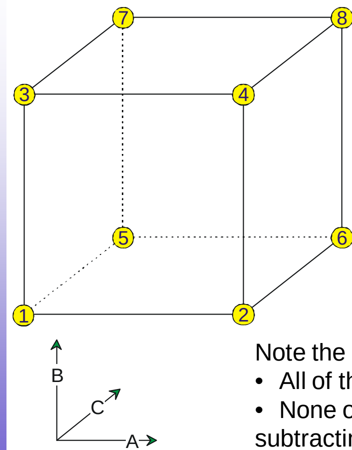


Std	A	B	C	AB	AC	BC	ABC	
1	–	–	–	+	+	+	–	y_1
2	+	–	–	–	–	+	+	y_2
3	–	+	–	–	+	–	+	y_3
4	+	+	–	+	–	–	–	y_4
5	–	–	+	+	–	–	+	y_5
6	+	–	+	–	+	–	–	y_6
7	–	+	+	–	–	+	–	y_7
8	+	+	+	+	+	+	+	y_8

With eight, purpose-picked runs, we can evaluate:
- three main effects (MEs)
- three 2-factor interactions (2FI)
- one 3-factor interaction (3FI)
- as well as the overall average

DOE—What's In It For Me 32

Design Construction
Independent Effect Estimates

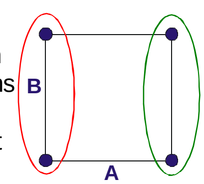


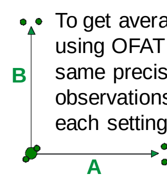
Std	A	B	C	AB	AC	BC	ABC	
1	–	–	–	+	+	+	–	y_1
2	+	–	–	–	–	+	+	y_2
3	–	+	–	–	+	–	+	y_3
4	+	+	–	+	–	–	–	y_4
5	–	–	+	+	–	–	+	y_5
6	+	–	+	–	+	–	–	y_6
7	–	+	+	–	–	+	–	y_7
8	+	+	+	+	+	+	+	y_8

Note the pattern in each column:
- All of the +/- patterns are unique.
- None of the patterns can be obtained by adding or subtracting any combination of the other columns
- This results in independent estimates of all the effects.

Relative Efficiency
DOE vs. OFAT

Hidden Replication
Average observations
Avg(+A) – Avg(-A)
estimate the **A** effect

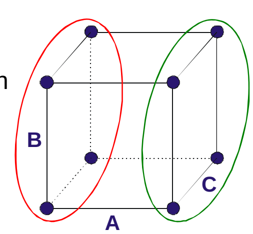


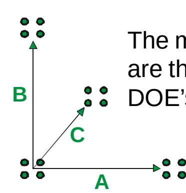


To get average estimates using OFAT that have the same precision as DOE, two observations are needed at each setting.

Relative efficiency = 6/4 = 1.5

Hidden Replication
Average of four observations
Avg(+A) – Avg(-A)





The more factors there are the more efficient DOE's become.

Relative efficiency = 16/8= 2.0

Relative Efficiency
Fractional Factorial

- All possible combinations of factors is not necessary with four or more factors.
- When budget is of primary concern…
  Fractional factorial designs can be used with four or more factors and still provide interaction information.
  - 4 – 12 runs (Irregular fraction) less than 16
  - 5 – 16 runs (Half-fraction) less than 32
  - 6 – 22 runs (Min Run Res V) less than 64

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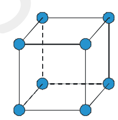

2^k Factorial Design
Advantages

- What could be simpler?
- Minimal runs required.
  Can run fractions if 4 or more factors.
- Have hidden replication.
- Wider inductive basis than OFAT experiments.
- Show interactions.
  Key to Success - Extremely important!
- Easy to analyze.
- Interpretation is not too difficult.
- Can be applied sequentially.
- Form base for more complex designs.
  Second order response surface design.

DOE—What's In It For Me 36

Bibliography

- "Experiment Design Made Easy, Course Book", Whitcomb, Kraber, Anderson, and Adams. 2009.
- "Workshop: Experiment Design Made Easy", <http://www.statease.com/clas_edme.html>
- "I'm a beginner in design of experiments (DOE)", <http://www.statease.com/beginner.html>

Other References:

"Stat-Ease Webinars on Design of Experiments", <http://www.statease.com/webinar.html>

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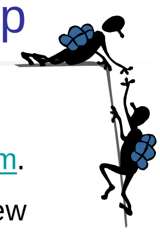
How to get help



- ❑ Search publications posted at www.statease.com.
- ❑ In Stat-Ease software press for Screen Tips, view reports in annotated mode, look for context-sensitive Help (right-click) or search the main Help system.
- ❑ Explore Experiment Design Forum http://forum.statease.com and post your question (if not previously answered).
- ❑ E-mail stathelp@statease.com for answers from Stat-Ease's staff of statistical consultants.
- ❑ Call 612.378.9449 and ask for "statistical help."

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Thanks!

Stick around for the follow up questions.

- If you need to leave us thank you for attending
- Copies of this and other presentations can be found at www.statease.com/webinar.html
- For those that would like “some” statistics the following three pages discuss the Central Limit Theorem.

DOE—What's In It For Me 39

Central Limit Theorem
Compare Averages NOT Individuals

- As the sample size (n) becomes large, the distribution of averages becomes approximately normal.
- The variance of the averages is smaller than the variance of the individuals by a factor of n.

$$\sigma_{\bar{y}}^2 = \frac{\sigma^2}{n}$$

σ (sigma) symbolizes true standard deviation

- The mean of the distribution of averages is the same as the mean of distribution of individuals.

$$\mu_{\bar{y}} = \mu_{y_i}$$

μ (mu) symbolizes true population mean

The CLT applies regardless of the distribution of the individuals.

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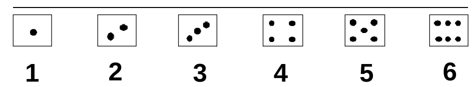
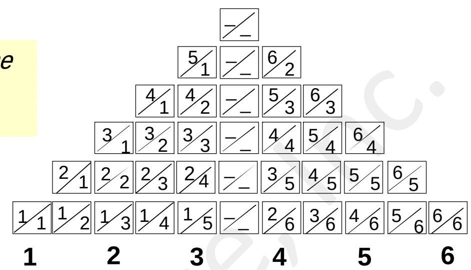
Central Limit Theorem
Illustration using Dice

Individuals are uniform; averages tending toward normal!



Example: "snakeyes" [1/1] is the only way to get an average of one.

Averages of Two Dice



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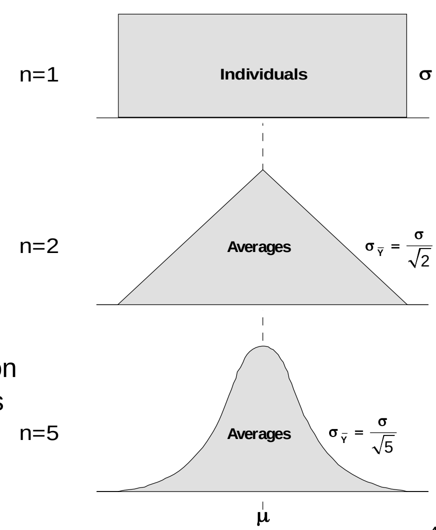
Central Limit Theorem
Uniform Distribution

- As the sample size (n) becomes large, the distribution of averages becomes approximately normal.
- The variance of the averages is smaller than the variance of the individuals by a factor of n.
- The mean of the distribution of averages is the same as the mean of distribution of individuals.



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