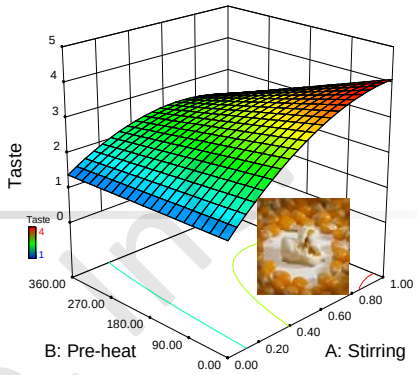


How to Get Started with DOE

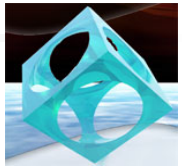
With an introduction to the Design-Expert® Software*

*Presentation is posted at www.statease.com/webinar.html

Feel free to press the raise hand feature on GotoWebinar, which I will watch for at intervals during my presentation. To avoid disrupting the Voice over Internet Protocol (VoIP) system, I will mute all. If I do not get to you, please accept my apology in advance. Then I'd appreciate you sending me an e-mail after the talk so we can discuss your issue(s) 'off-line.' -- Brooks

By Brooks Henderson, MS, Mat. Sci.
Stat-Ease, Inc., Minneapolis, MN
Brooks@statease.com

Mission and Agenda



Objective:

Show-and-tell what DOE can do with the aid of dedicated software from Stat-Ease and support of its experts.

Agenda:

1. Introduction to DOE
   - Brief description of factorial design
   - The 4-step factorial design planning process
2. Applying the factorial design process to optimize Movie Night!—Whirley Pop™ DOE

"*Theory guides, experiment decides*."

-- I. M. Kolthoff

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

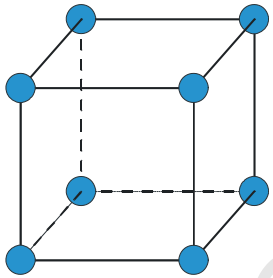
- *Micro*

DOE Attracts 3.5X More to Crayola Website

- *Harvard Business Review*

*Contact brooks@statease.com for these and other pubs – *likely some relevant for you*.

Introduction to DOE – Factorial Designs



1. Introduction to DOE
   - Brief Description of Factorial Design
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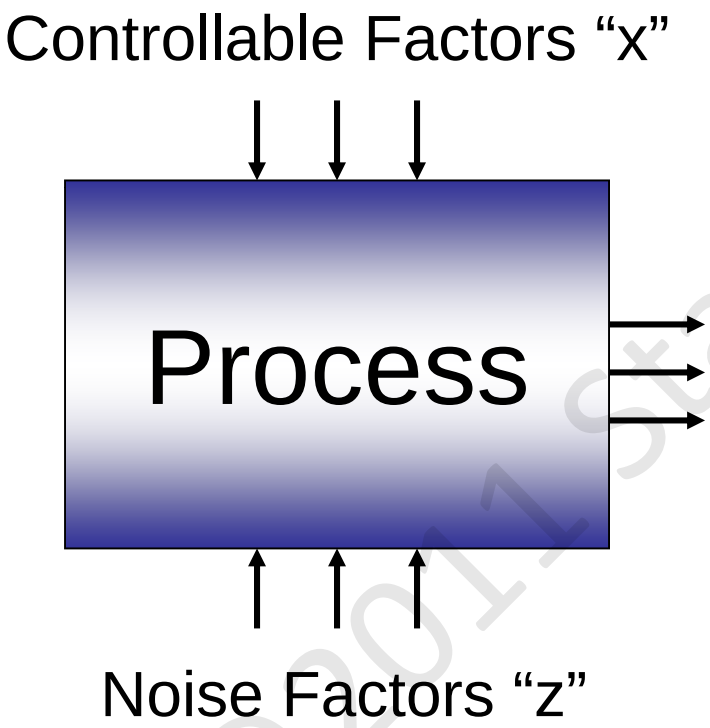
Design of Experiments



Let’s brainstorm.

What process might you experiment on for best payback?

How will you measure the response(s)

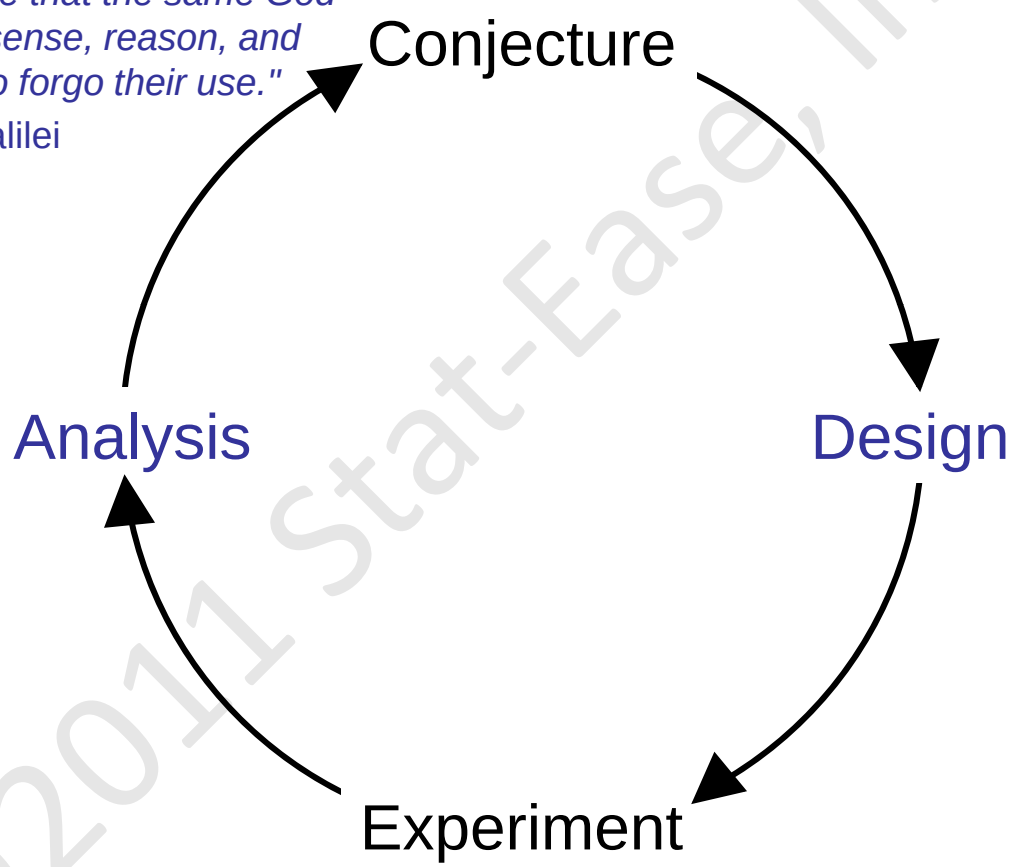
What factors can you control?

Write it down.

Iterative Experimentation

"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



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

DOE versus OFAT

Traditional Approach to Experimentation

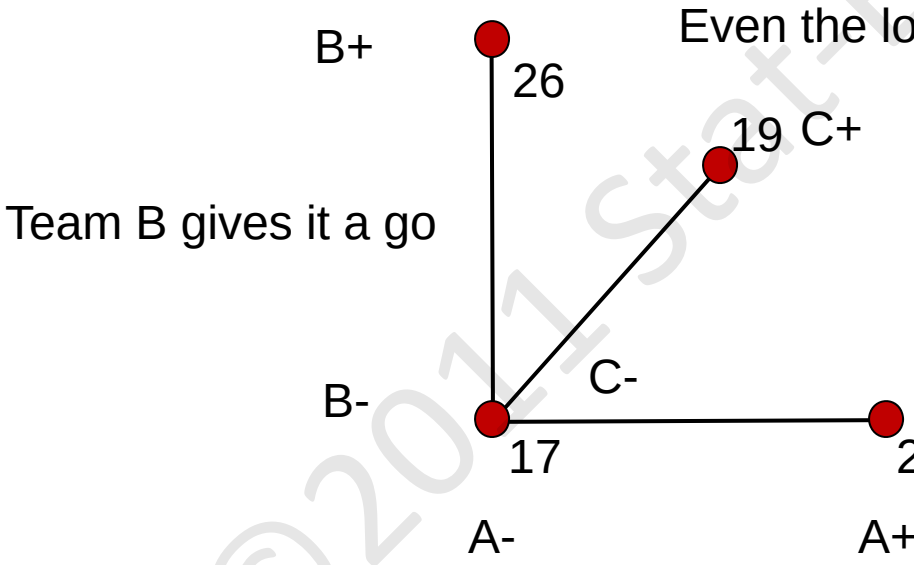
- Study one factor at a time (OFAT), holding all other variables constant
- Simple process, but doesn't account for interactions
- It is inefficient (serial processing)

Factorial Design

- Study multiple factors changing at once (parallel processing)
- Accounts for interactions between variables
- Maximize information with minimum runs

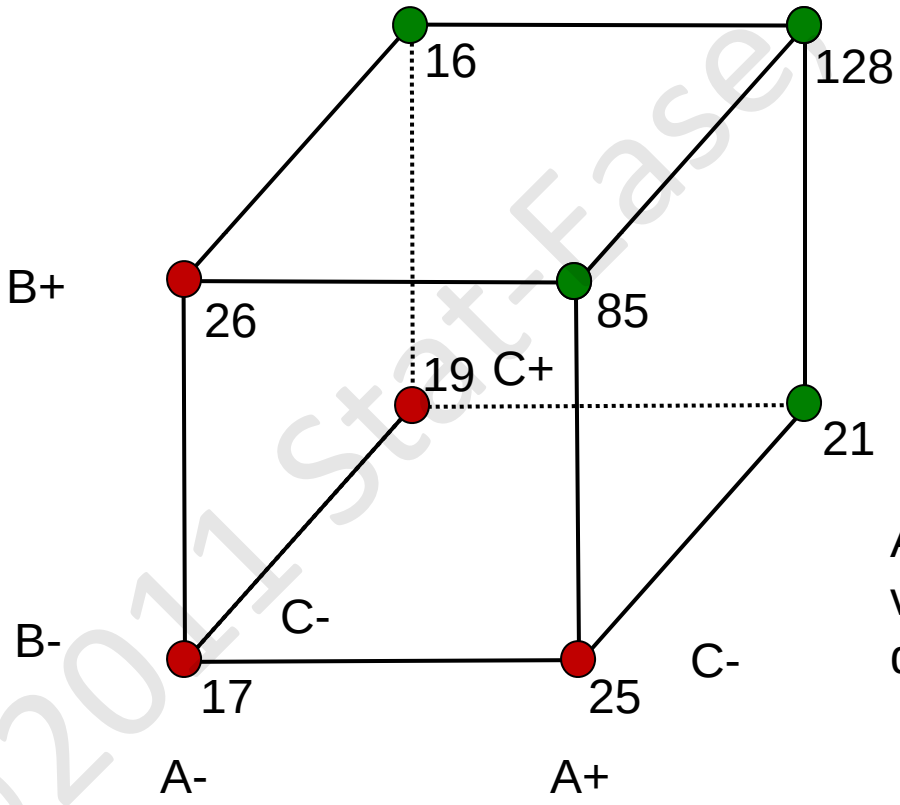
DOE versus OFAT

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



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.)

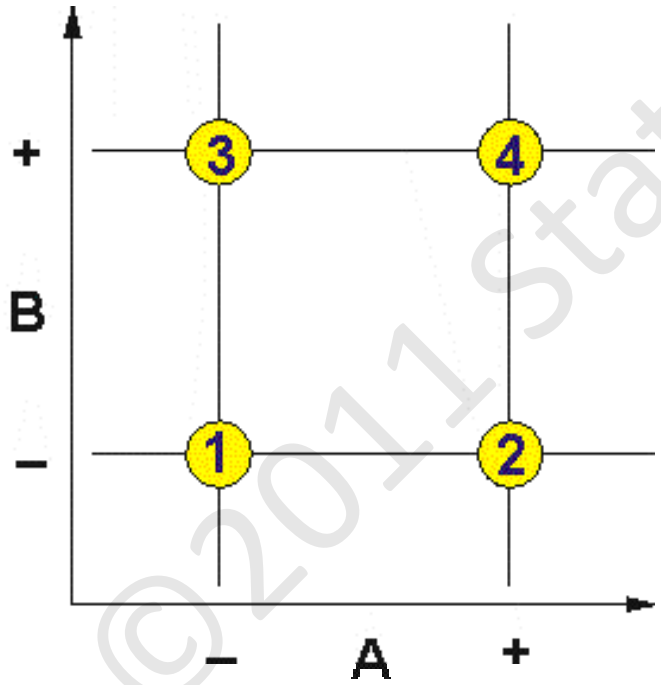
Motivation for Factorial Design

- 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.

Two-Level Full Factorial Design

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

Use statistics to identify the critical factors



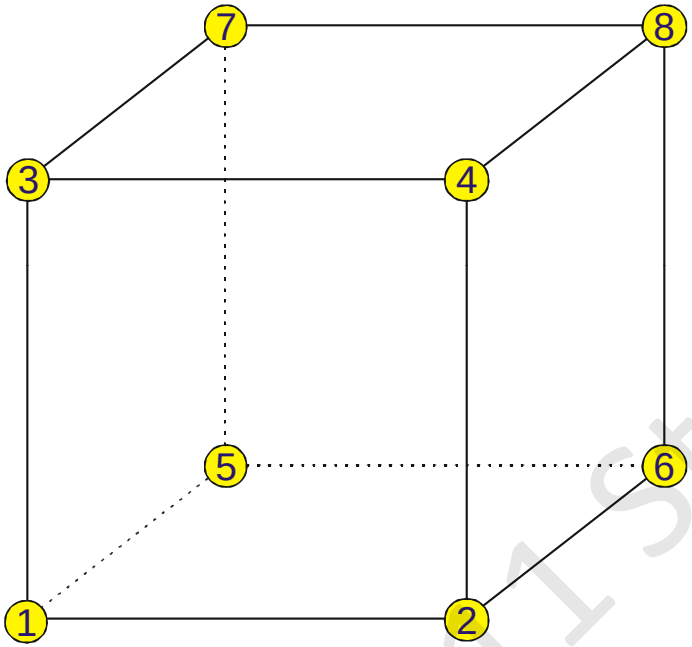
2^2 Full Factorial

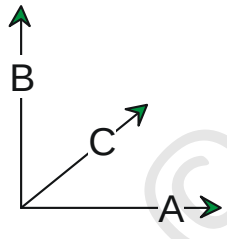
$$\text{Effect}(\Delta y) = \frac{\sum y_+}{n_+} - \frac{\sum y_-}{n_-}$$

What could be simpler?

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

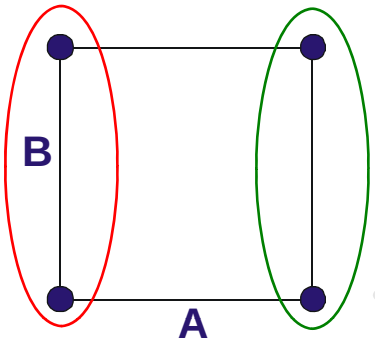
Note the pattern in each column:

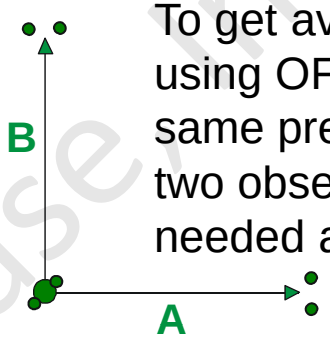
- All of the +/- patterns are unique.
- None of the patterns can be obtained by adding or subtracting any combination of the other columns
- This results in independent estimates of all the effects.

Relative Efficiency

DOE vs. OFAT

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

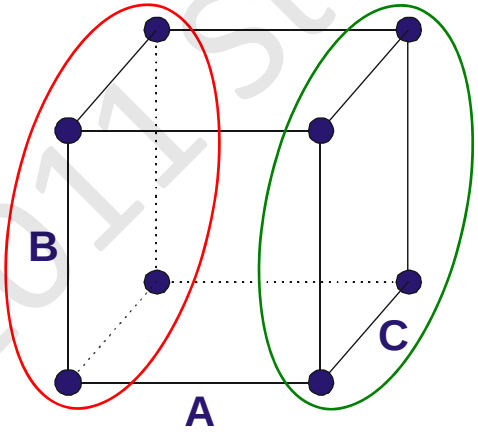


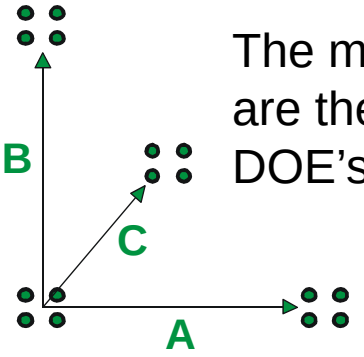


To get average estimates using OFAT that have the same precision as DOE, two observations are needed at each setting.

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

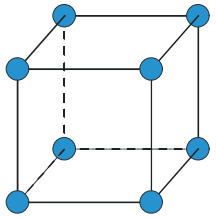
Fractional Factorial

- All possible combinations of factors is not necessary with four or more factors.

- When budget is of primary concern…

  Fractional factorial designs (instead of full factorials) can be used with four or more factors and still provide interaction information.

  - 4 factors –12 runs (Irregular fraction) instead of16
  - 5 factors – 16 runs (Half-fraction) instead of 32
  - 6 factors – 22 runs (Min-Run Res V) instead of 64



2^k Factorial Design

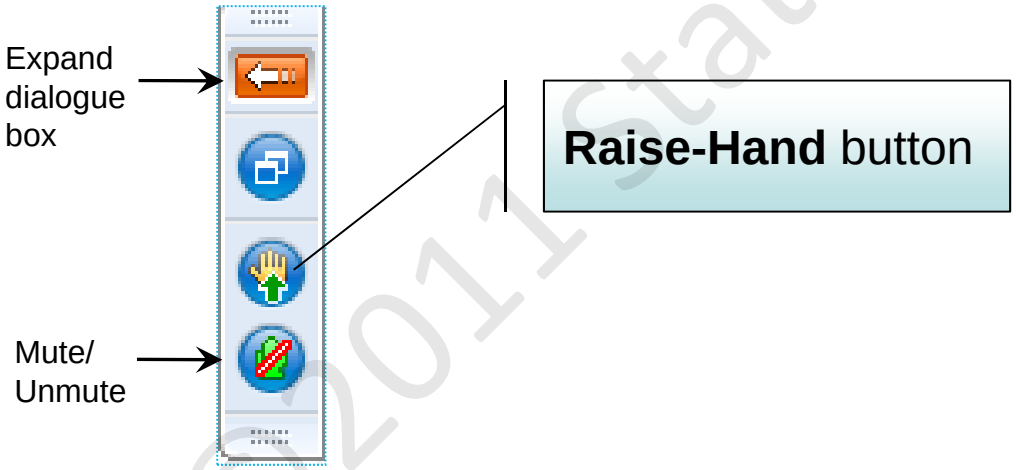
Advantages

- 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 difficult.
  - *Graphs make it easy.*
- Can be applied sequentially.
- Form base for more complex designs.
  - *Second order response surface design.*

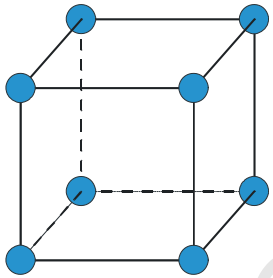
Questions?

Please Do

- Use the **Raise-Hand** button
- I will unmute your microphone so you can ask the question



Agenda Transition



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DOE Process *(1 of 2)*

1. Identify opportunity and define objective.
2. State objective in terms of measurable responses.
   a. Define the change (Δy) that is important to detect for each response.
   b. Estimate experimental error (σ) for each response.
   c. Use the signal-to-noise 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.*)

DOE Process *(2 of 2)*

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

Questions?

Please Do

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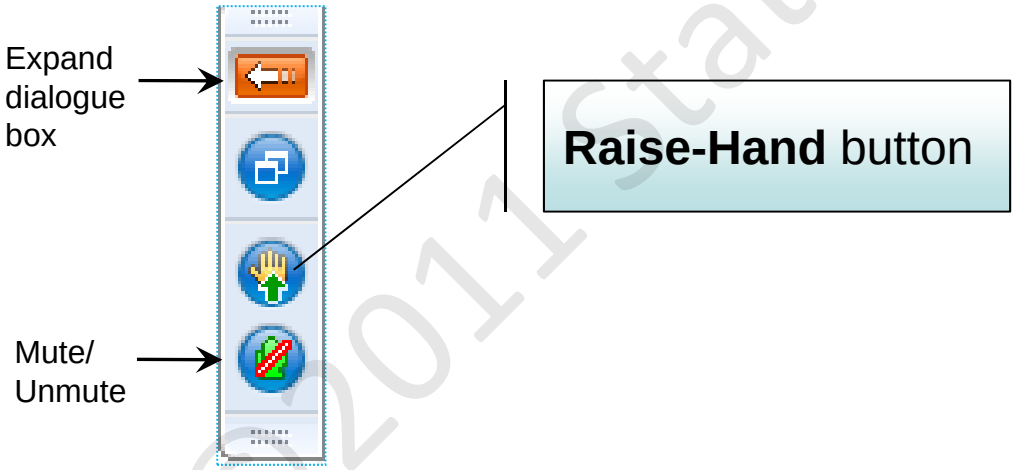

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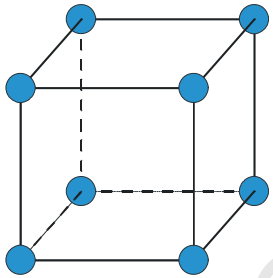

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Two-Level Factorial Design

Whirley Pop DOE

We conducted a 2^3 factorial design with center points. The factors are:

A. Stirring—fraction stirred

B. Pre-Heat Time

C. Popcorn Type

- ***Taste:*** *rated on a scale of 1 to 5 (best) and averaged.*
- ***Texture:*** *rated on a scale of 1(hard) to 5 (soft = best) and averaged.*
- ***UPKs*** *were counted.*
- ***Volume:*** *Estimated volume of popcorn in pot after popping*

* For full report, see Brooks Henderson's "Whirley Pop DOE" posted at our web site: http://www.statease.com/news/news1004.pdf

DOE Process *(1 of 1)*
Whirley Pop DOE

1. Identify opportunity and define objective.
    - Is stirring necessary?
    - Does Popcorn Type make a difference?
    - Determine whether to use pre-heat
2. State objective in terms of measurable responses.
    a. Define the change (Δy) that is important to detect for each response.
        - Taste: ± 2 on the rating scale of 1-5 (expect to see 3 unit change or more)
    b. Estimate experimental error (σ) for each response.
        - Taste: $\sigma = 1$
    c. Use the signal-to-noise ratio ($\Delta y/\sigma$) to estimate power.
        - Power for 2 unit change – 68%
        - Power for 3 unit change – 95%

DOE Process *(2 of 2)*
Whirley Pop DOE

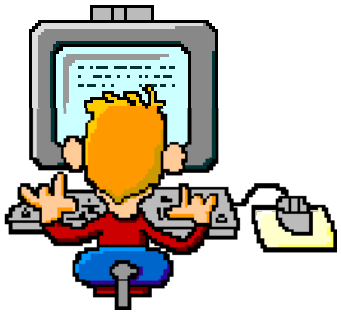
3. Select the input factors to study. (*Remember that the factor levels chosen determine the size of Δy.*)

	Name	Units	Type	Low	High
A [Numeric]	Stirring	Fraction of time	Numeric	0	1
B [Numeric]	Pre-heat	sec	Numeric	0	360
C [Categoric]	Popcorn Type	Brand	Categoric	Cheap	Costly

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

Whirley Pop DOE

Results



[Open Design-Expert Software File]

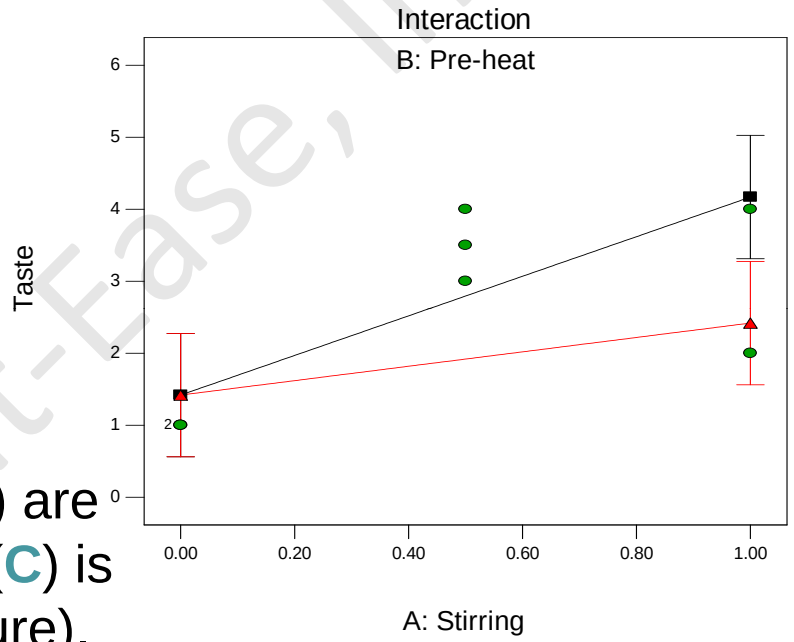
Design-Expert® Software
Factor Coding: Actual
Taste

Design Points

X1 = A: Stirring
X2 = B: Pre-heat

Actual Factor
C: Popcorn Type = Costly

B- 0.00
B+ 360.00

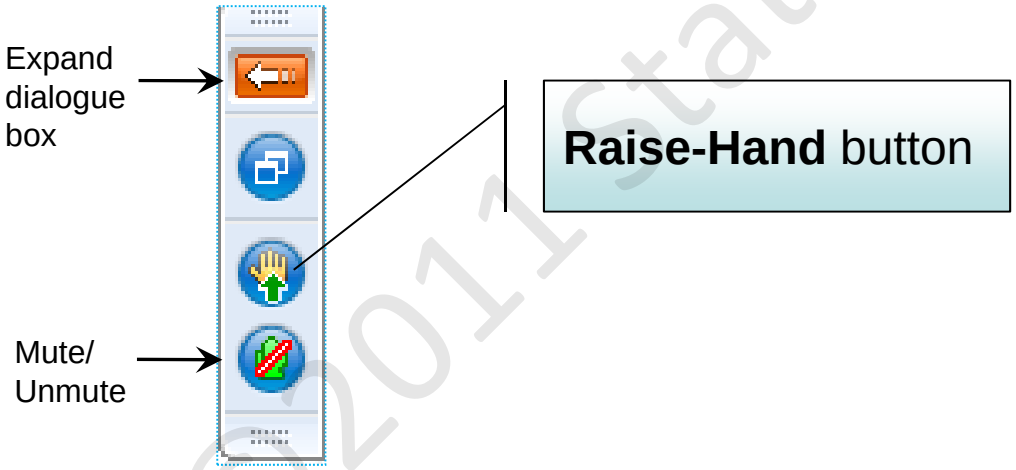


- Stirring and Preheat (**A** and **B**) are significant, but Popcorn Type (**C**) is not significant (except for texture).
  - ✓ Use constant stirring (1.0) and no preheat (0s)
  - ✓ Use Cheap popcorn to save money
- Center points indicate significant curvature. An intermediate level of stirring **MAY** give better taste and/or fewer UPKs. Augment to RSM.

Questions?

Please Do

- Use the **Raise-Hand** button
- I will unmute your microphone so you can ask the question



Statistics Made Easy®

For all the new features in v8 of Design-Expert software, see
www.statease.com/dx8descr.html

Best of luck for your experimenting!

Thanks for listening!

—Brooks

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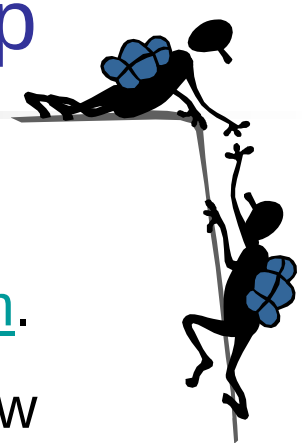
How to get help



- 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."

Bibliography

- "Experiment Design Made Easy, Course Book", Whitcomb, Kraber, Anderson, and Adams, 2011
- "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>

Appendix: Why OFAT seems to work

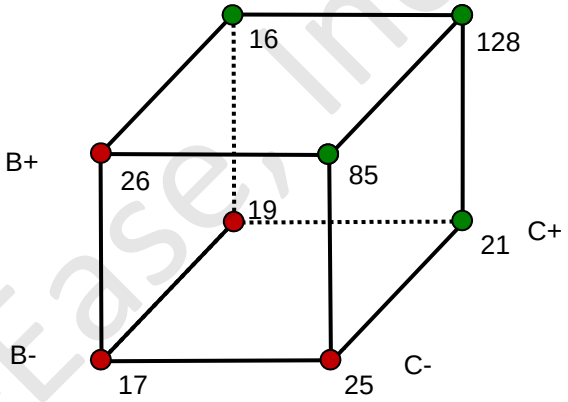
- OFAT approach confirmed a correct guess.
- There are only main effects active in the process.

- 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!