Designing More Efficient and Effective Experiments for Basic Research

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Maximizing this educational opportunity

Welcome everyone! To make the most from this webinar:

- Attendees on mute
- Questions addressed afterward
- Send further questions to shari@statease.com

PS: Presentation posted to www.statease.com/webinars/

Please press the raise-hand button if you are with me.
Stat-Ease YouTube Channel

Key Reference: StatisticsMadeEasybyStatEase

On this channel, look for the Academic Corner:

Agenda: Designing Effective Experiments

- Planning the DOE based on objectives
- Running the experiment
- Analyzing the data
- Confirming the results
Planning the Experiment

1. Define the **response(s)** to be measured – make sure the measurement system will produce accurate and ideally, numerical, results. (Not pass/fail)

2. What **factors** are likely to influence the response(s), and what factor range should be studied?

3. Choose a **design** that will provide the information you need. Consider your strategy of experimentation at this stage – are you doing:
   - Screening
   - Characterization
   - Optimization

4. Plan in advance to go back to the system to **run model verification points** to confirm your analysis results. **KEY to research!!**

Plan: Strategy of Experimentation*

*YouTube: Know the SCOR for Multifactor Strategy of Experimentation

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**Design Objective**

- **Detect main effects**
- **Define interactions**
- **Make precise predictions**

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Planning the Experiment
Choosing the Design – Use DOE Software!!

• **Screening** – assuming that interactions exist in the system, use a design that keeps main effect information **unbiased** from two-factor interaction effects.
  - Resolution IV (yellow), Res V (green) or better designs
  - NOT Res III (red) Plackett-Burman or Taguchi designs

• **Characterization** – use a design that can estimate all two-factor interactions (Full factorial or Resolution V).
  - Consider adding center points to test for non-linearity (curvature)

• **Optimization** – use a response surface design like central composite, Box-Behnken, or optimal (custom) design.

• **Formulations** – use a mixture design for either screening or characterization/optimization (likely an optimal design).

Why use DOE Software to design your experiment?

• Allows you to choose from modern design options that may be better than those used by previous researchers
• Defaults will provide a better design than what you would create by hand or using a textbook template
• Reminds you to consider adding center points, blocking, replicates
• Allows a check of **power (or precision)** to size the design properly
• Final design layout provided in random run order
• Easy to add response data (copy/paste to Excel if desired)

*Most graduate student DOE analysis problems are caused by errors made in building the designs.*
Planning the Experiment
Check for sample size – sizing the design*

1. Size your DOE appropriately for its type and purpose:
   - **Factorial Designs** – size via Power.  
     *The power to detect each individual effect/coefficient is key.*
   - **RSM/MIX Functional design** – size for Precision.  
     *Focus on the ability to predict the mean response with a defined amount of precision.*

2. For Power (factorial designs), define:
   - $\Delta y$: minimum change in the response you want the DOE to detect
   - $s$: standard deviation of the response (historical data)
   - Size to achieve power 80% or greater

*YouTube: How Many Runs Do I need? Using Power & Precision to Size DOE’s

3. For Fraction of Design Space (FDS) (RSM and Mixture), define:
   - $d$: precision of the predicted mean (predicted $y +/ - d$)
   - $s$: standard deviation of the response (historical data)
   - Size to achieve FDS 80% or greater

*Now you can answer the question...How many runs do we really need?*

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* Designing Efficient and Effective Experiments 10
Agenda: Designing Effective Experiments

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Executing (Running) the Experiment

Keys to running your experiment (1 of 2):

- **Control** things that may cause unexpected variation. **Block** variables that are changing, but you are not studying (different days, lots, equipment). *(Plan blocks during the design of the experiment so they are statistically correct.)*

- Run **replicated points** at separate points in time so that their variation contains all the natural process variation. Do not group replicates together, or simply copy the response measurements from one run to another. Consequence of doing this wrong: invalid lack-of-fit test.
Executing (Running) the Experiment

Keys to running your experiment (2 of 2):

• Use the random order provided by the software as much as possible, with this exception – if there is a condition that may not work, run that one first to check it out (re-number the runs!) If it doesn’t work, then you can re-plan the experiment and not lose a run.

• Document anything out of the ordinary that happens during the experiment – those notes may be important for diagnosing any unusual analysis results.

• Don’t forget to include time and resources for running those follow-up/confirmation runs!!! Verifying your results is a key part of research.

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Factorial Design Analysis Procedure

1. **Configure (Transform):** Without prior knowledge start with none.
2. **Effects*: Use Half-Normal plot to select effects to include in model, leaving the remainder to be pooled together for the residual.
3. **ANOVA:** Examine ANOVA and summary statistics.
4. **Diagnostics:** Use diagnostic graphs to validate model chosen. If transformation needed, return to Step 1.
5. **Model Graphs:** If model adequately represents response, generate contour and 3D plots.
6. **Move on to next response.**

*YouTube: Graphical Selection of Factorial Effects

Response Surface Analysis Procedure*

1. **Configure (Transform):** Without prior knowledge start with none.
2. **Fit Summary:** Comparative statistics on polynomial models. Note Suggested model will be default on next screen.
3. **Model:** Choose model for in-depth analysis (likely the default/Suggested model). Click Auto-Select for model reduction.
4. **ANOVA:** Examine ANOVA and summary statistics.
5. **Diagnostics:** Use diagnostic plots to validate model chosen. If transformation needed, return to Step 1.
6. **Model Graphs:** If model adequately represents response, generate contour and 3D plots.
7. **Move on to next response.**

*YouTube: Keys to Analyzing a Response Surface Design
Analyzing the Experiment
Choosing the Model

Keys to analyzing your data:

- Whether it is a factorial or response surface design, **don’t overfit the model**. Only include terms that are statistically significant or needed to meet model hierarchy. All other terms belong in Residual.
- For RSM/Mix designs, use the automatic **model reduction** tools (Auto Select) (recommended criteria: AICc and method: backward)
- **Adjusted and Predicted R-squared** should be in reasonable agreement with each other (within approximately 0.2) – too far apart is a sign that the model has too many terms in it (overfit).
- Check Diagnostic Box-Cox plot for a **transformation** recommendation.

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- **Confirming the results**
Confirming the results

**Final steps after analysis:**

1. Interpret the model graphs using subject matter knowledge.
2. Use numerical and/or graphical optimization* to find a “sweet spot”
   
   *YouTube: Multiple Response Optimization Unveiled

3. Confirm/verify the results – do the predictions work?
4. Write a report

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**Confirming the results**

1. Gather one single observation at the optimal settings.
   - Does 1 run provide a good estimate of the process?

2. Gather several observations at the optimal settings.
   - Use Confirmation node - If the mean is within the adjusted prediction interval, then the model has been confirmed.

3. Run a small experiment around the optimal settings.
   - Treat the optimal setting like a center point. Pick a small range for each factor. Compare the predictions at the center point in the new experiment to the prediction interval calculated by the previous analysis. Useful to get some sensitivity analysis in addition to confirming the previous model.
Telling the Story

What to include in your report? What does the audience need?

**Corporate management**
- Quick summary of DOE study objectives
- Final results/conclusions, with evidence of long-term gains

**Journal research article**
- DOE objectives, basic design information
- ANOVA, summary statistics like Adj & Pred R-squared, prediction equation, relevant model graphs that tell the story
- Include data (perhaps in appendix)
- Information about how final results were confirmed
- **Include enough so that your results can be verified by others**

Summary: Designing Effective Experiments

- Planning the DOE based on objectives
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These slides and the recording will be posted at: [www.statease.com/webinars/](http://www.statease.com/webinars/)
Resources*

These texts are available via Amazon or the publisher*, in soft covers or ebook. They can be purchased or rented for a short time.

* Taylor & Francis/CRC/Productivity Press, New York, NY.

Stat-Ease Training:
Sharpen Up Your DOE Skills

Modern DOE for Process Optimization
Mixture Design for Optimal Formulations

<table>
<thead>
<tr>
<th>Individuals</th>
<th>Teams (6+ people)</th>
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<tbody>
<tr>
<td>Improve your DOE skills</td>
<td>Choose your date &amp; time</td>
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<td>Topics applicable to both novice and advanced practitioners</td>
<td>Add company case studies</td>
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Thank you for listening!

Questions? Email shari@statease.com