STATeaser

ABOUT STAT-EASE® SOFTWARE, TRAINING, & CONSULTING FOR DOE

V8 Tools Make Analysis of General Factorials Slinkier

Early this year I got an inquiry from a German scientist characterizing natural fibers from a hemp-like plant. His specialty is high-performance composite materials. Using Design-Expert® software he studied three factors:

A. 3 positions along the stalk—bottom, middle and top.
B. 3 locations across the stalk—outer, inner and core.
C. 4 plant varieties.

This is a 3 x 3 x 4 factorial. The results, showing significant impacts from these variables, merited publication. However, a peer reviewer objected to one factor having more categories than the other, suggesting that one of the varieties be eliminated from analysis, thus making the experiment conform to a 3^3 (full three-level factorial) design matrix!

Mark Anderson, Principal

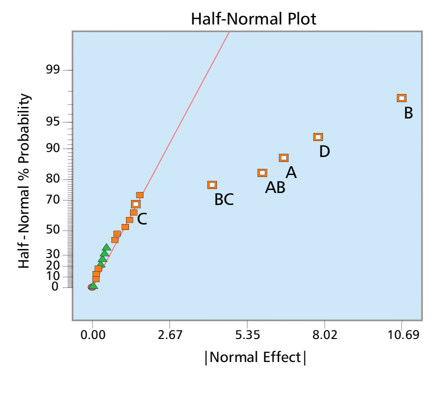

Fig. 1: Half-normal plot of effects from a 5x5x2x4x2 general factorial

This misunderstanding inspired me to discuss the topic of "general" factorials, such as the one done by the German material scientist. Of course, one need not keep the number of categories the same for every factor. See, for example, the presentation by DOE guru Douglas C. Montgomery on "The General Factorial Design" in his textbook *Design and Analysis of Experiments, 7th Edition* (Section 5.4). Many factorials do not fall into neat 2^k or 3^k 'buckets' (k representing the number of factors). Why exclude anything?

Stat-Ease accommodates the construction of general factorials with all combinations and, via optimal design, experiments with only a fraction of the runs. Version 8 of Design-Expert (or Design-Ease® software) makes the analysis of these designs

—Continued on page 2

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Stat-Ease
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—*Continued from page 1*

easier than ever via half-normal selection of effects—formerly available only for two-level factorials. For example, see the screen shot in Figure 1 on page 1, which comes from an experiment on 5 woods glued with 5 adhesives, using 2 applicators with 4 clamps at 2 pressures. The vital effects become apparent at a glance!

If you care to delve into the statistical details of this wonderful invention by Stat-Ease Consultant Pat Whitcomb and Advisor Gary Oehlert, contact me for the slides from "Graphical Selection of Effects in General Factorials"—winner of the Shewell Award for best presentation at the 2007 Fall Technical Conference (co-sponsored by the American Society for Quality and the American Statistical Association). However, for a simple demonstration of how it can be done with Design-Expert, continue on.

A three-factor experiment on spring toys

An experiment detailed in my book (co-authored by Pat) *DOE Simplified* (Chapter 7, "General Factorial Designs," pp 138-143, Second edition, Productivity Press, 2007) involved four spring toys (three of them Slinky® brands) applied to an incline with varying slopes (two levels) by either a child (my daughter) or an adult (me). We did all 16 combinations (4x2x2) in a randomized run order. The response was the time taken by the spring toys to 'walk' down the ramp. (If you've never seen a Slinky go down a stairs or the like, go to YouTube and enter "Slinky" in the search field to bring up a vintage television commercial.)

Prior to release of version 8 of Stat-Ease software the process of picking effects required tedious iteration with the analysis of variance (ANOVA), beginning with a breakdown of the sum of squares (a measure of variance), such as that shown in Table 1. (See *DOE Simplified* for the procedure.)

Term	DF	Sum of Squares	Mean Square
A	3	18.68	6.23
B	1	2.91	2.91
C	1	0.33	0.33
AB	3	0.88	0.29
AC	3	1.03	0.34
BC	1	0.014	0.014
ABC	3	1.71	0.57

Table 1: Breakdown of variance from experiment on spring toys

Thanks to the inventiveness of Pat and Gary, we needn't go down that mind-numbing numerical road—the picture provided by the half-normal plot tells the story: See Figure 2.

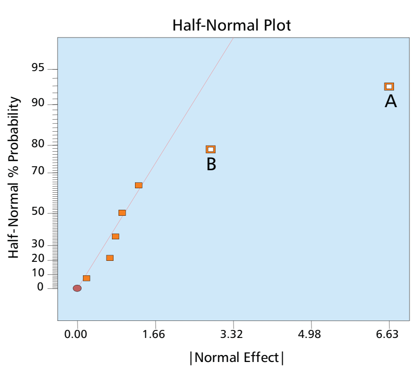


Fig. 2: Half-normal plot of effects from 4x2x2 general factorial experiment on spring toys

This is all I really wanted to demonstrate—the utility of the half-normal plot for picking effects. Not surprisingly, the main effects of factors A and B are statistically significant ($p<0.05$).

See Figure 3 for the final results. The springs behaved as expected from the physics:

A. Lesser diameter coils (small generic and Slinky Junior) took less time to walk down the board.
B. They went down faster with the steep incline.

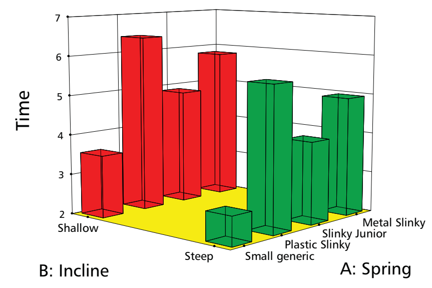


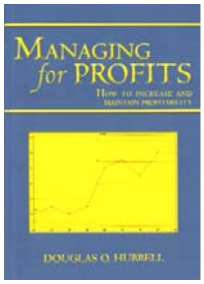
Fig. 3: 3D response surface for significant effects on walking time for spring coils

I'm just glad that Stat-Ease software makes experiments like this so easy. Also, I was relieved to see results that showed me and my daughter being equally adept at playing with Slinkies—fun for girls and boys of any age.

—Mark Anderson, mark@statease.com

Slinky is a registered trademark of Poof-Slinky, Inc.

New book for Managers by Douglas O. Hubbell



Managing for Profits is a new handbook for managers written by Stat-Ease contract trainer, Douglas O. Hubbell. It aims to help with the daily management of company-wide improvement. Tools suggested include charting of current data, Pareto analysis of root causes, and implementation planning for improvement of the seven systems which make up a company: safety, quality, cost, delivery, innovation, morality, and the environment. The book is available on Amazon.com for $19.95. For more information, please contact Douglas Hubbell at pii@msn.com.

Modern Alternatives to Traditional Designs

Design of experiments is one of the many tools that should be used for continuous improvement of a product or process. However, there are now a wide range of designs to choose from. It is possible to get stuck from time to time, wondering where to start. Should I choose a classic fractional factorial, or how about one of these new options with fancy names such as a Minimum-Run Resolution V design? Just the long names themselves are enough to scare some people back to the familiar options! This article will help you choose the right design for your purpose.

Let's do a comparison of traditional designs versus some modern alternatives:

- Orthogonal fractional-factorial designs vs. minimum-run fractional factorials
- Central composite response surface designs vs. Optimal (custom) designs

The classic fractional-factorial design already comes in a variety of flavors, generally labeled the resolution of the design. Resolution IV designs (color-coded yellow in Design-Expert® software) estimate the main effects cleanly but leave the two-factor interactions (2FI's) aliased with each other. These designs are recommended for screening. Resolution V designs (color-coded green in Design-Expert software) cleanly estimate both main effects and 2FI's. These are great tools to more completely characterize a process.

What's new with a Minimum-Run Resolution IV ("MR4") or V ("MR5") design? They are non-orthogonal, which means that the aliasing patterns will be somewhat messy, complicated by coefficients that are not the normal value of 1.0. The effects estimates become very slightly biased and can depend on the other terms

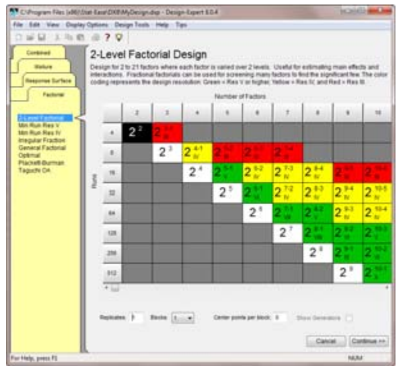


Fig. 1: Design tabs in Design-Expert v8 software

selected for the model. This sounds rather intimidating to analyze, but Design-Expert v8 software handles it with ease. As effects are chosen on the half-normal plot, the remaining effects are automatically recalculated and re-positioned on the plot so you can immediately see the impact of selecting each effect.

Why would you want to bother using a design option that has some uncertainty in the analysis? These are MINIMUM-RUN designs! It's a trade-off between the cost of running the experiment, and the slight bias in the effect estimates. If a regular fractional-factorial design fits your budget and DOE requirements, then by all means use it. But, sometimes you can add just a few more runs and move from a lower resolution design (III or IV), to a minimum-run design (IV or V) and get a lot more information for not much additional cost.

The central composite design ("CCD") has traditionally been the work-horse of response surface methods. It has a predictable structure (5 levels for each factor). It is robust to some variations in the actual factor settings, meaning that you will still get decent quadratic model fits even if the axial runs have to be tweaked to achieve some practical values. This is the design of choice when it fits the problem.

Optimal designs are "custom" design options and they also come in a variety of alphabet-soup flavors—D, IV ("eye-vee"), A, G, etc. Custom optimal designs often have fewer runs than the central composite option. Because they are generated by a computer algorithm, the number of levels per factor and the positioning of the points in the design space may be unique each time the design is built. This may make novices to optimal designs a bit uneasy. But, optimal designs fill the gap when:

- The design space is not "cuboidal"—there are constraints on the operating region.
- There are categoric or discrete numeric factors to deal with.
- The expected polynomial model is something other than a full quadratic.
- You are trying to augment an existing design.

The classic designs provide simple and robust solutions and should always be considered first when planning an experiment. However, when these designs don't work well because of budget constraints, or practical design space constraints, don't be afraid to go "outside the box" and explore your other options. The goal is to choose a design that fits the problem!

If you need more guidance, our DOE workshop instructors are only a phone call or email away and are happy to provide some expert advice. Just send a message to stathelp@statease.com or call 612.378.9449 and ask for statistical support.

—Shari Kraber, shari@statease.com

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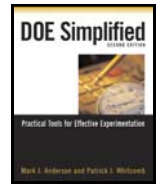

Do you know anyone who would benefit by using Design-Expert® design of experiments (DOE) software? If so, do them a favor and pass along this referral order form signed by you. If they use it to place an order for a NEW Design-Expert license (does not include upgrades or renewals), we will include a free *DOE Simplified, 2nd Edition* book with their order—all thanks to your recommendation! ☺ To be eligible for this promotion, sign and date this form. Then have your friend fill it out and fax it to 612.746.2069 or scan and e-mail it back to us. Offer expires June 30th, 2011.

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