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

Workshop Schedule

Experiment Design Made Easy (EDME)
March 6-7, 2012: San Diego, CA
May 8-9, 2012: Minneapolis, MN
$1295 ($1095 each, 3 or more)

Response Surface Methods for Process Optimization (RSM)
March 8-9, 2012: San Diego, CA
$1295 ($1095 each, 3 or more)

Mixture Design for Optimal Formulations (MIX)
April 17-18, 2012: Minneapolis, MN
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Advanced Formulations: Combining Mixture & Process Variables (MIX2)
October 25-26, 2012: Minneapolis, MN
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Designed Experiments for Life Sciences (DELS)
February 29-March 1, 2012: Minneapolis, MN
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Designed Experiments for Assay Optimization (DEAO)
May 2-3, 2012: Minneapolis, MN
$1495 ($1195 each, 3 or more)

Basic Statistics for DOE (SDOE)
February 28, 2012: Minneapolis, MN
$595 ($495 each, 3 or more)

Free Webinar: Basics of RSM for Process Optimization, Part 2
See it at www.statease.com/webinar.html.

Fourth European DOE User Meeting, Vienna, Austria
June 26-28, 2012—Save the date!

Workshops limited to 16. Multiclass discounts are available. Contact Elicia Bechard at 612.746.2038 or workshops@statease.com.

Sophisticated DOE tools produce tasty cookies time after time

Using tools in Design-Expert® software, Andy Sleeper, the principal of Successful Statistics LLC, developed this intriguing case study on baking cookies at various times and temperatures. It illustrates the use of propagation of error (POE) for robust design.

"After playing with the POE, I found the optimal solution I was looking for!" —Andy Sleeper

Andy Sleeper, Successful Statistics, LLC

Table 1 shows the results of his 2^2 factorial experiment, which he replicated 5 times in a randomized plan. (To save space, the results are condensed into the four factor combinations laid out in standard order.) The flavor was rated on a Likert scale, with 1 being raw, 4 the ideal, and 7 charcoal.

Andy used this data in a talk* to show how an interaction can be used to select the most robust recipe. You can see on the half-normal plot in Figure 1 (on page 2) that AB does fall off the lineup of pure error triangles—in fact it's significant at $p<0.05$ according to the ANOVA (analysis of variance).

A:Time (min)	B:Temp (deg F)	Flavor (Likert)
8	325	2, 2, 2, 2, 3
12	325	4, 5, 4, 4, 5
8	375	2, 3, 2, 3, 3
12	375	7, 6, 5, 7, 7

Table 1: Results from two-level factorial design on cookies

This model (A, B, AB) produces the contours shown in Figure 2 (on page 2).

Andy observed a ridge of "4-ness", but he really wondered how to pin down a particular combination of time and temperature. By entering the standard deviations for the two factors shown in the screen shot on page 2 (Table 2) and applying POE, he enabled Design-Expert to reveal (via numerical optimization) the answer flagged in Figure 2: 10.83 minutes at 332.9 degrees F.

—*Continued on page 2*

—Continued from page 1

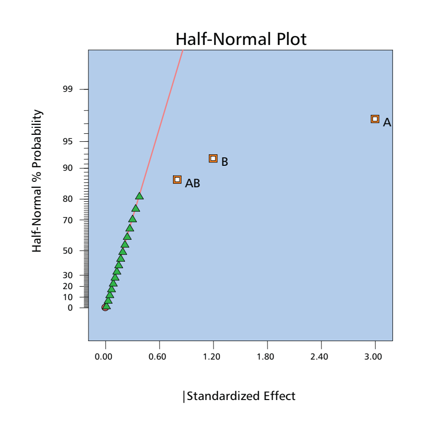

Fig. 1: The half-normal plot of effects reveals an interaction

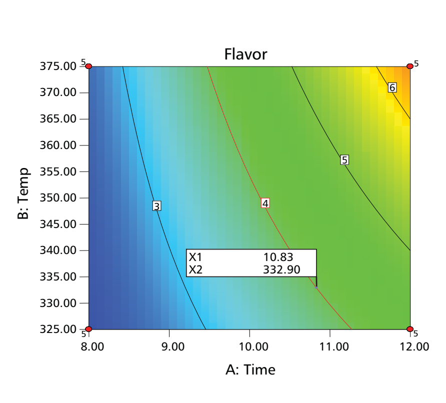

Fig. 2: Contour plot with ideal flavor red-lined

	Name	Units	Type	Std. Dev.	Low	High
	Time	min	Factor	0.1	8	12
	Temp	deg F	Factor	2	325	375
	Flavor	Likert	Response	0.632456	2	7

Table 2: Standard deviations of factors (entered) and flavor (derived from ANOVA)

Help on POE copied from Design-Expert: "The propagation of error (POE) method finds settings that minimize variation in the response. It makes your process or product more robust to variations in input factors. In essence, the POE method involves application of partial derivatives to locate flat areas on the response surface, preferably high plateaus. For details on the mathematics, see "Robust Design—Reducing Transmitted Variation", a paper by Whitcomb and Anderson presented at the 50th Annual Quality Congress in 1996. (Contact Stat-Ease for a reprint.)"

Andy learned that the most robust (minimum POE) solution depends on the relative control over time and temp. Depending on those values, the best conditions for baking the cookies will be at one end or the other, or in the middle. Andy said "now that I understand it better, this is powerful stuff, and I don't know any other software that does it. I'm going to add this to my presentation."

If you'd like to play around with Andy's data, send me a request by e-mail and I will provide the file in Design-Expert version 8 format (".dxp") or in older layouts as needed. While you're at it, why not bake some cookies as food for thought?

—Mark J. Anderson, mark@statease.com

*"Robust Design Simplified," ASQ Lean Six Sigma Conf., 2008 , andy@oqpd.com

Practical Aspects of Algorithmic Design of Physical Experiments, from an Engineer's Perspective*

*(This article is based on the Shewell Award presentation at the 2010 Fall Technical Conference by Pat Whitcomb and Wayne Adams.)

Good response surface designs take into consideration the objectives of the study—not just statistical criteria. "Alphabetic optimality is not enough!" advise Pat and Wayne. They are referring to the debate over D versus I versus other design criterions designated by letters.

Before expanding on the advice by Pat and Wayne, let's address the issue of optimality. Our Design-Expert® software offers several options, but the default settings lead you to one of these two primary choices:

- D-optimal, which minimizes the determinant of the $(X'X)^{-1}$ matrix and thus maximizes information about the polynomial coefficients. Design points gravitate to the edges of the design space (good for estimating main effects and interactions) and other locations optimal for estimating specific parameters, such as the center point for the quadratic term. See the standard error plot in Fig 1a (on page 3), for example.
- IV-optimal ("eye-vee"), which minimizes the integral of the prediction variance across the design space and thus provides lower average variance over the design space. This equates to minimizing the area under the fraction of design space (FDS)** curve. Design points get placed more uniformly across the entire region. However, individual points may end up at somewhat peculiar

Practical Aspects of Algorithmic Design of Physical Experiments, from an Engineer's Perspective* *(Continued from page 2)*

places. See Fig 1b, for example. (This design and the D-optimal one were built via the Response Surface tab for a quadratic model on two factors.)

If the experimenter were to design an experiment based purely on these criteria, they would be juggling the options of either estimating the coefficients best (D-optimal), or minimizing the prediction variation (IV). However, neither design provides the information needed to evaluate the sufficiency of the assumed model!

At this stage the "practical" aspects of design come into play. Two important types of points never get considered when taking a purely "alphabetic" stance:

- Lack-of-fit (LOF), and
- Replicates.

Lack-of-fit points are positioned "in-between" the model points. They allow you to test the validity of your assumed model. For instance, if you choose linear, then the model points move to outer edges, so the center of the design space becomes a good location for a LOF point. Of course, lack-of-fit points decrease the optimality criteria, but this is a good trade-off from an engineering perspective. Figures 2a and 2b show how shifting 4 of the original model points (D vs IV; respectively) to ones picked for lack-of-fit change the overall distribution.

Replicate points allow the calculation of a "pure" estimate of the experimental error of the system, independent of the model assumptions. This pure error provides the necessary benchmark for testing lack of fit. By default Design-Expert suggests enough replicates to accomplish this test, but not so many that it blows the budget on runs.

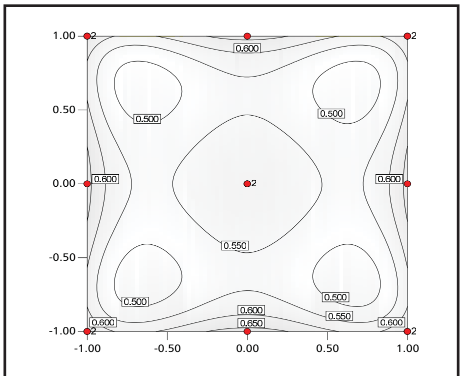

Figure 1a:
14-point D-optimal design

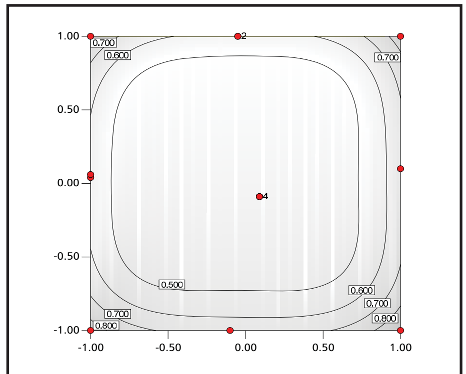

Figure 1b:
14-point IV-optimal design

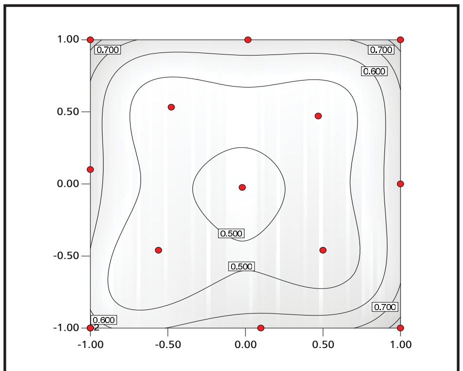

Figure 2a: 10-point D-optimal with 4 LOF points

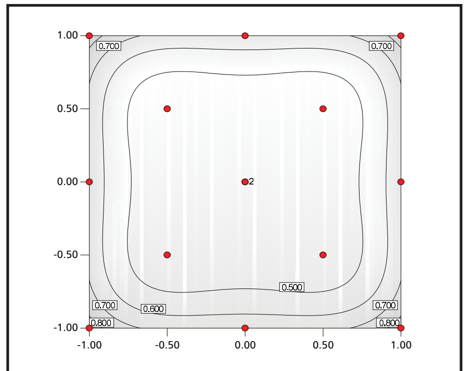

Figure 2b: 10-point IV-optimal with 4 LOF points

Let's get back to an obvious question: Which optimality criterion is best—D or IV? We suggest via the defaults in Design-Expert that experimenters designing optimal factorials go with D, because this criterion fits the model coefficients most precisely—most important for screening purposes. In contrast, the default optimality for response surface designs (either for process or mixture optimization) is IV, because this criterion most precisely estimates the model predictions.

In summary, alphabetic optimality cannot overcome engineering issues such as:

- Studying the wrong problem
- Measuring the wrong response
- Not having adequate precision
- Studying the wrong factors
- Having too many runs outside the region of operability.

Design-Expert is unable to remedy all these real-life problems but it does its part for practicality by suggesting you augment optimal designs with lack-of-fit and replicate points. On behalf of the Stat-Ease Consulting Team (stathelp@statease.com) I wish all of you good luck with your 2012 experiments!

—Shari Kraber, shari@statease.com

**"FDS—A Power Tool for Designers of Optimization Experiments", 9/08, Stat-Teaser.

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01/12

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