STATeaser

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

Workshop Schedule

Experiment Design Made Easy (EDME)
October 4-5, 2011: Minneapolis, MN
December 7-8, 2011: Minneapolis, MN
$1295 ($1095 each, 3 or more)

Response Surface Methods for Process Optimization (RSM)
October 6-7, 2011: Minneapolis, MN
$1295 ($1095 each, 3 or more)

Mixture Design for Optimal Formulations (MIX)
September 13-14, 2011: Leuven, Belgium
—*(See page 4 for details on above course)*
October 25-26, 2011: Minneapolis, MN
$1295 ($1095 each, 3 or more)

Advanced Formulations: Combining Mixture & Process Variables (MIX2)
October 27-28, 2011: Minneapolis, MN
$1495 ($1195 each, 3 or more)

Designed Experiments for Life Sciences (DELS)
November 2-3, 2011: Minneapolis, MN
$1495 ($1195 each, 3 or more)

Designed Experiments for Assay Optimization (DEAO)
December 13-14, 2011: Minneapolis, MN
$1495 ($1195 each, 3 or more)

Basic Statistics for DOE (SDOE)
December 6, 2011: Minneapolis, MN
$595 ($495 each, 3 or more)

Free Webinar: Basics of RSM for Process Optimization, Part 1
Thursday, September 8th at 2:00 PM
See www.statease.com/webinar.html.

SPECIAL OVERSEAS CLASSES, see p.4

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

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Fly Your Way to Better DOE

Brooks Henderson, Statistical Consultant

I recently taught a Design of Experiments (DOE) class to the chemical engineering students at the South Dakota School of Mines and Technology (SDSM&T). I relish this opportunity every year. It is always inspiring to work with these young and inquisitive minds. The highlight of the whole class is the Helicopter Flyoff competition. Here, the students compete for glory.

Before we get to the results of this year's Flyoff, here is a little background. The class is taught in two parts, with a special project in between sessions. The goal of the project is to make the best paper helicopter for the Flyoff. The students break up into teams and are given the task of making a paper helicopter. Of course, this can't be just any old paper helicopter. It must be a tried and tested helicopter, found to have optimal flight characteristics after surviving the rigors of a DOE.

Fig. 1: Helicopter in flight. This was dropped from the second story above

First, the students set up a DOE in Design-Expert® software and test their ideas. Then, they analyze the results. Finally, they use the results to set up and make a helicopter with the optimum characteristics for the Flyoff. The Flyoff is a friendly competition which gives them extra motivation on the project. The goals in the competition are twofold. First, the helicopter must counteract gravity (i.e., fly) for as long as possible. Secondly, it must be accurate. This means it will fly straight down to a bulls eye (a blue X taped on the floor) without wobbling offline. The formula for computing the composite score for the flyoff is simple. Multiply the Flight time (in sec) by 10. Take this quantity and subtract off the deviation from the

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bulls eye (in inches). Each team takes 3 drops and their highest score is counted in the competition. The project and subsequent competition are a great teaching tool. They force the students to actually apply the DOE principles they learn in class.

Many lessons are learned about setting up and analyzing DOEs. Even better, the participants experience all the pitfalls and learn the precautions needed when actually setting up and running experiments. The projects stir up good topics for discussion. Things such as, what are the best measurements to use? How do we ensure consistent results and accurate measurements? Was there a special cause for any unexpected results? These are all great questions that need to be answered in every experiment.

This year, we decided to kick the competition up a notch. Instead of dropping the airplane from an eight-foot high ladder, we dropped it from a 19-foot high balcony. This proved to make quite a difference. The higher drop height really made the helicopters look like they can fly, instead of just falling for a couple of seconds and spinning a few rotations.

The new drop height also inspired some good questions. For example, with the added flight time, is the accuracy negatively impacted? Halfway through our competition, we suspected just that. A large fan from the ventilation system turned on with a conspicuous hum. Did this affect the results by blowing the helicopters off target or creating an updraft? If so, what could we do to make it fair for all the teams involved?

I considered revising the formula for the new 19-foot drop height, but decided not to do that this year. Now that I've collected some data, I'll analyze it and see if changes are necessary. I always enjoy changing things up a bit. After all, isn't trying something new what experimentation is all about?

Results

The students had a lot of good ideas for factors to test. Team Slytherin, who got second place, did an outstanding job on their DOE. They tested 5 factors in a 2^5-run full factorial and made by far the most accurate helicopter. Two of their factors, Paper Wt. (A) and Tape Amt. (B), contributed to accuracy. They are shown in Figure 2 below. Though they may help accuracy, they can be detrimental to flight time. This plot clearly shows a significant interaction between Tape Amt. (B) and Paper Wt. (A). The red line shows that if the high amount of tape is used, then the weight of the paper has no effect on the flight time. However, if the low amount of tape (black line) is used, than you can use the lower paper weight to achieve higher flight times. It is a tradeoff between flight time and accuracy that must be optimized by the DOE.

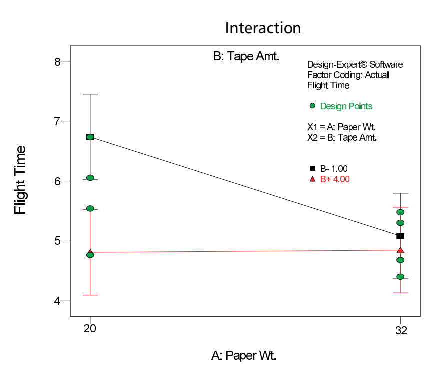

Fig. 2: Interaction plot from Design-Expert software showing Flight Time vs. Paper Weight

The winners of this year's flyoff were Team Aerial Assault. They shattered the record for composite score by getting a 55.78 versus the old record of 32.61. Of course, the higher drop height gave them a huge advantage over previous classes in flight time. This was not outweighed by the slightly poorer accuracy. All but one of the teams doing a statistically designed experiment thoroughly outperformed my hastily constructed helicopter. I built it without the benefit of a DOE, using just some engineering guesses and a few trials. It only achieved a score of 33.69, proving that an engineer's best guess or assumed knowledge can be beaten by a set of properly designed experiments. Your knowledge can only take you so far. So, I say, "Show me the data!"

—Brooks Henderson,
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P.S. To see an exciting video montage of the Flyoff, check out the May 10 *Stats Made Easy* blog posting at http://statsmadeeasy.net/2011/05/video-of-paper-helicopter-fly-offs-at-south-dakota-school-of-mines-technology/.

P.P.S. The paper helicopter experiment is a great way to practice your DOE skills. For a list of this and other fun do-it-yourself experiments, see the document entitled *DOE It Yourself: Fun Science Projects* compiled by Mark Anderson, Principal at Stat-Ease. It is available on our web site at: http://statease.com/pubs/doe-self.pdf. Particularly enticing to me as a sports fan are the "Tabletop Hockey" and "Golfing" experiments. The list is extensive, so take a look. You are sure to find something fun with which to hone your skills!

Power of DOE Using Qualitative vs. Quantitative Variables

Consider two identical experiments with two factors at three levels each: material (A) and temperature (B). This is a 3x3 experiment with 4 replicates—36 total runs (see table 1). In Experiment #1 temperature is treated as qualitative, i.e., a categoric discrete factor. In Experiment #2 it is treated as quantitative, i.e., a numeric continuous factor. The experiments are exactly the same, but by changing the designation of each variable as categoric or numeric you change how Design-Expert® software treats those variables.

Power is interpreted as the probability of seeing a change in the response of size "x" in units for standard deviation.

For Experiment #1 the model is A, B and AB. The table for the power is shown below.

Power at 5% alpha level to detect signal/noise rations of:

Term	StdErr**	0.5 Std. Dev.	1 Std. Dev.	1.667 Std. Dev.
A[1]	0.235702	16.40%	53.40%	94.20%
A[2]	0.235702			
B[1]	0.204124	16.40%	53.40%	94.20%
B[2]	0.117851			
A[1]B[1]	0.288675	9.60%	27.30%	68.20%
A[2]B[1]	0.288675			
A[1]B[2]	0.166667			
A[2]B[2]	0.166667			

Basis Std. Dev. = 1.0
For Categorical Terms the minimum power for each group of terms is reported.

So for the main effect of factor A we have a 94.2% chance of seeing a change in the response of 1.667 standard deviations.

For Experiment #2 the model is A, B, AB, B^2 and AB^2. The table for the power is shown below.

Power at 5 % alpha level to detect signal/noise ratios of:

Term	StdErr**	0.5 Std. Dev.	1 Std. Dev.	1.667 Std. Dev.
A[1]	0.408248	16.40%	53.40%	94.20%
A[2]	0.408248			
B	0.204124	21.90%	65.60%	97.60%
A[1]B	0.288675	12.40%	37.60%	81.20%
A[2]B	0.288675			
B^2	0.353553	27.60%	77.80%	99.50%
A[1]B^2	0.5	7.30%	15.00%	35.20%
A[2]B^2	0.5			

Basis Std. Dev. = 1.0
For Categorical Terms, the minimum power for each group of terms is reported.

It is important to note that:

Material Type	Temperature (deg F)					
	15		70		125	
A1	130	155	34	40	20	70
	74	180	80	75	82	58
A2	150	188	136	122	25	70
	159	126	106	115	58	45
A3	138	110	174	120	96	104
	168	160	150	139	82	60

Table 1: The table of the experimental data is shown above.

- The quantitative model from Experiment #2: (A[1], A[2], B, B^2, A[1]B, A[2]B, A[1]B^2, A[2]B^2) and the qualitative model from Experiment #1: (A[1], A[2], B[1], B[2], A[1]B[1], A[2]B[1], A[1]B[2], A[2]B[2]) are equivalent.
- The B and B^2 terms from the quantitative model are equivalent to the B[1], B[2] terms from the qualitative model.
- The A[1]B, A[2]B, A[1]B^2, A[2]B^2 terms from the quantitative model are equivalent to the A[1]B[1], A[2]B[1], A[1]B[2], A[2]B[2] terms from the qualitative model.

Compare the two tables for the main effect of factor A: Notice that the power is the same. The "A" terms are both qualitative and the experiments are identical, so they should be the same.

For the main effect of factor B, though, there is a small difference. For Experiment #1 the power at 1.667 standard deviations is 94.2% versus in Experiment #2 the power is 97.6% for the main effect of factor B and 99.5% for the quadratic effect of factor B (B^2). So we have a little advantage here in treating B as quantitative.

For the AB interaction term we are looking at the AB from Experiment #1 compared to AB and AB^2 from Experiment #2. For the AB term in Experiment #1 the power at 1.667 standard deviations is 68.2% versus 81.2% for Experiment #2. But we must also look at the 35.2% power for the AB^2 term in Experiment #2 and this is not so good. In this case we have good power (81.2%) to estimate the term of interest, the 2-way interaction, but have poor power in estimating the AB^2 term. Usually this term is not included in the model anyway so the poor power is not a concern. Note that if you want better power to estimate this term you can use Design-Expert to augment the design to give you more power.

This change in power between the experiments occurs because of the qualitative treatment of factor B in Experiment #1, which consumes more degrees of freedom than if it had been designated as a continuous factor.

The lesson here is if you have a factor that is continuous, then you should treat it so because you can get more statistical power to see the changes of interest.

Another reason to treat a numeric factor as continuous is that a continuous factor models the full range of that factor. In this example that means predictions can be made at any temperature between 15 and 125 °F. A categoric factor only models the discrete combinations of the factors. In this example that means predictions can only be made at temperatures of 15, 70 and 125 °F. This is as compelling a reason to treat temperature as a continuous factor as any increase in power.

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Overseas Workshops Coming Up This Fall!

08/11

Stat-Ease is offering overseas workshops this Fall in both Belgium and India. If you live in one of these areas and haven't been able to attend a workshop in the United States, we invite you to take advantage of this unique opportunity. Stat-Ease's most experienced trainers will help you understand the power of DOE to advance your business or organization. Sign up today!

1. Mixture Design for Optimal Formulations (MIX) *(Belgium)*

If you work with mixtures, already know the basics of experimental design, and would like to find your ideal formulation, Stat-Ease's "Mixture Design for Optimal Formulations" workshop is the class for you. This workshop will teach you how to experiment most effectively using mixture designs to find the sweet spot where all your specifications can be achieved. For more information, see http://www.statease.com/clas_mix.html.

Details

September 13-14, 2011, €1000, Leuven, Belgium in association with CQ Consultancy and StatSquare.

Sign up for this workshop at http://www.cq.be/en/prodserv/training/training_detail.php?ID=16&sID=65.

2. Designed Experiments for Industry (DEI) *(India)*

The DEI workshop offers an overview of all the DOE tools. You'll work through two days of case studies that demonstrate how DOE leads to peak performance. For more information see http://statease.com/clas_dei.html.

Details

November 15-16, 2011, US$1495, Trident Nariman Point Hotel, Mumbai, India. Contact Elicia Bechard, Workshop Coordinator, at workshops@statease.com to sign up.

We hope to see you in class soon!

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