

stat teaser

Workshop Schedule

DOE Simplified

January 18: Minneapolis, MN
April 5: Detroit, MI

An overview of DOE concepts, this workshop illustrates an array of tools and design types. \$195

Experiment Design Made Easy

January 9-11: Atlanta, GA
February 6-8: Dallas, TX
March 13-15: San Jose, CA
April 17-19: Minneapolis, MN
June 5-7: Detroit, MI

Study the practical aspects of Design of Experiments (DOE). Learn about simple, but powerful, two-level factorial designs. \$1195

Real-Life DOE

March 20-21: Minneapolis, MN

Refresher course - analyze real data sets and learn how to deal with messy problems! Working knowledge of factorial designs is required. \$995

Response Surface Methods for Process Optimization

March 6-8: Philadelphia, PA
April 24-26: San Jose, CA

Fine-tune processes and maximize profitability by locating the optimal conditions. \$1195

Mixture Design for Optimal Formulations

February 13-15: Atlanta, GA
May 15-17: Minneapolis, MN

Learn all the skills you need for mixture design in this course. \$1195

Robust Design: DOE Tools for Reducing Variation

June 5-7, 2001: Philadelphia, PA

Use DOE to create products and processes that are robust to varying conditions. Factorial and RSM proficiency is required. \$1195

See www.stateease.com for descriptions and pricing. Attendance limited to 20. Reserve your place by calling Sherry at 800.801.7191 x18.



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Do You Want to Make a Million Dollars? Use DOE Tools for Robust Design

Several years ago I attended a workshop by George Box on advanced tools for DOE. When someone asked him for an opinion on low-resolution fractional factorials, he said that running these experimental designs is like kicking your TV to make it work. I relayed this observation to students attending the September presentation of *Robust Design: DOE Tools for Reducing Variation*, a Stat-Ease workshop. Just then one of the monitors buzzed and its display degraded into a series of vertical lines. I promptly called back the technician from the computer rental company.

He gave the monitor a sharp slap and the screen cleared. I half-expected the display to say, "Thanks, I needed that."

This is literally a wacky repair process, which I don't recommend.

After this incident I returned from class to find the September 2000 issue of *Quality Engineering* magazine, a very practical publication by the American Society of Quality. In this issue, Box (and Stephen Jones of Boeing) present a thought-provoking "Quality Quandries" column on robust design ("Split Plots for Robust Product and Process Experimentation," Vol. 13 (1), pp 127-134). Box and Jones show how split plots can be helpful for making products robust to environmental factors. They cite a study done by engineers at a medical packaging company in Madison, Wisconsin who studied five "design" factors: paper



supplier (A), solids content (B), cylinder type (C), oven temperature (D) and line speed (E) each at two levels in a fractional factorial design. The resulting batches of product were then shipped to the customer, who subdivided each of them into sub-batches to study two "environmental" variables (not controlled very precisely) at their site: sealing temperature and sealing dwell time.

This is a neat example of engineers from both ends, producer and consumer, collaborating to find robust configurations of process and product. In this case the ultimate objective was the reduction of sealing failure, thus ensuring sterility of the packaged materials. The experiment produced a clear-cut winner: a setup (number 5 in the table shown on page 2) that behaved almost perfectly under all environmental conditions, which led to reported **savings of several million dollars.**

The design can be entered into Design-Ease® or Design-Expert® software, but don't bother, because as

- cont. on page 2

- continued from page 1

Box and Jones say:

"Murphy never sleeps and planned experimentation provides him with an almost irresistible temptation."

As you can see by the asterisks, much of the data was missing, and worse yet, two levels of one of the factors got switched inadvertently, which unbalanced the design. The good results show just how robust the tool of factorial design is to Murphy's mischief.

Here's some food for thought as a postscript. Ironically, in the case noted above, the experimenters chose to do only eight runs for the "design" matrix, presumably because of the expense. With five factors, the best you can do is Resolution III (main effects aliased with two-factor interactions). At this point you may be thinking that running such a badly-aliased design would be like slapping your computer monitor to make it work, because if anything does come out significant, you won't know for sure what caused the change. This certainly would be true if you want to screen factors and find the vital few. But if you've already developed a system and simply wish to see if it will

Setup	A	B	C	D	E	Failures (avg)
1	+	-	-	+	+	8, 4, *, 0, *, 7, (4.75)
2	+	-	-	+	-	*, *, *, *, *, *, (*)
3	-	-	+	-	+	3, 2, 1, 1, 0, 0, (1.17)
4	-	-	+	-	-	7, 1, 1, 2, 0, 4, (2.50)
5	+	+	+	-	+	0, 0, 0, 0, 0, 0, (0.00)
6	-	+	+	+	+	4, 0, 0, 1, 1, 1, (1.17)
7	-	+	-	+	+	9, 1, 0, 0, 4, 5, (3.17)
8	+	+	-	-	-	2, 1, 3, 1, 0, 0, (1.17)

This two-level design generates a million dollar breakthrough!

be robust to variations in control factors (and environmental variables in this case), it may make sense to minimize runs (and cost) by choosing a low-resolution design. If nothing comes out significant, you then proclaim the process rugged (a very good outcome assuming it's producing in-specification results). Otherwise, do a complete foldover, which requires doing another block of eight runs with all levels (signs) reversed. This can be done very easily with Design-Ease or Design-Expert software via the Design Tools, Augment Design option. After the foldover, including all 16 runs, the hypothesized main effects are aliased

only with three-factor interactions (3fi's), so the foldover increases design resolution from III to IV. This is good.

A final thought: by investing in 16 runs from the start, you achieve resolution V for five factors, thus clearing both main effects and two-factor interactions from all but 3fi's or higher. Of course, it's easy to look back and realize what should've been done. The trick is to arm yourself with **knowledge** of experiment design principles, spend a decent amount of time **planning**, make some hard decisions, and finally - **just do it**.

- Mark J. Anderson

Case Study Reprints Available

Three new case studies illustrating the use of designed experiments in industry are now available as reprints (see the order form on back).

#49: "Design of Experiments Software Helps Clear Wafer Transport Traffic Jams," reprinted from *Micro*, July/August 2000. A supplier of automated material handling equipment combines DOE with simulation to optimize the critical parameters for designing automated systems.

#50: "Success With DOE" by Mark J. Anderson, reprinted from *Quality*,

April 2000. Using excerpts from his book, *DOE Simplified*, Mark illustrates the concept of using statistics as a tool for extracting information from data.

#51: "Statistical Technique Saves Big in Building Medical Cooler" by Raquel Wager, reprinted from *The News (Air Conditioning/Heating/Refrigeration)*. An appliance manufacturer applies DOE to optimize design of a cooler and saves nearly \$100,000 in the process.

Do you have a success story you would like to share? If so, contact Heidi Hansel at Stat-Ease (heidi@statease.com).

Where can you find us?

Two chances to learn about innovative DOE methods!

April 24-26 — Quality Expo
Rosemount, IL

May 7-9 — 55th Annual Quality Congress, Charlotte, NC

See us at Booth 721

Talk by Pat Whitcomb & Mark Anderson (Presenter):

Making the Most From Low-Resolution Fractional Factorial DOE (Foldover & Semi-foldover: Augmenting Resolution IV 2^{k-p} Designs)

V6 Tricks with Design-Ease & Design-Expert —Eliminate Nuisance Variability with a Latin Square Design

This case study is taken from Douglas Montgomery's "Design and Analysis of Experiments", 5th edition. A complete tutorial for this case study, including the data, can be found on our web site at www.statease.com/publish.html#cases.

The Latin Square is a one-factor design that extends blocking to eliminate two nuisance sources of variability. For example, suppose we want to study the effects of five different formulations of rocket propellant. We also want to block (or average over) two nuisance factors - the batch of raw material and the operator. We can set up a 5x5 Latin Square design (see the figure below).

Raw Material Batch	Operator				
	1	2	3	4	5
1	A	B	C	D	E
2	B	C	D	E	A
3	C	D	E	A	B
4	D	E	A	B	C
5	E	A	B	C	D

Latin square design for five formulations

The five different categorical levels (formulation type) are designated by the letters A-E. The two potential sources of variation are the batch-to-batch and operator-to-operator differences. Since there are five formulations of interest, we need to use five batches of raw material (the row) and five different operators (the column).

In Design-Expert 6 you can build this design by using a **General Factorial** design with three factors. The first factor should be the blocking variable "Raw Material Batch" with names such as

"Batch 1" - "Batch 5". The second factor should be the blocking variable "Operator" with similar names. The third factor is the "Formulation" with levels A-E.

Sort the design by Standard Order. This setup will create the full factorial of $5 \times 5 \times 5 = 125$ runs. The Latin Square only has 25 runs so we need to delete rows 26-125 (in standard order) from the design layout. Once you have 25 rows, the formulations need to be assigned correctly. Type in the letters that represent the five formulations in a cyclic order. Use the order from the first figure and type in A, B, C, D, E (Operator 1), B, C, D, E, A (Operator 2), and so on through Operator 5. Now the design is complete, although you should randomize the runs before running the design.

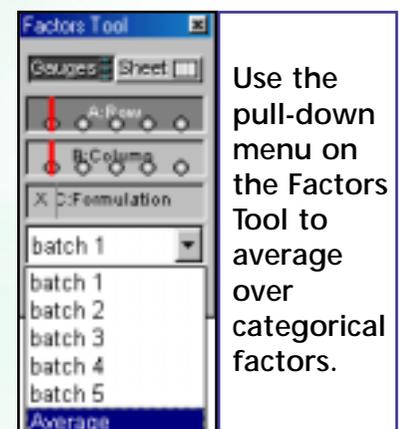
Once data has been collected and is entered into the software to be analyzed, the model terms have to be designated correctly. Remember that factor C (Formulation) is our only independent factor here and factors A and B are really blocks. The effects screen (see the figure below) must be modified to reflect this in order to get the correct analysis of variance. Right click on "A" and choose "Block". Right click on "B" and choose "Block". Right click on "C" and choose "Model". Now you can

Term	DF	Sum of Squares	Mean Square	F Value
Intercept				
A	4	68.00	17.00	
B	4	190.00	37.50	
C	4	330.00	82.50	
AB	12	120.00	10.00	
AC		Allowed		
BC		Allowed		
ABC		Allowed		
Residuals	0	0.000		

Effects screen

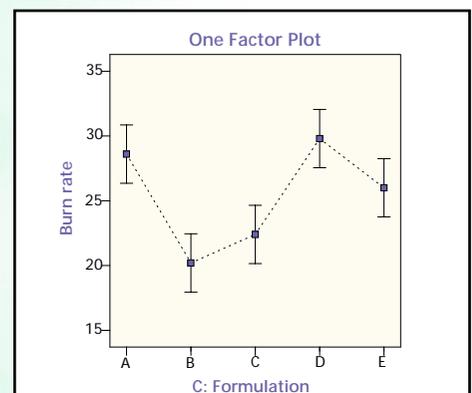
proceed with the analysis as always.

When you get to the Model Graphs select the One Factor Plot of factor C (Formulation) while averaging over the uncontrollable blocking factors (A and B). You can make this change on the Factors Tool palette as shown below.



Now you can get a clear picture of how changing formulation affects burn rate: A & D are significantly higher than B & C, with E somewhere in the middle. (See the figure below.)

-Pat Whitcomb & Shari Kraber



Plot of C: Formulation, averaged over A and B

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Do you want to improve your product or process? If so, try Design-Expert 6.0 software (our premier package with many new designs and features - see www.statease.com for details and a trial copy), or save money by buying the simpler Design-Ease 6.0 software. A trial copy of DE6 comes with the book, *DOE Simplified: Practical Tools for Effective Experimentation*. You can order it below.

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