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Strip Block Design Gives Battery Experiment a Charge

In my last column, I wrote about experimentation on nectar from a fruit grown in the jungles of Brazil.[1] Now I shift to the manufacturing sector of this mighty South American country and focus on reducing defects in batteries.

The design of experiments (DOE) I want to illustrate, called a "strip block," came out of the field of agriculture in the late 1930's. The authors of the case study[2] credit Soren Bisgaard, then a professor at the University of Wisconsin (UW), for introducing them to the concept of applying this design for product improvement. I, too, first learned about a closely related design called a "split plot" at UW in Madison from Professor Bisgaard and his mentor George Box. Inspired by their presentation, I wrote tutorials showing how easily these designs can be analyzed with Stat-Ease® software.[3] Therefore, after attending a presentation of this Brazilian battery case in May of 2004 at the ASQ Annual Quality Congress in Toronto, I wanted to see if I could reproduce their results in similar fashion.

Before getting into the nuts and bolts of the design itself, here's a quick overview of the problem. The Brazilians produce 40 million batteries per year, of which 2 million (5%) failed inspection. The major cause for rejection was open-circuit voltage (OCV) falling above the specification limits.

Row	Run #	Battery Assembly Factors				Curing Conditions (500 batteries each combination for a total of 2000 per row)				
						E	–	+	–	+
		A	B	C	D	F	–	–	+	+
1	11	–	–	–	–					

Table 1: Strip block structure for a battery experiment

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High OCV leads to batteries that become dead on arrival (DOA).

This DOE on DOA batteries (could you see that one coming?) focused on four manufacturing factors, not named for proprietary reasons, and two variables related to the curing—temperature and humidity. Each cure takes five days in the one available chamber. Therefore a full 2^6 factorial would require 320 days (= 64 x 5). Here's where the structure of strip block comes to the rescue. The experimenters laid out a randomized design of 16 runs on the first four factors at two levels each. As I understand it, they then made 2000 batteries for each of the 16 runs. Each lot of 2000 was then split into four sublots and randomly designated to four combinations of temperature and humidity (two levels for each of these curing variables). See Table 1 (on page 1) for the basic structure of the experiment (only the first row is shown out of 16 in the design).

After completing all 16 manufacturing combinations in this manner, the four groups of 8000 batteries each (= 16 x 500) were cured in randomized order of four varying temperature and humidity combinations. Thus, by utilizing a strip block design, the rate-limiting curing stage took only 20 days!

Now I had to do some tedious work due to not having the actual response data—the mean OCV. Fortunately, the statisticians who wrote up this study provided all 63 effects, up to and including the five-factor interaction ABCDE. For factorial modeling of an orthogonal two-level array like this, the coefficient is just one-half the effect. I entered the resulting coefficients in the simulation editor available in Stat-Ease® Design-Expert® software

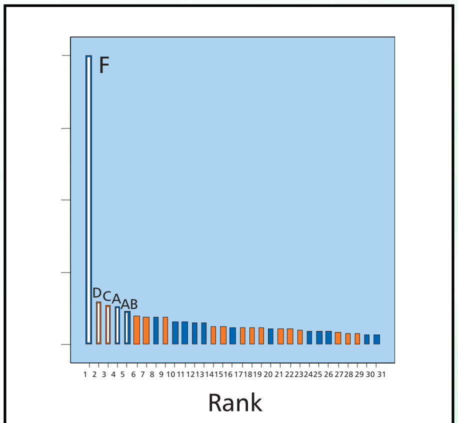

Figure 1: Ordered bar chart of effects (- is blue, + is red)

via its Design Tools. Then I set up a 2^6 design in the software and ran the simulation to generate all of the responses. Note that the effects in a strip block (or split plot for that matter) are estimated exactly as if a completely randomized experiment had been conducted. They are shown in Figure 1 as an ordered bar chart (Pareto) of absolute values.

	Term	Stdized Effects	Sum of Squares	% Contribution
	Intercept			
M	A-Assembly A	-4.20	282.24	1.43
M	B-Assembly B	-1.50	36.00	0.18
M	C-Assembly C	4.30	295.84	1.50
M	D-Assembly D	4.70	353.44	1.79
X	E-Temperature	1.60	40.96	0.21
X	F-Humidity	2.30	16692.64	84.74
M	AB	3.70	219.04	1.11
e	AC	1.80	51.84	0.26
e	AD	1.00	16.00	0.081
X	AE	2.50	100.00	0.51
X	AF	0.90	12.96	0.066

Model / Block / Error / Ignore

Figure 2: Ignoring all but assembly effects

Notice how the effect of F (humidity) stands out. However, due to the way this experiment was conducted with randomization restricted, the effects must be segregated into three groups for assessment of statistical significance:

* 15 assembly effects (A, B, C, D and their interactions)
* 3 curing effects (E, F and EF)
* 45 interaction effects between assembly factors and curing variables (for example, AE and ABCDEF).

First, I looked only at the assembly effects, with all others set to be ignored ("X") by Design-Expert as shown in Figure 2. (The "M" designates model terms and "e" is error.)

Figure 3 (on page 3) shows the half-normal plot of the assembly effects. According to the authors, the effects revealed by this plot led to beneficial adjustments of factors A, B, C and D.

Of course, there's not much to work with for the curing part—only 3 effects, but the experimenters believed that the extraordinarily large impact of humidity (F) was real. As it increased, the OCV response decreased—a desirable outcome.

When plotted on normal probability paper (as I was able to reproduce in Design-Expert), none of the other 45 estimable effects in the third group stood out.

Ultimately, the Brazilians reduced their rate of rejected batteries by 80 percent. The strip block design structure made this six-factor experiment possible by eliminating the curing stage as a bottleneck. With the proper segregation of effects, their statistical significance can be assessed correctly. This is made easy via normal probability plots (or half-normal, which Stat-Ease prefers). As an aficionado of DOE, I got a real charge out of this battery case!

PS. Another thing I found intriguing was that a brainstorming session generated 29 variables thought to affect

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DOE Events Calendar

Stat-Ease will be appearing at many events this year. If we are in your neighborhood, please stop by and say hello!

August 7–11—Joint Statistical Meetings, Minneapolis, MN, Booth #402

Roundtable Discussion by Shari Kraber: *"Successful Strategies for Screening Designs"*

September 14–16—5th Annual Conference of ENBIS, Newcastle upon Tyne, United Kingdom

Talk by Pat Whitcomb: *"A Factorial Design Planning Process"*

October 10–11—MN ASQ Conference, Minneapolis, MN

October 20–21—49th Annual Fall Technical Conference, St Louis, MO

Talk by Pat Whitcomb: *"Using a Pareto Chart to Select Effects for a Two-Level Factorial DOE"*

October 24–28—Design of Experiments and Response Surface Methods Workshops, Overland Park, KS (Kansas City area)

Instructed by Geoffrey Vining, Ph.D. and Connie Borror, Ph.D., Statistical Productivity Consultants (SPC). For more details, please refer to http://www.spcstat.com.

New Workshop Coming in September—
The Crash Course on DOE for Sales & Marketing

The "Crash Course on DOE for Sales & Marketing" workshop is specifically designed for business professionals. This course provides a fast and practical introduction to the use of experimental design in a non-industrial setting. The workshop has three main goals:

1. To make DOE more approachable for sales and marketing teams.
2. To present simple and workable ways to deal with historical data.
3. To demonstrate the application of high-tech screening and full-factorial designs to identify the factors that control results—even when dealing with a large number of factors.

The "Crash Course on DOE for Sales & Marketing" workshop has been developed from the ground up to demystify statistical design of experiments. It's recommended for anyone wanting to improve sales and marketing practices.

Using applicable case studies, practical DOE tools are taught as well as a step-by-step approach to planning experiments. The emphasis is on bridging the gap between theory and practice. The approach is as hands-on as possible, with many illustrations and exercises, minimizing time spent on statistics and lengthy, difficult calculations. This workshop is ideal for those seeking a systematic approach to testing what works and what doesn't in regards to sales, marketing, and other critical business data.

Date: Thursday, September 29, 2005
Location: Stat-Ease, Inc., Minneapolis, Minnesota
Fee: $995 ($795 each, 3 or more)
Instructor: Dr. Paul Selden

For more information, see http://www.statease.com/clas_smdoe.html.

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the rate of battery rejects. Each of the team members was given an imaginary 100 dollar bill to invest as they liked in specific ideas. The six factors chosen for the DOE were those that got the greatest amount of funny money—amusing, yet effective for narrowing down the choices intelligently.

[1] "Mixture Design Enhances Nectar from Exotic Amazonian Fruit," March 2005 Stat-Teaser newsletter.

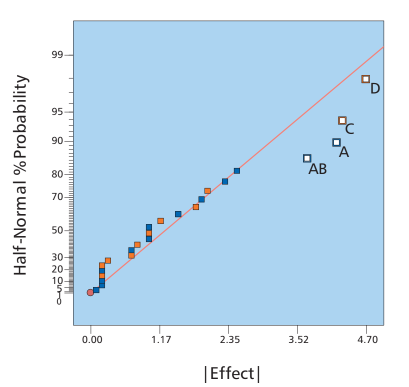

Figure 3: Half-normal plot of assembly effects

[2] Carla Almeida Vivaqua, Andre Luis Santos de Pinho, "On the Path to Six Sigma Through DOE."

[3] See the Program Tips chapter in the "User Guide" for Design-Ease® and/or Design-Expert software (both of which are posted at http://www.statease.com). Refer to the section titled "Neat Tricks: Two-Level Factorial Analyzed as a Split Plot."

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Stat-Ease is Seeking a DOE Professional

07/05

Job Description:

Stat-Ease, Inc. offers an opportunity for an energetic person to join our team. The position requires a combination of instructional and technical development skills. Job responsibilities include teaching design of experiments (DOE) workshops, providing statistical support to clients, defining test cases for software development, researching statistical methods for future software implementation, conveying statistical concepts to programmers, writing/editing technical materials, and other duties based on experience. This is a full-time position located in Minneapolis, MN with 30% travel.

Minimum qualifications:

- Masters degree in Statistics
- Hands-on design of experiments knowledge
- Excellent verbal and written communication skills
- Strong math skills

Desired background:

Experience teaching statistics to non-statisticians, 2+ years in a manufacturing or industrial environment (may include internships), exposure to mixture design, computer programming (C++ desirable), and the development of online course materials.

Contact:

E-mail resumes to Shari Kraber at shari@statease.com.

Deadline:

August 10, 2005

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