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Workshop Schedule

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Sixth-Graders Experiment with Flying Disks

If you like to play with flying disks and/or enjoy children, you will get a kick out of a study done earlier this year by my daughter Katie (on the right in the picture) and her cousin. Katie has been keen on doing experiments ever since she worked as my laboratory assistant on a test of spring coils for the book, "DOE Simplified."*

The 7th graders at Katie's private school traditionally do science projects for display at an annual school fair. Sadly for Katie, we decided to enroll her in the local junior high school for the 2002-2003 school year, so it appeared she'd miss the opportunity to do an experiment. Katie, however, begged her science teacher to allow her to do a project in 6th grade for extra credit. She then talked her cousin into being her assistant and me into being the experiment designer and data cruncher. (Katie knows how to make her father happy!)

The above picture tells the story of what Katie decided to do for her science project—test flying disks of varying designs and colors. She hypothesized colors would not make a difference. At this point, I thought it a good idea to add

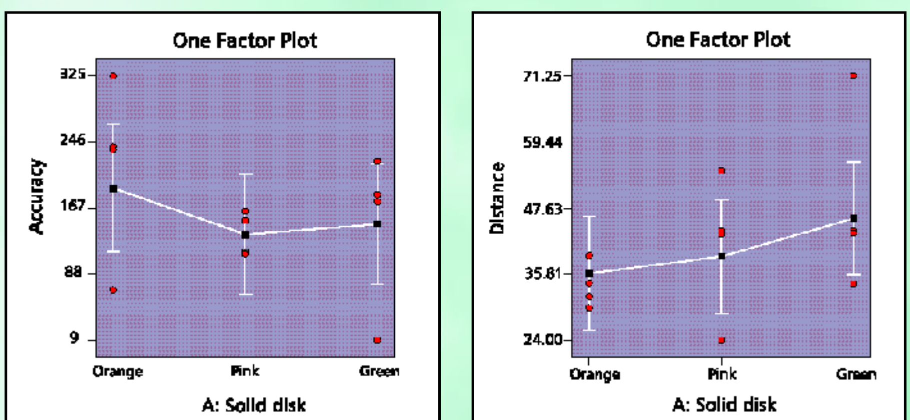

Fig. 1 - Effect of color on accuracy (left) and distance (right) for solid disks.

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— Continued from page 1.

my own hypothesis that the shape (solid vs. ring as pictured on page 1) would matter. Katie did not dispute this. (Thank goodness!)

Now I went to work as the experiment designer and established the following factors affecting performance of the flying disks:

- Thrower (cousin versus Katie)
- Shape (solid versus ring)
- Color (three for each design)

I established two responses to measure performance:

- Accuracy (inches off a target set up in the front yard)
- Distance (feet for throws done in the local park)

Using Design-Expert® software I set up a completely replicated (two throws each), randomized test plan, blocked by thrower. Unfortunately the colors did not match, so each type of flying disk needed to be analyzed separately by color. To keep things simple, I set up four different data files:

- Solid disk accuracy versus color
- Solid disk distance versus color
- Ring disk accuracy versus color
- Ring disk distance versus color

The results are shown in the effects graphs on page 1 and above. As you can see by the overlapping least significant difference (LSD) bars in Figures 1 and 2, Katie was right—color does not significantly affect the performance of either type of flying disk. Katie's questions about the impact of color now can be answered, but what about the shape of the flying disks? These effects, calculated by ignoring color as a factor, can be seen in Figure 3.

Notice that shape makes little difference on accuracy, but the girls got significantly greater distance from the ring disk. As an aficionado of flying disks, I am not surprised by these results. I've found that the ring geometry offers several advantages for recreational use by novice throwers:

- Easy to throw (evidenced by the data)
- Easy to catch (you can put your arm through the hole)
- Less hazardous and damaging (due to its light weight)

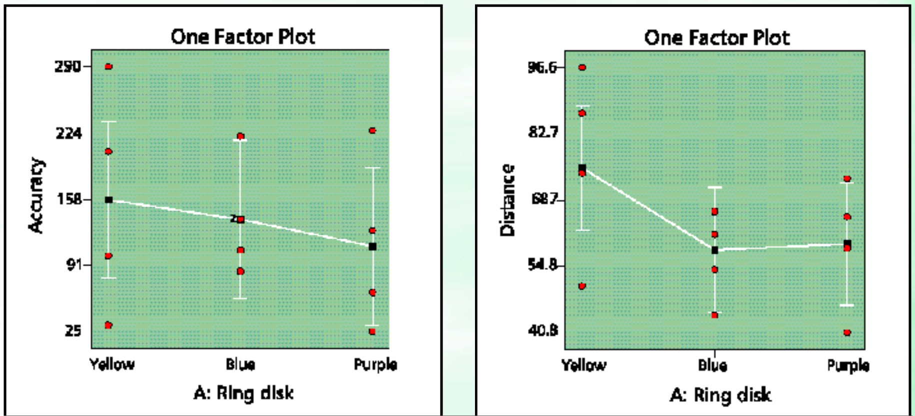

Fig. 2 - Effect of color on accuracy (left) and distance (right) for ring disks.

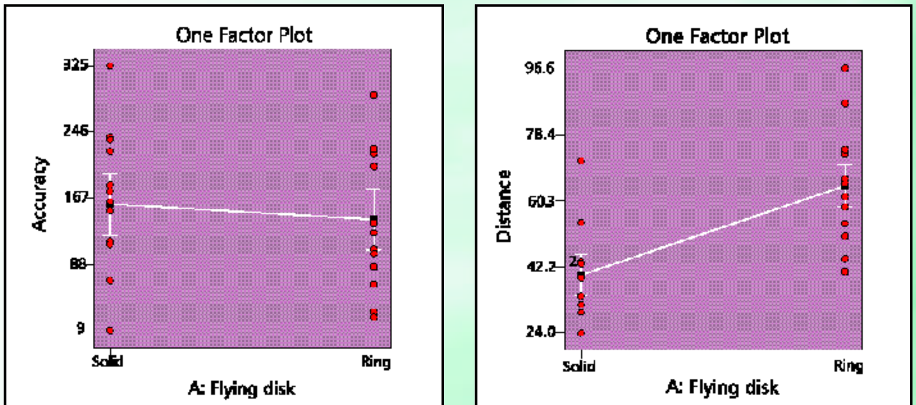

Fig. 3 - Effect of design (solid vs ring) on accuracy and distance.

This experiment proved to be educational not only for Katie and her cousin, but also for me. It aroused my curiosity about the psychological impact of color on human performance. It would've been helpful to achieve consistency in the colors of the two designs, such as the same shades of red, blue and yellow (primary colors) for each. Then conceivably some bias may have arisen for one color and against another that would cause significant differences in performance. I suspect this could be induced in impressionable subjects. For example, what if I had told Katie and her cousin that orange-colored disks never go very far?

Another option would be to measure accuracy and distance simultaneously, thus saving the girls a great deal of effort and arm weariness. However, this may not be the best choice for separating the responses of accuracy vs. distance.

Do you have any other ideas? Please feel free to e-mail me your comments and suggestions.

Mark *(Mark@StatEase.com)*

P.S. After writing this article, I learned from an expert in plastic molding that color additives *do* affect physical characteristics. Katie is even smarter than I thought!

* See page 125 of "DOE Simplified" (available for purchase via the Internet at www.statease.com).

How to Avoid DOE Disaster by Shari Kraber

DOE disasters fall into two main categories. First, you may discover that you can't detect the effects you wanted. You "know" the effects are there, but the analysis results aren't showing them. The second possible disaster is that you discover significant effects, but confirmation runs cannot validate them—you have "discovered" the wrong answer. Let's explore the possible reasons for these two types of DOE disasters and look at how you can avoid them.

Disaster #1: No effects found

The key to avoiding this disaster is to have an understanding of how an effect is detected. It is a matter of signal versus noise. The signal should be stronger than the noise in order to detect it. If it isn't, you can attack either side of the system. The signal can be increased or the noise can be decreased.

The signal is the amount of change in the response that is created by changing a factor level. The louder (i.e. larger) the signal, the easier it is to detect. You can make a signal larger by increasing the range of the factor levels. A general recommendation for setting the factor ranges is to set the levels far enough apart so that you would expect to see a difference in the response, but not so far that you don't get measurable data from both levels. (Note that I didn't say "good" data, only that it has to be measurable.)

Noise is usually trickier to address. First you need to determine the sources of noise. Here are some possible culprits:

- Measurement error
- Uncontrolled process variables
- Operator to operator differences
- Raw material changes

The sources of noise fall into two categories - those things that are part of running the experiment, and the measurement of the response itself. During an experiment, it is desirable to hold everything constant that you can, except for the factors that are part of the experiment. Unfortunately, not everything is controllable. For example, temperature and humidity often fluctuate. You may simply have to live with the additional variation that this adds to your results.

The measurement system must be addressed directly. It is critical that each response be a quantifiable measurement. I am convinced that a flawed measurement system is the number one reason for not finding statistically significant results. Measurements may be inaccurate or not precise enough to show statistically significant differences between runs. In such cases it may pay to be creative. A particular type of measurement may not be one that you want to use in everyday production, but if it will give you accurate, numerical results for the purposes of a DOE, it will be worthwhile to use.

The final note here is that experimenters should be familiar with the concept of the "power" of a design. Power is the ability of a design to detect an effect of a specified size. The effect size is generally stated relative to the size of the standard deviation of the process. For instance, the effect might be sized two times greater than the standard deviation of the process. Power is expressed as a probability, i.e. the power of a design to detect an effect of 2 sigma might be 80%. Power is directly related to the number of runs in the design. As the number of runs increases, the power to detect effects increases. A caution, 8 run or smaller designs do not have the power to detect effects that are small. Effects need to be 2½ - 3 times the size of the process standard deviation in order to have a high probability of being found in an 8-run design.

Disaster #2: Wrong effects found

Even worse than not finding effects is to incorrectly identify effects. How is it possible to find effects that aren't really there? The actual problem is one of mis-identification when you are using fractional factorial designs. Look at the effects identified in Figure 1.

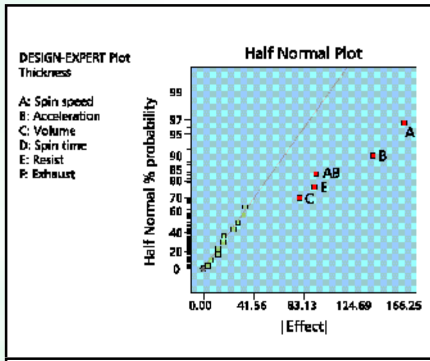

Fig. 1 - Five significant effects are shown.

The half normal plot of effects is a typical tool used to identify effects from a two-level fractional factorial design. In this case, 6 factors were explored in 16 runs (a half fraction) rather than the complete 32 runs for a full factorial. Five effects look statistically significant because they fall away from the line that represents the normally distributed effects (those belonging in error). Software often shows the labels of the effects as shown in this picture. What is not so obvious is that underneath the skin of a fractional factorial design is a set of aliases. An alias is one mathematically calculated effect which actually represents more than one term.

Figure 2 shows the alias list for this example. You can see that each main effect is aliased, or paired, with two three-factor interactions. Since we generally believe that three-factor and higher interactions are unlikely to be

— Continued on page 4.

— *Continued from page 3.*

significant, there is no cause for alarm here. But, look at the term labeled "AB."

Factorial Effects Aliases
[Est. Terms]Aliased Terms

[Intercept] = Intercept
[A] = A + BCE + DEF
[B] = B + ACE + CDF
[C] = C + ABE + BDF
[D] = D + AEF + BCF
[E] = E + ABC + ADF
[F] = F + ADE + BCD
[AB] = AB + CE
[AC] = AC + BE
[AD] = AD + EF
[AE] = AE + BC + DF
[AF] = AF + DE
[BD] = BD + CF
[BF] = BF + CD

Higher order aliases are not shown.

Fig. 2 - Alias list.

It is aliased with the term CE. This means that the calculated effect is actually the sum of the true effects of AB and CE. One of these effects might be real and the other not, but it is impossible to know with the current amount of information. It is very easy (but not necessarily correct) to assume that the terms labeled on the plot are the true effects. It is imperative whenever you use a fractional factorial design that you have the alias list at your side. In this case you could state that the main effects are A, B, C, and E, and that there are two possible interactions, either AB or CE or both.

Fractional factorials can give misleading results if you don't pay attention to the aliasing behind them. On the other hand, with proper usage, fractional factorials are a wonderful and essential tool for designed experiments. You certainly don't want to leave them behind, just educate yourself to use them properly!

Wrapping it up

A "DOE disaster" does not have to happen. You gain process understanding from every experiment. If you find no significant effects, you can state that the factors you studied, over these ranges, do not change the response more than the normal process variation. If you didn't find effects, but still believe they exist, you can either increase the signal, or reduce the noise. An understanding of the fractional factorial design that you are using can prevent discovering the "wrong" effects. Now that you recognize that aliases exist, you should be looking at the alias structure of any fractional design you create. As with most things in life, education remains the key to success.

Shari Kraber *shari@statease.com*

09/02

Look for us at these upcoming events: **September 11**, Intl. Tire Exhibition & Conf., Akron, OH *(Talk by Mark Anderson)*
September 30, Vinyltec 2002 Conference, Itasca, IL *(Talk by Mark Anderson)*
October 17–18, Fall Technical Conference, Valley Forge, PA *(Talk by Gary Oehlert + Booth exhibit)*
November 18, Intl. Wire & Cable Symposium, Orlando, FL *(One-day course by Pat Whitcomb)*

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