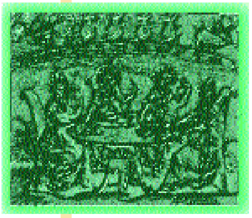
Design of Experiments

FEATURE

By Mark Anderson

Industrial physicists no longer can afford to experiment in a trial-and-error manner, changing one factor at a time, the way Edison did in developing the lightbulb. A far more effective method is to apply a computer-enhanced, systematic approach to experimentation, one that considers all factors simultaneously. That approach is called design of experiments (DOE), and corporations across the nation are adopting it as a cost-effective way to solve serious problems afflicting their operations. DOE provides information about the interaction of factors and the way the total system works, something not obtainable through testing one factor at a time (OFAT) while holding other factors constant. Another advantage of DOE is that it shows how interconnected factors respond over a wide range of values, without requiring the testing of all possible values directly.

DOE considers all the variables simultaneously and predicts response over a wide range of values



DOE fits response data to mathematical equations. Collectively, these equations serve as models to predict what will happen for any given combination of values. With these models, it is possible to optimize critical responses and find the best combination of values. DOE software is tremendously fast, enabling the testing of many factors in just days. That's drastically shorter than the months, if not years, spent testing only a handful of factors using the traditional method. DOE takes some of the art out of experimentation, replaces it with science, and yields better results.

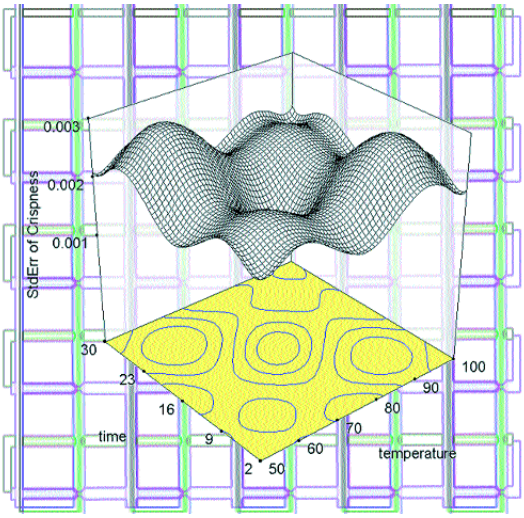


Figure 1. Software generates rotatable 3D plots of interacting variables.

Consider the experience of the John Deere Engine Works (Waterloo, Michigan) and its search for a way to improve paint adhesion to aluminum components while eliminating the increasingly expensive chromate-conversion coating process as a pretreatment to painting. It was difficult to find a basis for improving the paint's adhesion because John Deere's data did not clearly indicate the cause of the paint's limited performance, says supply management engineer Wayne Mills.

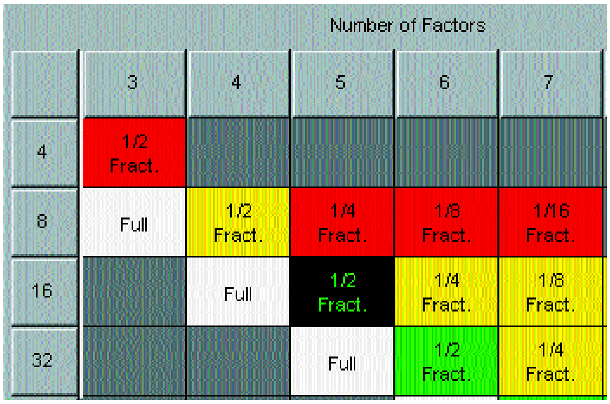
John Deere first ran a screening design to identify the important variables among the 12 that its experimental team had established, which included the casting method, pretreatment process, paint type, and the concentration of adhesive ingredients. The results surprised everyone. Chromate conversion had very little effect on paint adhesion, but paint type proved a very significant factor. No one at John Deere had considered paint type as a major player. More tests narrowed the variables to three: chromate conversion, paint type, and surface treatment. A three-dimensional-cube plot generated by the DOE software clearly showed how the three variables interacted. The results again identified paint type as the major problem.

To confirm the software's results, Mills and his colleagues performed a traditional one-variable test with several data points. This final test convinced all the members of the experiment team. As a result, John Deere solved its paint adhesion problem and eliminated the chromate-conversion pretreatment process from aluminum parts—a change that has saved the company nearly $500,000 annually, according to Mills.

Better approach

When attacking a new design challenge, an industrial physicist must consider many factors simultaneously. Variations may occur, for example, in casting, machining, finishing, plant conditions, parts assembly, machines, and operators. Besides this group of obvious factors, there are subtler ones—factors that only those very familiar with the process can identify, such as the length of the production cycle. And still other complications stem from the interactions of factors among themselves, which are generally understood by no one.

The physicist who must justify experimentation by supplying a cost-benefit ratio is under pressure to gain



	Number of Factors				
	3	4	5	6	7
4	1/2 Fract.				
8	Full	1/2 Fract.	1/4 Fract.	1/8 Fract.	1/16 Fract.
16		Full	1/2 Fract.	1/4 Fract.	1/8 Fract.
32			Full	1/2 Fract.	1/4 Fract.

Figure 2. John Deere broke free from an expensive coating process after this software program design builder guided experimenters to a profitable two-level factorial design.

the maximum amount of information from each experimental run. After all, a detailed study of all factors is generally cost- and time-prohibitive if it requires many runs. Because of this, physicists must limit the number of factors tested to the most obvious. The contributions of the factors they assign as minor are rarely discovered. Later, after months of testing, the experiments end. The process shows improvement, but how much more would the process have improved if other factors had been studied? That's usually not answered with the conventional approach.

In OFAT, the first factor is fixed as a "good" value, the next factor is examined, and on and on to the last factor. Because each experimental run considers only one factor, many runs are needed to get sufficient information about the set of conditions contributing to the problem. This consumes a hefty amount of time and money, along with running a high risk of error. Another limitation is that when factors change, they generally change together, so it is impossible to understand the best solution by pointing to a single, isolated factor. Traditional OFAT experimentation frequently reduces itself to no methodology whatsoever—just trial and error and a reliance on common sense. In contrast, the systematic DOE approach provides information about the interaction of variables and the way the total experimental system works, something generally not attainable through the OFAT approach.

Eastman Kodak (Rochester, New York) found DOE quite cost-effective when its professional imaging finishing department had difficulty forming a small steel clip with consistent reliability. The 4×1×0.005-in. clip, used to seal one end of preloaded photographic film envelopes, required a tight tolerance of a few thousandths of an inch during a critical stamping operation in which three angles and a radius were formed. According to Peter Runke, senior manufacturing engineer, Kodak did not know whether it needed to improve the tooling or spend several thousand dollars for a new stamping machine.

After performing 32 experimental runs with DOE software, the Kodak team found that of the six factors it identified for examination, three were significant. Blade clevis (ability to split) created the main effect. Blade shim (taper) was second, and tool pressure was third. Runke says this evidence proved that the fault lay in the tooling, not in the machine itself. This provided the justification for retooling, and Kodak took the opportunity to design the tool as one piece to further ensure high repeatability. This contrasted with the former tooling, which used components that had to be taken apart and reassembled for each new run.

By applying the DOE experimental method, Kodak saved the cost of a new stamping machine and through retooling, increased repeatability to 100%, reduced scrap by a factor of 10, slashed inventory, and reduced setup time from 8 hours to 20 minutes.

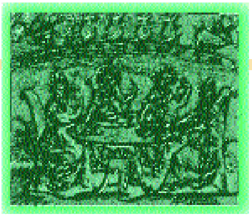
Software speeds DOE application

For decades, a few physicists have been manually applying DOE principles by using algorithms found in handbooks. During the last 15 years, the development of DOE software packages has made DOE more accessible to physicists and engineers. Today's software is mostly menu-driven, and statistical jargon is minimized. Developers have eased the complexity surrounding DOE by increasing the emphasis on graphically displayed results over numerical tables. The software is relatively inexpensive, currently ranging from $100 to $1,500. With a little training (typically a three- or four-day workshop), people can integrate DOE into their experimentation strategies.

The first step in using DOE software is to define the factors and the range in which each factor varies. Once the factors and their ranges are determined, the user enters the values into the software. The first experimental run identifies important factors. Subsequent runs fine-tune the critical factors. To confirm the software's results, the experimenter performs a traditional one-factor test with several data points.

The advantage of DOE software is its ability to show the physicist real-world results. DOE helps physicists complete the testing process faster than the traditional experimental method. Just as important, DOE reveals solutions that would not be apparent without it.

Ski manufacturer K2 Corporation (Vashon, Washington), a division of Anthony Industries, encountered a number of processing problems when the company



retooled its existing molds for a new “cap” ski design that featured a smooth, encased look. The new skis exhibited dimples, blisters, and other troublesome surface problems. The top layer of the skintight plastic casing made every blemish visible and impossible to sand off. Scrap rates soared to 30%, says Douglas O. Hubbell, director of process improvement at Anthony Industries.

To attack the problem, K2 ran a DOE screening design on 17 factors, four of which turned out important to the ski defects: core placement, core extension material, top thickness, and base width. DOE revealed a surprising interaction—which OFAT experimentation would never have identified—between the top thickness and base width that pointed to the need for different dimensions, Hubbell says. K2 confirmed the accuracy of the statistical predictions by conducting standardization procedures. The company made the process adjustments recommended by the DOE software, which eliminated the blemishes. K2 then put DOE to work to solve other processing problems.

By applying the DOE experimental method, Hubbell says, K2 has dropped press downtime from nearly 250 labor hours a week to a mere 2.5 hours and has dramatically reduced delamination scrap from 1.8 to 0.12%. In addition, DOE helped K2 streamline many processing steps and eliminate some costly materials, such as a synthetic rubber filler.

DOE offers industrial physicists and their engineering colleagues the opportunity to design better parts at lower cost and in less time. Its cost-effectiveness, greater speed, and ability to reveal design solutions not apparent with the traditional experimental method make the DOE approach increasingly vital in maintaining American industry’s competitive edge. Ω

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