If you haven't yet applied multivariable testing to your business, get moving. Whether you run a factory, a mail-order house or a hospital, it will probably improve your performance.

The new mantra: MVT

By Rita Koselka

FIVE YEARS AGO a Raychem Corp. subsidiary in Oak Ridge, Tenn. called Elo TouchSystems was losing $3 million a year making touch-sensitive computer screens for products like automatic teller machines. The culprit: a devastating 25% reject rate. "Our screens had chicken skin," recalls Robert Roeser, Elo's president. That's a bubbling between the screen and the coating. "We were forced to have a police mentality—inspect everything—because we had no idea how to make them come out right every time."

Raychem was ready to close the place. "We already had two huge volumes from 18 months of quality improvement efforts," Roeser says.

As a last resort Roeser sent for a quality control consultancy, QualPro, which had ties to Oak Ridge, the huge nuclear production facility outside Knoxville. QualPro sent Roeser no electronic engineers, no Japanese quality circle gurus. It sent him some statisticians. Withing months they lowered Elo's defect rate to less than 1%. Within two years Elo had cut the number of quality inspectors in half and was breaking even. Today it's probably making $15 million on $50 million in sales.

Statisticians? The guys with clipboards and Comptometers saved a factory?

They did it by changing the way Elo experimented with its production process. Previously, Elo's engineers would test one hypothesis at a time—they would see what they could do to the output by changing the adhesives used in assembling the screens, or by changing how the polyester coversheet was shaped.

QualPro took a different approach. It designed experiments in which several variables were altered all at once. The solution to the yield problem would never have surfaced in their old testing method. It turned out they had to change three things at the same time: the type of polyester, the coversheet shaping process, and the adhesive. That was the difference between success and failure for this electronics plant.

"Experiment," said Cole Porter in the song. "Make it your motto day and night." Has American business overlooked simple advice?

Explaining this triumph of the statistical approach, Charles Holland, the 51-year-old founder and head of QualPro, says: "If you test factors one at a time, there's a very low probability that you're going to hit the right one before everybody gets sick of it and quits."

What QualPro's statisticians did at Elo was apply the science of multivariable testing—MVT for short—to the company's business problems. Using the MVT discipline, a factory, a utility, a retail chain, a hospital or almost any kind of organization can experiment with how changes in its processes affect the outcome. By tweaking the inputs, the factory gets a higher yield, or the open-heart surgery department gets a lower mortality rate, or the utility gets a faster collection of its accounts receivable.

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You've never heard of MVT? You will. It's the natural outgrowth of the quality control movement that has swept across the business landscape in the past two decades. MVT picks up where quality control leaves off. It doesn't just tell you how to raise the quality of your output. It tells you how to do that cost-effectively.

Columbia University Business School Professor Peter Kolesar, an expert on operations research, sings MVT's praises this way: "Experimental design is only a part of the quality movement, but when it is applicable, it can be an extraordinary and almost magical thing."

Lots of business managers test changes in their operations. What they don't often think to do—or don't have the resources to do—is to test many variables at once, as Elo did on its screen production line.

Another example: Boise Cascade. It had been fiddling with small variations in its pulping process at a DeRidder, La. paper mill for years, with modest success. Then it set up a formal MVT process involving eight variables. Out came the counterintuitive conclusion that the mill could maintain its paper quality while switching to a cheaper grade of wood. Results: equal or better paper and savings of more than $3 million a year.

"This [MVT] is a way of life with us," enthuses Chris Nelsen, paper production manager at Boise Cascade. "It is how we do everything. At three in the morning, some guy on the late shift in the mill will decide to do a 2x3 factorial experiment to figure out what chemicals to use on some piece of machinery. Almost 800 people in our southern operations have attended one-day seminars on design of experiments, and we have more than 30 who are trained to run advanced experiments."

QualPro is one of a handful of small consulting firms that have made a business of applying statistics to the quality movement. Among the others are Mercer Management Consulting in Lexington, Mass., Process Management International in Minneapolis, the American Supplier Institute in Allen Park, Mich. and various independent statisticians organized by ASQC. A Minneapolis software firm, Stat-Ease, sells most of the software these MVT types use. Experimental design is now being taught formally at Motorola University in Schaumburg, Ill.

By and large, however, the wellknown strategic consultants and Big Six accounting firms are still strangers to MVT. "It's the one area all the big firms have overlooked," says Mark McComb, quality director at American National Can.

The power of experimental design is its efficiency with data and that it forces decisions to be based on facts, not politics or emotions.

That hasn't stopped some big corporations from discovering the possibilities on their own. DuPont has been adjusting the knobs on its Victoria, Tex. factory for years to boost the output of adipic acid, an ingredient in nylon. Beginning in late 1994, its engineers discovered the tricks of multivariable testing. Results: an increase in production of 10 million pounds with no additional expenditure.

Says Charles Roesslein, vice president of information services at Southwestern Bell Telephone: "In the Austin [Texas] market, we have about 100 people trained by QualPro currently doing 25 projects. I wish all my managers thought in those terms. It takes the 'I believe' out of [decision making]. It broadens your problem-solving ability, puts some rigor in your thinking."

MVT is a new way of thinking for some statisticians, too. Their role, classically, has been to test innovations, not to discover them. You give the experimenter a new manufacturing process, and he will rigorously test whether it is superior to the existing process. But going beyond that was not in his job description.

MVT changes the statistician's job description. It now becomes: Come up with some innovations. Go to the shop floor. Talk to the client's production workers. Make a list of a lot of other ways to change the process. Test dozens of them. Pour these variations into a beaker and see what comes out. Train workers to try it themselves.

In the new multifactor testing framework, the experimenter becomes the inventor. The experiment is so sweeping that it leads to innovations by itself. Goerge Box, a professor at the University of Wisconsin and a leading theorist in the design of experiments, expresses it in this way: The statistician moves from "a test-oriented mindset" to a "critical catalytic role in the process of discovery and development."

Some tasks have always had a certain natural experimentation built in. What chef has not said to himself, "Let's try it this way"? Process industries like chemicals, food processing and smelting are subject to constant adaptations. Now some very different businesses are discovering the possibilities of experiment.

Hospitals, for example. Saint Luke's Hospital in Kansas City was worried about the use of warfarin, an anti-blood-clotting drug which can be fatal if used improperly. Warfarin was the drug most commonly misused with dangerous results at Saint Luke's. In 1992 the hospital worked with QualPro to experiment with ways to keep patients from misusing the drug. The team tested seven factors to better educate patients and provide emergency access to nurses. They found that by having a standardized instruction sheet and having the pharmacist discuss the drug with patients, there was a 68% improvement in patient understanding of how to safely use the drug.

"The power of experimental design is not only its efficiency with data, but that it forces a team to make decisions based on facts," says QualPro's Holland. "Hierarchy, politics or emotions are refuted with data."

Holland, who has a statistics doctorate from the University of Tennessee, began to see the power of MVT when he was helping build atom bombs. In 1969 he was working as a statistician at a Union Carbide operation in Oak Ridge. Part of bombmaking is producing precisely shaped pieces of carbon-impregnated urethane foam. The pieces weren't good enough. Almost 85% failed inspection. The obvious way to solve the problem was to refine the process by which these parts were formed. But this solution would have involved a huge outlay for machine tools.

Holland came up with a different solution by rereading a classic text, *The Design of Experiments*, by the British statistician and biologist Sir Ronald Fisher (1890-1962). Fisher was more than a great theoretician. He was also a practical scientist, who put his statistical theories to work in agriculture. In industrial settings, however, his work on experimental design was underappreciated.

Holland could see the relevance of Fisher's work to solving manufacturing problems. He interviewed engineers and production workers on the urethane line. From them he selected 15 factors that could have a bearing on parts quality. The variables were mundane things like the shape of the tab that kept a metal lid in place, and the temperature, speed and position of a mixing blade. Holland began experimenting with these variables and soon found that changes in the speed and position of the blade, easy adjustments to make, profoundly affected the defect rate. The division enjoyed zero rejects for the last five years of the project, without any new capital investment.

Experimental design for a movie theater

Imagine you are running a movie theater chain and you want to maximize your weekly profit. Options: Jack up your ticket price by a buck; take out bigger ads in the local paper; give away the popcorn. The last suggesting, from a projectionist, runs against your instincts, but you agree to give it a whirl.

You could test any of these variables in isolation. But a statistician persuades you to test all three at once. That way you are more likely to pick up any interesting effects from an interaction between two of the variables.

Experiments are costly because frequent changes in your business unsettle the customers. So you have to plan your tests very frugally.

The brute force approach is to try every possible combination, ranging from no changes to changes in all three variables. Total trial runs needed: eight.

A more elegant solution: Run just four of the eight trials, but pick them carefully to extract the maximum information. The pattern is called Plackett-Burman, after the two British statisticians who designed it in 1946. It overlooks some possibilities, but it does capture a profit boost from an interaction between the free popcorn and the ticket price (test 6). It turns out that free popcorn, although it cuts out your popcorn revenues, still pays for itself in higher profits from sodas. It also allows you to raise your ticket price without alienating customers. The experiment also shows that bigger ads don't pay for themselves.

Plackett-Burman experimental designs can make for much, much larger savings when there are more variables at stake. It works beautifully most of the time, but it's not foolproof. In a four-run trial (at left), it wouldn't pick up the effect of a three-way interaction.

The brute force approach

Test	A. Raise ticket price	B. Advertise more	C. Give out free popcorn	Profits ($thou)
1 •				10
2			✓	15
3		✓		5
4 •		✓	✓	10
5	✓			12
6 •	✓		✓	20
7 •	✓	✓		7
8	✓	✓	✓	15

The Plackett-Burman shortcut

Test	A. Raise ticket price	B. Advertise more	C. Give out free popcorn	Profits ($thou)
1				10
4		✓	✓	10
6	✓		✓	20
7	✓	✓		7

A. Raise ticket price	B. Advertise more	C. Give out free popcorn
No 1+4 avg = $10,000	No 1+6 avg = $15,000	No 1+7 avg = $8,500
Yes 6+7 avg = $13,500	Yes 4+7 avg = $8,500	Yes 4+6 avg = $15,000

A Plackett-Burman test of how to make toast?

Test	A. Plug in toaster	B. Put in bread	C. Push button
1			
4		✓	✓
6	✓		✓
7	✓	✓	

Erroneous conclusion: There's no way to make toast.

STEVE RAMOS/FORBES

In 1969 Holland published a white paper on the project for the Atomic Energy Commission. The report went largely unnoticed. But forces were already in motion that would soon make MVT a concept whose time had come.

While Holland was working in Oak Ridge, W. Edwards Deming, a physicist who helped reconstruct Japan during the Occupation, was spreading the gospel about quality. For a long time Deming was without honor in his homeland, but after the Japanese car companies started to whip their American competitors, Deming could no longer be ignored.

Deming, who died in 1993, laid the groundwork for MVT on the factory floor by paying meticulous attention to small variations in results. Deming tried to get workers to think about how to control a manufacturing process so that it would turn out consistent products: Some of these computer disks are coming out with imperfections. What's the cause? Did we use enough of the cleaning solution? Did we apply the right amount of iron oxide and resin? If not, let's fix it.

From there it was a short stop to Holland's line of thinking: Let's try different solutions. Or different amounts of oxide or types of resin or anything else we can think of.

Before starting QualPro in 1982, Holland worked with Deming, who opened the doors to many of QualPro's clients, including Ford and Proctor & Gamble.

The design of experiments involves some cleverness. It may cost a lot of money to shut down a production line and rearrange it; it may take precious months for a billing department or a mail-order operation to see whether a novel way of doing things will pay off. MVT is the science of gleaning the most amount of information from the least amount of costly testing.

Consider the brute force approach to testing variables. If you have ten factors that might influence a final result—either alone or in some combination that you can't guess ahead of time—then you have to run 1,024 trials. That's how many ways there are to include or reject ten independent items from a list. For each of these trials, you need a reasonably large sample to be sure of detecting an improvement—maybe 100 widgets or heart patients. The test becomes impossible to practice.

The MVT practitioners take a more subtle approach, in which 12 tests are made to do the work of 1,024. The stripped-down experiment can't uncover the effect of all possible combinations of factors, but it can uncover a major effect of any one factor and many of the interactions. If factor three works surprisingly well in combination with factor nine, you will pick that up (see box, p.117). "We find that one-third of the variables that we test only show an effect in combination [with other factors]," says Holland.

One-factor-at-a-time testing became outdated 70 years ago, but it has taken an extraordinarily long time to trickle down.

One QualPro client was selling sneakers in 100-odd stores. On the table: a proposal to boost sales with a costly, high-tech display.

Kieron Dey, a Welsh statistician who heard about Holland's work and joined him in 1988, took over the case. He persuaded the shoe chain to run some tests before committing to the expensive new displays. He wanted to look at a whole range of changes, in sales techniques, advertising, separation of shoes by color, and various discounts, as well as the displays.

Surprise: The flashy new display did boost sales. But not nearly as much as the simple combination of using the old display case while arranging the shoes by color. A limited test combining new displays with color separation wouldn't have uncovered this fact because, as it happened, the color idea was sensory overload on top of the new display cases.

Dénouement of this case: The client didn't spend the money on new displays and was still able to push sneaker sales up 33%.

"One-factor-at-a-time testing became outdated 70 years ago, but it has taken an extraordinarily long time for this to permeate teaching in engineering schools, and to change the methods of experimentation used in manufacturing," says University of Wisconsin's Professor Box. He adds: "But the good news is, because of past neglect, many important new possibilities that depend on interactions [between variables] are waiting to be discovered."

One of Professor Box's star disciples, Christer Hellstrand, went to work for SKF, the world's largest maker of ball bearings. In 1985 SKF was trying to redesign part of its manufacturing process to cut costs. The managers wanted to use a cheaper design for the "cage," the metal collar that holds the balls in place. But they worried that this change might make the bearing less durable.

Hellstrand convinced the managers to widen the experiment. First he elicited two other ideas by talking to production workers: Change the heat treatment of the bearing's inner ring to make it harder and tougher, and tighten the clearance between the balls and the outer ring of the bearing.

Some surprises soon popped out of the data. Using the cheaper cage didn't hurt the bearing. And while neither suggestion from the production line, by itself, made any difference, implementing both suggestions resulted in a bearing *five times* as durable.

Why had no one stumbled on this before? Simply because the engineers had never experimented with combinations of things.

If factory engineers are rigid in their thinking, marketing and service sector managers can be even harder to deal with, says Holland: "They don't want a process, they don't want to be standardized. They want to think what they do is art. But they are wrong."

In late 1994 Southwestern Bell needed help. At the same time that it was trying to reduce errors on service orders, one of its biggest customers, the Texas state government in Austin, was complaining about response times to its service calls. QualPro's consultants prescribed simultaneous five-month tests of 15 alterations in the way the company did business. Among them: Do we have weekly meetings for the customer service representatives? Do we have performance incentives? Should the service rep or a separate typing pool type in orders? Should the reps or lower-paid clerks answer the phones? Should we change the length of the employee training? Cure: keep those meetings, have clerks do the typing but not the phone answering, and go with the shorter training.

Experiment. Make it your motto day and night. Anything about the way your company does business that should get a second look? Can your production workers come up with 12 variables to change? Experiment, and you may be astounded at the results.