WE NEED BROADER INTERACTIONS

The author rightfully laments the disconnect between industrial and academic statistics. As his comments suggest, the root causes rest in the differing criteria for success. Industrial statisticians are rewarded for what they have done (lately) to enhance the welfare and profitability of the firm. They need to be especially sensitive to the agenda of the manager to whom they report at any point in time.

Academic statisticians are a more independent breed and feel less need to follow any drummer's beat. The most important measure of success is their record of publications – especially in academically oriented journals. Broadening the criteria for academic accomplishment is all important for narrowing the gap with industry.

But what can we do – despite the flaws in the system? The author suggests that academics concentrate their research on problems that are most pertinent to industry. I urge stronger working partnerships. Here is the opportunity. Industrial statisticians encounter a wealth of practical problems. They do their best to develop and implement useful practical solutions. And then they go on to the next problem. Most have long formal or mental lists of problems on which they would like to work further some day. But life is finite, and that day rarely comes. In contrast, academic statisticians are often starved for real problems, so they select those that they think are real, do the work and hope that somebody "out there" will find the results useful.

So, let's get together and collaborate! The industrial statistician can provide the problems and the real challenges, some good examples and sanity checks as the work progresses, and the academic does much of the technical development and documentation (and might be the senior author of any publication). Geographical adjacency is extremely helpful in such an arrangement, as is some up-front residence in the industrial environment.

I have one related suggestion to university statisticians. Consider inviting an industrial colleague to co-teach an evening course with you. You will have to do most of the work, but the industrial statistician can add an important practical touch by recounting experiences – perhaps even from that day's work. I tried this with Josef Schmee at Union College some time ago, and we believe the class came away with a much better appreciation of what is important and what is not (like hypothesis testing) in "real life."

In addition, I urge academic statisticians to interact more closely with their colleagues across the campus – and not just as consultants. We find at GE CR&D that working with colleagues in control theory, materials science, computer science and so on, not only keeps us on our toes, but can lead to results that well exceed the sum of the individual contributions. It must surely be that way in academia, too. In addition to better focused research, this might also lead to some useful interdisciplinary co-teaching.

CONCLUSION

These comments cover only a few of the many areas raised by the author. In fact, Banks' paper can spawn many more on such topics as how statistics really contributed to the Japanese quality revolution, the role of acceptance sampling in proactive quality improvement programs, total quality management, the ubiquitous role of control charts and so on.

All this, of course, attests to the value of the article. I thank David Banks for his excellent and thought-provoking comments and the editors of *Statistical Science* for providing a forum for presenting and discussing these. Finally, I thank my colleagues, Will Alexander, Necip Doganaksoy and Mark VanDeven – all recent Ph.D.s (or soon to be) who have chosen industry – for their valuable inputs.

Comment

Robert V. Hogg

During the Fall semester of 1991–1992, I had a developmental leave and embarked on a "quality journey" in which I visited 20 companies and 8 universities and attended 4 meetings. Most of these stops were related to my efforts to learn more about quality improvement in manufacturing, health care and education. I was on the road most of the time from early September through the middle of January, 1992, except for breaks at Thanksgiving and Christmas. It convinced me that that was too long for a man of 67

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to live out of a suitcase. The opportunities to learn that this trip provided me were, however, invaluable, and some of my observations are reported in my "A quality journey" (Hogg, 1993).

In addition to this journey, my 43 years as a professional statistician have given me a few opportunities to observe how industrial statisticians improve products and services. As with David Banks, I feel that those in industry have a better sense of practice than I do, but at least I do have a better perspective on this topic than most academic statisticians. Since beginning to organize the "Hogg Conference" of 1984, reported in the *American Statistician* (Hogg, 1985), I have really taken great interest in what has become commonly known as Total Quality Management (TQM). In 1986, the University of Iowa started a small M.S. program in quality management and productivity from which we graduate only three to five students each year. I am certain, however, that Pete Jacobs of 3M, among others, can vouch for the quality of our "products." It was one action that I took to respond to what I thought were weaknesses in applied statistics M.S. programs, not only at Iowa, but throughout the United States. I have more to say about improving those programs later.

I must start with Banks' article by saying that I agree with almost all of his observations. Thus, I emphasize some of his points by simply using different words. These comments are more or less in the same order as his.

1. Not only has TQM been a boon to consultancies, but it has promoted the employment of some statistical "hacks" and charlatans in quality improvements.
2. There is a great deal of waste in training in industry. While an outside expert is absolutely necessary in some situations, qualified in-house statisticians can more easily provide "just-in-time" training: the *right topics* at the *right time* in the *right amount*. One example of this was at Saturn. After initial help from faculty members at the University of Tennessee, most courses are now taught by persons within the Saturn operation.
3. As Banks notes there is a lot of hoopla associated with the quality movement, and much of TQM is common sense that many 14-year-olds can apprehend. Nevertheless, many are doing things quite the opposite of good TQM. As examples, consider the following: (a) Workers are not empowered and they are afraid to speak up because they do not trust their supervisors; (b) the manufacturers' convenience is put ahead of the customers' actual requirements which are often unknown; (c) management is too far removed and often has little understanding about what is actually going on in the plant; (d) neither suppliers nor customers (external and internal) are used on teams trying to improve the total process.
4. To follow up on (3), let me observe that I had the opportunity to talk to about 30 individuals who were finishing Tennessee's excellent basic Three-Week Institute. In this, the participants alternate a week in Knoxville with a month at their organization, where they are expected to work on projects before returning to the university. So these participants had some knowledge of good practice of TQM. I asked them to rate subjectively their companies' quality improvement efforts on a scale of 1 to 5, in steps of one-fourth. Despite the fact that these companies had enough interest in quality to fund this training, the median score was 1.25. One individual wanted to give his firm a zero, even after I told him the lowest rating was a one. I did other surveys like this of all U.S. firms (for example at a StorageTek supplier conference), and my guess is that at *best* the median of all U.S. firms is about 1.75. If organizations (including those in governments, health care and education) would use some of this "common sense" TQM, we would be much better off. The truth of the matter is that they do not unless the "chief" is obsessed with quality improvement. Bob Galvin of Motorola is an excellent role model of a CEO who is obsessed.
5. Benchmarking need not be only against competitors. For illustration, to improve its warehousing and distribution processes, Xerox examined the efforts of the catalog retail firm L. L. Bean.
6. Relationships among people become so important in the practice of TQM. Often each person is a customer, then a processor and finally a supplier. If you recognize the existence of all your customers and suppliers (mostly internal) and the importance of them to you, your appreciation and treatment of them will certainly improve, at least mine has.
7. While teams must be stressed, I believe that a certain balance between the individual and the team should be achieved because we do not want to stifle an individual's solution to a problem. As a matter of fact, balance must be considered on many fronts: for illustration, between constancy of purpose and continuously improving. We also recognize this in Banks' remark: "No company in the world has achieved zero defects, and none will spend infinite sums to achieve it." That is, there must be a balancing point in considering the benefits and the costs of any change.

Now that I have emphasized and expanded upon a few of the points that he made, let me comment more explicitly about Deming, Taguchi, capability indices, statisticians and statistics in companies, M.S. programs in applied statistics and personal quality improvement.

W. Edwards Deming

These comments were elicited because of Banks' remark that "corporate executives walk their corridors clutching copies of Deming's *Out of Crisis*" like Chinese bureaucrats did with Mao's book. Not that Banks suggested otherwise, but I think that Ed Deming is a great man. I have read a lot of his material and have really tried my best to understand him. I am doing better at it but I have much to learn about his philosophy. Many of his 14 points lead to a desirable reduction of variation in the processes, like his admonitions to select a single supplier for a single part, to drive out fear and to eliminate quotas.

I believe that I am even starting to understand his message about the importance of analytic studies and prediction rather than the use of tests of hypotheses or even confidence intervals. For example, we so often have an old way of doing something and a proposed new way. So we run an experiment collecting data from the "old" and the "new." To many of us this seems like a two-sample problem and we make appropriate assumptions, solve it and make appropriate suggestions. However, often the new way is done in a lab situation or with prototypes. Certainly, we can analyze the numbers, but what is that going to tell us about how the new method will work if put into practice? Statisticians must clearly work with the experts in that area to make appropriate "extrapolations" and predictions from those test situations. Predictions are, in Deming's view, the purpose of analytic studies. It seems to me that this means that the statistician must truly become part of the team—a collaborator with those investigating proposed new methods. In doing so the investigators must use all possible information available, much of which is prior. Thus I find a strong Bayesian element in Deming's teaching, and it seems as if we must take this into account, either formally or informally, in making predictions.

Now in saying that Deming is great, I do not imply that the other quality gurus are not. I just know Deming and his work better. I have met Joe Juran and heard his two-day presentation. Joe is much more articulate than Ed is. As a matter of fact, I often find that Deming's presentations lack a lot of polish; but maybe that is an important part of his style—and effectiveness. I have often said that for me, he crammed a one-day course into four days when I attended one of his four-day seminars. However, I understand variation and most of the participants did not have this background. I watched others attending the conference and Deming's "Red Beads" and other discussions seemed to be extremely effective. I truly believe that managers would do much better than at the present by adhering to Deming's 14 points.

Genichi Taguchi

Taguchi has been controversial. Statisticians criticize the designs that he proposes to use (many of which are not his); yet he got the engineers to run carefully designed experiments which is a huge part of the battle. Walter Liggett of NIST spent one year in Japan, and he reports that he found that engineers there "experiment, experiment, experiment"! This is no doubt due to Taguchi's influence, and we must give him credit for his effectiveness.

The "Taguchi loss function" looks like square-error loss to me; something Gauss even understood a long time ago. But Taguchi put it on a graph along with the specifications and it made some sense to the engineers. That is, even though the items are within "specs" there is more loss as they drift away from the target.

The signal-to-noise ratio introduces the variance as a response variable (as well as the mean). While that ratio is not always the correct measure, it does require that the investigator consider the variance.

The same could be said about Taguchi's insisting that the product be robust to the "environment," in which the environment might include parts going into that product. Ron Snee uses the word ruggedness for this concept, and I rather like that term.

Capability Indices

From my experience the most important capability index is

$$C_{pk} = \frac{\min\{\text{USL} - \hat{\mu}, \hat{\mu} - \text{LSL}\}}{3\hat{\sigma}}.$$

At least, I saw lots of C_{pk} values on my quality journey. Unfortunately, people in the industry do not recognize that C_{pk} is a random variable, being computed from sample observations. Thus a value of 1.38 might be okay while a value of 1.29 is considered bad, and both are simply computed values of a statistic. Of course, good statisticians recognize this, but managers do not and important decisions are often made on the basis of these values.

Statisticians have considered the distribution theory of C_{pk}; often it is approximate and derived assuming the underlying distribution is normal. If that underlying distribution is highly skewed or has long tails, things can get very wild. My recommendation is a simple one: just plot the histogram associated with the data or some reasonable estimate of the underlying density and compare it to the specs. If these data are well within the specs, then C_{pk} will be large. If some of the data points are close to or exceed the specs, then C_{pk} is unacceptable.

This statistic C_{pk} is an attempt to find one measure to describe how the process is doing. It gives us some idea, but it is not perfect and people must recognize this fact. But they do not and it does concern me since I saw so much use of C_{pk}. We must teach the positives and the negatives of any method. I applaud statisticians like Robert Arnold of Hewlett–Packard and Phil Ross of Saturn using and teaching C_{pk} values and "Taguchi methods" if they explain the good and bad points.

It was interesting for me to return to Iowa City in January, 1992, about the time the second edition of Hogg and Ledolter (1992) was out, and that book did not include any "Taguchi or C_{pk}." From my experiences, we should have something about each of these topics in it. I guarantee both will be in the third edition – explaining the good and bad points of each. Of course, then Banks can give us an even higher score than he did this time. Incidentally, for obvious reasons, I cannot argue with his ratings, but I do recognize that we can improve. That is good TQM.

Statisticians and Statistics in Companies

Roughly I agree with Banks' rather fair assessment of the use of statistics in industries and, in particular, in the quality movement. I have consistently said 85 to 90% of the gains can be made by using the "quality culture" and only 10 to 15% with statistics. Of the latter, most of it is made by using the seven tools: flow diagrams, Ishikawa fishbones (cause and effect), Pareto charts, histograms, basic graphics (including run charts), scatterplots and control charts. Note that I did not use the "magnificent seven" of Ishikawa as I included flow diagrams and deleted checksheets. The former can be very effective, and I agree with Banks that the checksheet is a generic procedure for capturing data. I also wanted to make certain run charts were mentioned because Banks did not list them explicitly and Hogg and Ledolter forgot them (other than in control charts) in the first edition. I also add that I agree with Banks' suggestion that statisticians could contribute to the development and use of the matrix diagram or what I have heard called the "house of quality," which is used in quality function deployment (QFD). It does try to assess the correlations between "the wants and the hows."

Statisticians could take a stronger leadership role in the quality movement than they do now. This is often the fault of the statisticians (and their instructors) who have emphasized becoming experts in "technical skills" rather than "people skills." In making presentations, I always remind students to "Keep It Simple, Statistician" (KISS) rather than showing off too much with his or her statistical "know how." If others want to know more, they will ask.

Rather than teaching too much fancy statistics to a few in a company, it would be better to teach the concepts of statistical thinking and simple statistics to as many as possible. Not that we can make everybody scientists, but we can get people to think a little about the scientific method. I believe that it was George Box who wanted to be more *democratic* in this "problem solving" process by including workers on the line. We do not want anyone to leave his or her brain at the door as we once did in mass production. Each worker must clearly understand this if TQM is going to work.

There certainly are still some technical research problems that could help in quality improvement:

1. Possibly there is more to be done on control charts with correlated data.
2. From seeing some of the work of Chuck Heckler's at Kodak, I would agree with Banks' suggestion of looking more into partial least squares and high dimensional multivariate analysis, particularly with response surfaces. I saw this at other places too, like Baxter and DuPont.
3. BBN and others on my journey stressed the importance of software reliability. It is interesting to note – and somewhat sad to an educator – that BBN emphasized "information empowerment" in software to compensate for the declining level of math and science skills among the American workers.
4. Like Banks, I found geometric conformance important, not only for tolerance specifications, but often to achieve "error-proof" assembly of products.

Applied Statistics M.S. Programs

I am not as certain as Banks is that the "Master's programs are already tightly packed." I guess they are packed if we want to continue to teach students as if all of them are going to be professors at Berkeley. This, however, seems ridiculous to me; let's think more about what students are going to be doing in *their* futures and construct programs accordingly.

Most of our incoming graduate students should in their first year take sequence courses in both statistical theory and applications (usually regression and design). If a student is to be a Ph.D. student, he or she should take a third sequence in mathematical analysis. However, for a terminal M.S. student, I have proposed in my report of my quality journey a third sequence in "appreciation of statistical thinking," taking into account the other statistics courses that they are taking simultaneously. Topics included in this two-semester sequence are the following.

- Collecting data (sampling surveys, design of experiments)
- Quality culture (philosophies of Deming, Juran, etc.)
- Use of quality teams and minute papers for course improvement
- Seven basic tools (including control charts, capability indices and understanding of common and special causes)
- Scientific method (plan-do-check-act)
- Importance of understanding variation and prediction
- More graphical skills
- Communication and people skills
- Working on project from beginning to end
- Case studies of important problems
- Time series (in particular, exponential weighted moving averages)
- Computers and appropriate software
- Basic multivariate analysis
- Messy and large data sets
- Ridge regression, Taguchi methods, response surfaces, nonlinear regression
- Simulation, bootstrapping and so on.
- Cluster analysis, classification.

I believe that this list includes most of the topics Banks wants to teach, at least in a superficial way. As different from Banks, however, I would teach some TQM because I believe that it is important for our students to have some understanding of these principles and the gurus involved in the quality movement. That is, I would like to think that our students would have heard of Deming, Juran, a fishbone, a Pareto chart and benchmarking when they go to industry. Just like they may not be an expert in bootstrapping, they would at least be exposed to some of this terminology associated with TQM.

Banks and I do not differ too much in our views. For example, I also note the consulting activity advocated by Boen and Zahn and their stress on good oral and written communication skills. I think that our problem is introducing this in our programs. In the fall semester, 1993–1994, under a "topics" course number, I plan to give one semester of such a sequence as a trial. I hope that all new applied masters students as well as those interested in our Quality Management programs, will take the course. Not every faculty member, however, agrees with me, and I might be disappointed in the enrollment. I will have more facts in January of 1994 and maybe even by that time have enough students interested in a second semester of such a course, given by a more qualified instructor than Hogg. At least I am following Bob Galvin's advice of "Damn it, do it."

Personal Quality Improvement

After studying all of the ideas from TQM, I am convinced that the only way to improve quality in manufacturing, health and education is to begin with the individuals who are involved. As I left Bob Galvin's office, he reminded me that quality is very personal. People can establish visions, aims and missions for themselves. They can immediately start collecting personal data and discover what "defects" regularly impede them from moving toward their vision. They can then work continually to reduce these personal defects. Once everyone in an organization feels this way, the infrastructure to achieve everything a committed CEO wants has been established.

Even at 68, I am trying to improve every day. So while my trip to organizations practicing continuous process improvement is finished, my own quality journey is far from over.

Comment

Vijayan N. Nair and Daryl Pregibon

Our views and experiences are quite different from those portrayed in David Banks' article. We are much more optimistic about the future of industrial statistics. A broad view of industrial statistics includes applications in science and technology that includes manufacturing, software production, business and marketing and service industries. All these areas share a common need for information, the raw materials of which are data. From the perspective that statistics is the science that transforms data into information, we

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