sional in industrial environments, and hence of greater significance in the relationship between industrial and academic statisticians, is economics – costs, revenues, profits, patents, intellectual property rights. Proprietary restrictions on data and results contrast sharply with many academic statisticians' experiences and, coupled with a bottom line emphasis, are sometimes viewed as unscientific.

Banks writes in Section 5: "[I]t is my impression that students at all levels should anticipate a credential deflation upon graduation." The ensuing paragraph appears to accuse the typical non-academic employer of underestimating the expertise of a newly employed statistician, while exempting academic employers of such underestimation. I have a fairly good memory of my start at Bellcore, and credential deflation was not an issue!

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Comment

Gerald J. Hahn

Wow! This article is a commentator's delight! It packs in more provocative ideas – and probably succeeds in offending more readers (from CEOs to Californians) – than any paper I have ever read in a technical journal; moreover, it does so in an IMS journal – not exactly a hotbed of radicalism! Its broad title "Is Industrial Statistics Out of Control?" is, in fact, too modest, and somewhat rhetorical. The author takes on academic statistics as well, and throws in five book reviews to boot! The article makes enticing reading – like a good novel, I found it hard to put down. And, amazingly, I found myself agreeing with many of the author's points! I am more competent to discuss Banks' remarks on industry than on academia – but that does not stop me from commenting on both.

FIRST SOME PLAUDITS

Add my "hear, hear" to:

- "Intelligent use of simple tools will achieve about 95% of the knowledge that could be obtained through more sophisticated techniques."
- "The real danger in the ubiquitous Taguchi cult is that industry users may copy the inefficiencies as well as the insights." I also welcome the increased appreciation of planned experiments that has accompanied the Taguchi fervor, but, like other statisticians, am dismayed at the combative attitude toward past work of some of Taguchi's more avid supporters.
- "Companies ... must have access to Ph.D. level statisticians, who may not be developing new theory, but can comfortably command the old." What is frequently needed are extensions of current methods tailored to the problem at hand.
- "Contrary to most students' beliefs, defining the problem can be the greatest service the statistical consultant provides; this task is often fluid, difficult and without unique solution. Unless students see this process for themselves, they usually think in terms of end-of-the-chapter exercises and struggle to find an exact match between a recently taught tool and the client's naive statement of the problem."
- "New industrial statisticians should be prepared to quickly build a very deep understanding of the industry that employs them." A solid scientific background is extremely helpful in this regard.
- "Superficial exposure to a great range of methods (cluster analysis, ridge regression, CART, the bootstrap, etc.) may be better education than the current drill in the mathematical consequences of sufficiency, Fisher information and the strong law of large numbers." Modern statistics is much broader than what can be embedded in one, or even many, Ph.D. programs. While academics can, to some degree, choose their own playing field, industrial statisticians cannot. Thus, the most industry can expect from an academic program is that it builds fundamental understanding, exposes students to a wide variety of important areas – and then helps them develop the skills to rapidly learn more as needed.
- "Some academic statisticians regard most indus-

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trial statisticians as the ones who were not good enough to succeed at a university." They might even be right – although I might word it a little differently! Graduates suited for industry are likely to become impatient with the academic environment and slow pace of the university. High grades is *one* of the things that we, in industry, look for in candidates – but it is only one of many. We need excellent communicators (who can talk in their customer's language, rather than in statistical jargon), good listeners, hard workers, team players and fast learners. We look for people who are enthusiastic, who are willing to work simultaneously on multiple projects, who are self-confident – without being arrogant, who can rapidly diagnose a problem and see the big picture, who are willing to ask fundamental questions and challenge assumptions, who are good at selling projects and themselves, who can cope with frequent management reviews and changes of direction – and who are still cheerful at the end of the day. It is not an environment that is conducive to proving theorems – but it is hectic and exciting!

AND NOW FOR SOME RESERVATIONS

- I feel few statisticians really believe that the Japanese "use sophisticated quality control methodology." Instead, they agree with the author that the Japanese success has "rested almost entirely upon rudimentary statistical methods." So what? The fact that the methods are rudimentary does not make them any less statistical.
- "Information from the customer or assembler regarding noncompliant parts . . . seems to be the only appropriate basis for estimating change in the number of bad parts produced." This suggests the reactive approach of the past, rather than the proactive environment we should champion.
- "Partial least squares is a hot area in industrial statistics." Maybe it should be, but I cannot say that it is. I do agree that "it is now widely used in chemometrics."
- "Technical proficiency can be a liability in statistical practice." The fact that some world class statisticians cannot be trusted with data is, in my opinion, despite their proficiency and not because of it.
- "Of more conventional subjects, it seems that survey sampling is not ubiquitously used, nor are any of the more mathematically athletic aspects of time series." Students going into industry should have training in time series – many applications require understanding how processes change over time. As for survey sampling, a solid appreciation of different sampling strategies both provides improved general understanding and is useful in its own right, even though we may not always be sampling human populations.

FUTURE DIRECTIONS

If industry is concerned merely with short-term payoffs, the only support that academics can reasonably expect is as consultants in responding to immediate crises when in-house talent is not available. This should be a growth area – as industry moves to "leaner staffs" and fewer in-house specialists.

But what if industry, or, for that matter, government is willing to extend its interests beyond the immediate? I agree with Banks that there is limited demand for marginal enhancements or extensions of already highly exploited narrow technical areas. However, there are wider horizons that warrant exploration.

The challenge is clear. Why did we wait for Taguchi to suggest test plans to help design products that are robust to variability in the manufacturing and use environment? Why have neural nets become principally the domain of electrical engineers, when in fact, they should be another weapon in our arsenal – to whose further development we can, in fact, contribute? Why is it taking us so long to recognize that statistical process control and automatic control theory are not two separate competing technologies, but should be integrated to the benefit of all?

One reason why we have been so slow on the uptake is the introverted environment in which academics operate. Topics for research, especially for Ph.D. dissertations, are often determined, not by finding out what is needed by users, but by examining past research to see how the results might somehow be extended (irrespective of whether such extension is needed). A high premium is placed on solution tractability – especially if it can be achieved by clever mathematics. For many years, major research in product life data analysis focused on the exponential distribution – not because this model has much practical relevance, but because the underlying mathematics is "doable". It would, however, be unfair to put all the responsibility on academics. We, in industry, have also been remiss in articulating the issues and needs.

So what are the new horizons? I agree with the author's list of research topics, but I would like to step back and suggest some elements of the broader environment that should guide us.

Leading the Charge for Proactive Improvement

Traditionally, statisticians are number counters. In industry, they were – and sometimes still are – called in only *after* the problem to measure the damage and to assess the value of short-term corrective actions. With the drive for continuous quality improvement has come the recognition that statisticians are more than (to use Herb Ginsberg's terminology) coroners that sign the death certificate. Although we may enter the scene reactively, we must push for a proactive role in helping identify root causes to avert problems and providing early warning signals to minimize the impact of those problems that have slipped through. In short, we need to be part of the team of problem solvers, and problem researchers, rather than passive consultants.

Responding to the Challenges of Rapid New Product Introduction

The reduction of the elapsed time between the decision to develop a new product and its large-scale manufacture is today a key item on management's agenda. Rapid product introduction, however, carries with it the danger of prematurely bringing to market a product that fails to meet high quality and/or reliability standards. Thus, a technology for rapid new product evaluation is also needed. This technology must be sequential so as to work in parallel with new product development and be responsive to design changes. It may require new concepts for accelerated testing, based upon physically reasonable models. Indeed, the areas of product life data analysis and accelerated testing provide important opportunities for statisticians.

Making Statistics More Robust to Use by Nonstatisticians

There is a saying among industrial practitioners that "statistics is too important to leave to statisticians." As the author has pointed out, this is the Japanese viewpoint. The general availability of user-oriented software, from spreadsheets to statistical languages, makes statistics readily accessible to nonstatisticians, whether we like it or not. (We should like it, because, despite the pitfalls, it is the right way to go and should leave us time to attend to more challenging – and proactive – tasks.) Also, we are successfully imparting more literacy at an earlier age. (A 12-year-old recently lectured me about the advantages of the median over the mean as a descriptive measure.) One of the challenges, then, is to help get the "right stuff" into computer programs – to provide practitioners general insights and to reduce the likelihood of leading them astray. That includes encouraging more incisive graphical displays and playing down statistical obscurities, such as measures of kurtosis, in the outputs. All of this might seem somewhat mundane to some academics, but just because a method is easy to use does not mean that it is easy to develop. Software for designing experiments presents special challenges and emphasizes the difference between what a computer can readily do, such as generating a matrix of test points, and what it cannot, such as recognizing nesting and split plot situations.

Meeting the Challenges of a "Data-Rich" Environment

In many applications, we have moved from the case where the major challenge is to squeeze the maximum information from a limited data set to one where we are data rich; in fact, the ability to collect data often outstrips the capability to convert such data into useful information. Our concerns, today, are a great deal less with statistical efficiency – and a lot more with gaining understanding and helping protect the general user from pitfalls and narrow assumptions. Our approach needs to be amended accordingly.

Extending our Horizons in Familiar Terrain

I agree that adding a few new technical wrinkles to infrequently used experimental designs or embedding in control charts more mathematical sophistication than is warranted by the underlying assumptions is of questionable value. However, the general topics of experimental design and statistical process control are far from devoid of interest to teachers and researchers. We just need to look more broadly. For example, how can we extend the concepts of experimental design from lab-type studies to expensive, large-scale testing, often subject to severe practical constraints, such as for aircraft engines or steam turbines? Or how can we adapt experimental design concepts to make them most useful in service industry applications? Or how can we extend SPC concepts to deal with a wide variety of practical situations, ranging from the manufacture of small batches to processes with automatic readings that provide data every second? And, for that matter, how can we effectively build more "long-term memory" into control charts?

Improving our Understanding of How to Conduct and Evaluate Analytic Studies

Deming has emphasized the difference between what he calls "enumerative studies" and "analytic studies." Enumerative studies are generally assumed in our courses and research. In such studies, one usually takes a random sample from an existing, finite, well-defined population. However, many practical investigations in industry, including most experimental investigations, involve analytic studies. In an analytic study, one observes the current process with the goal of making predictions about, or improving, a future, usually different, process. The assumptions underlying statistical inference for an enumerative study are inappropriate for an analytical one. We need a better foundation for both the evaluation of analytical studies and their planning so as to make them sufficiently broad. Also, as teachers, academics need to instruct their students about the differences and the consequences.

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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