industrial statistician. He quite rightly identifies the need to build a very deep understanding of the industry which employs them. This remark stimulated me to go back and read again Hahn and Boardman's (1985) excellent *Amstat News* article on the statistician's role in quality improvement. There is little point in quoting selectively from it. I think it is worth reading from time to time no matter how clever and experienced a statistician we think we are because it focuses on the personal traits we require to be effective as industrial statisticians.

David Banks presents confusing messages about TQM, perhaps in an attempt to be provocative. He may be right to claim "that there are dozens of definitions of TQM, but none with any mathematical precision," but it is clear to me that Dr. Deming's philosophy provides a well-defined and consistent approach which can be applied successfully in any industry (not without sustained effort over many years). I am certain that the long-term gains from TQM will not, as seems to be claimed, be realised by "any new theory of management."

Being provocative may stimulate thought but I think a potential industrial statistician reading "TQM correctly shifts corporate attention to the customer, at every level of the business. From the TQM perspective, each employee is a two-legged profit machine" will develop quite the wrong attitude toward management and the role of statisticians in improving their employer's business. This is because TQM is about the management of people. It may be easier to see this in service industries (which now account for well over half of GDP in developed countries) but it applies equally to manufacturing. Reading *Out of the Crisis* helped me develop as a manager and I am sure corporate executives will benefit from it too. If nothing else, it should teach them not to look at employees as two-legged profit machines. Dr. Deming's advice on driving out fear, instituting training and removing barriers is all about improving people and their working environment. It may be true that any good manager can apply the nonstatistical aspects of a TQM philosophy. Statisticians should realise that they can do that and more, because we should have good analytical intelligence and the knowledge to select and use appropriate techniques. This is why we can make a unique contribution, if our attitude is right.

Although I have concentrated my remarks on TQM, I know that industrial statistics is not just about TQM and that it is important to have some statisticians who can apply advanced techniques (incidentally, I agree entirely with what David Banks has to say on the topics needed to be covered in industrial statisticians' training) but I am sure we can contribute more if we can dispel fear and can institute training in the simple techniques which are central to most process and product improvement schemes. By doing so we will ensure that industrial statistics continues as a growth industry – whose products are appreciated by contented customers.

Comment

G. K. Robinson

It is good to see such a candid article on industrial statistics. I agree with David Banks that the way forward is to discuss our problems and uncertainties frankly and honestly.

I have little direct knowledge about industrial statistics in the United States. However, it seems reasonable to assume that Australian experience is relevant, since many senior managers in the two countries have been influenced by the same consultant gurus.

The first of my comments is to suggest that Banks has ignored the fundamental question of whether statisticians should take a role in changing the managerial climate, the second looks at the overall thrust of Banks' article from a different viewpoint and the third refers to Taguchi's work.

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1. THE ROLE OF STATISTICIANS IN CHANGING THE MANAGERIAL CLIMATE

Deming (1982), Joiner (1985), Hahn and Boardman (1985) and others have argued that statisticians have an important role to play in changing the managerial climate of enterprises in ways which are often referred to as "Deming's 14 points for management" or as Total Quality Management (TQM). Most statisticians have not thought about this view or consider it to be an overstatement. However, the statisticians that agree

with the view are an extremely influential group who should not be ignored.

Let us refer to industrial statisticians who spend their effort trying to change the managerial climate in the enterprises with which they are working as *management statisticians* and to industrial statisticians who do other types of industrial consulting as *problem-solving statisticians*. Many industrial statisticians are problem-solving statisticians for the majority of their consulting time and management statisticians for a small part of their time.

Banks has not expressed a view as to whether statisticians should play an active role in changing the managerial climate. My view is that statisticians should be active in changing the managerial climate, but that apprenticeships as problem-solving statisticians should be served first. Also, problem-solving statisticians should endeavour to become familiar with the activities of management statisticians.

Part of the rift between industrial statisticians and academic statisticians is that most academic statisticians have no understanding of the possible managerial-climate-changing role for industrial statisticians.

2. COMPARISON WITH OTHER AREAS OF APPLICATION

Questions that seem to interest Banks although he does not explicitly raise them are "Should the statistical profession be particularly concerned about industrial statistics?" and "Are the difficulties associated with industrial statistics comparable to those of other consulting work?"

Some of the characteristics of industrial statistics relevant to these questions are as follows.

Importance

The task of making enterprises more efficient and profitable is undeniably important. Both management statisticians and problem-solving statisticians can contribute to it. Much other statistical consulting is also important but if willingness of customers to pay is used as the criterion for judging importance then management statistics is probably the most important area of statistical consulting.

Need for Simple Methods

Banks has stated the view that the benefit of statistical methodology to the Japanese economy seems to have been achieved mostly by the widespread use of very simple statistical ideas. An alternative view is that the managerial climate associated with the use of the "seven tools" has been of benefit to the Japanese economy. Under either view, it seems that much of the statistics which is of use in industry is elementary by the standards of academic statisticians. Complicated statistical ideas are undoubtedly of use for some problem-solving statistical work, and Banks has listed some important areas. I think that the statistical profession should also present the view that expert statisticians are better at using simple statistical methods than non-statisticians – just as a qualified structural engineer is employed to perform the trivial-to-an-expert calculations to check that the roof of your house is strong enough.

Respect from Clients and the Need to Serve Apprenticeship

I agree with Banks that "[n]ew industrial statisticians should be prepared to quickly build a very deep understanding of the industry that employs them." Problem-solving industrial statisticians need to understand the industries that employ them just as statistical consultants in other areas do. However, management statisticians must learn about management as well as learning about the industries in which they are working.

Problem Ownership

Problem-solving statisticians ought to own parts of the problems that they are involved with, in much the same way as statistical consultants in other areas. Often this means being part of a team which collectively owns a problem. Management statisticians must take some ownership of the problem of changing corporate culture.

Relevance of Current Research by Academic Statisticians

I agree with Banks that the gulf between academic and industrial statisticians is great. Banks highlights the fact that much of the technical content of statistics courses is not appropriate for statisticians who will be employed as problem-solving statisticians. This is true, just as it is true for statisticians who will be employed in other areas. However, industrial statisticians, being familiar with the principle that productive activities should attempt to satisfy their customers, tend to be more forthright in saying how they would like academic statisticians to change. Management statisticians are unlikely to be interested in the current research of academic statisticians.

3. TAGUCHI'S CONTRIBUTIONS

Taguchi's many contributions are not of equal value. As stated clearly by Box (1985), Taguchi's quality engineering ideas are very valuable. These include his contribution to the use of squared error loss rather than specifications, his use of "parameter design" to reduce variability and to reduce sensitivities and his use of "tolerance design" to make cost-effective choices.

I believe that his packaging of fractional factorial designs is of some value. Its advantage over the usual

presentation is that fractional factorial designs can be laid out with less effort. This way of presenting fractional factorial designs uses orthogonal arrays, linear graphs and interaction tables. Variations to this way of presenting fractional factorial designs have been suggested by Tsui (1988), Wu and Chen (1992) and Robinson (1993).

In contrast, Taguchi's method called "accumulation analysis" has been shown to be inferior to the alternatives and should be ignored. See Hamada and Wu (1990) and the subsequent discussion.

I agree with Banks and with Box (1985) that industry should try to profit from Taguchi's insights but not suffer loss by copying inefficiencies.

Comment

William H. Woodall

This paper by David Banks serves a useful purpose in provoking discussion of some important ideas in industrial statistics. Many of Banks' comments are needed to counter some of the more exaggerated claims of those overselling TQM, SPC and designed experiments to industry. The audience of the paper is most likely to be academic statisticians who are not heavily involved in industrial applications. Because some readers may not be familiar with industrial statistics, I offer a much different view of process monitoring and control charting.

CONTROL CHARTING

Banks' radical, and perhaps overstated, opinion is that most research on control charting is useless and work in the area should be discontinued. This opinion is based, however, on an unrealistic premise. Although I agree that much of the information regarding process performance could be obtained by appropriate time series plots, knowledgeable process engineers are very rarely, if ever, available to regularly review plots and think about process performance. In industrial applications, one or more less-experienced operators are responsible for maintaining a number of charts. Increasingly, the charts are computerized. Under these conditions, a process engineer is called in only if a chart exhibits unusual behavior calling for investigation. With operators or computers, guidance in the form of control chart rules is required. Although there is no substitute for knowledge of the process, the fact that some decision rule is needed for ongoing monitoring is an unavoidable fact of life in practical applications. Much of Banks' criticism of research on control charting appears to stem from the assumption that no decision rules are needed with a time series plot to form a control chart.

Given that some rules are needed, the issue becomes rule selection. Standard Shewhart charts with 3σ limits are the most commonly used charts in industry. These charts have served industry well, but they are often used inappropriately. They can be very misleading in some applications, such as those involving autocorrelated data or several components of common cause variability.

Banks' brief description of the EWMA control chart is not accurate. He states that the EWMA chart of Roberts (1959) "examines residuals from a forecast of the process based on the discounted past." Actually, the EWMA control chart has limits which are based on the assumption of independence of the observations over time. It is easy to confuse this traditional EWMA chart with the forecasting methods recommended by Montgomery and Mastrangelo (1991) for autocorrelated data.

With the exception of that of Reynolds et al. (1988), Banks dismisses research on control charting as having corrupted a good idea. Since Banks chose work on the trend rule by Davis and Woodall (1988) as an example of misguided theoretical particularization, let us briefly summarize the contribution of this paper so that the reader can decide if Banks' view is correct. A trend rule signals that a process is not in statistical control if a specified number of consecutive points on a Shewhart chart are either all increasing or all decreasing. The trend rules were added to improve the detection of gradual drifts, or trends, in the mean. The trend rule based on seven points is one of two supplementary rules recommended by Deming (1986, p. 321). This rule is also widely used in the automobile industry in the U.S. and Europe. Davis and Woodall (1988) show, however, that the trend rule is ineffective in detecting trends in the underlying mean of the process. With the underlying variability of the quality characteristic, the Shewhart control limit is almost always crossed before

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