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.

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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 the trend rule signals. Matching the false alarm rates of the competing charts, it is more effective to narrow the Shewhart 3σ control limits to detect a trend in the mean than to use a trend rule. It has never been demonstrated under any model, realistic or not, that the trend rule is effective with the Shewhart $\overline{X}$-chart. Thus, Davis and Woodall (1988) recommended that its use be discontinued. Use of the trend rule does not appear to be a good idea.

There are some more important issues that can lead to significant improvements in the way control charts are applied. Traditionally, the concept of "statistical control" has included only the case of independent and identically distributed observations over time. Much of the current research on control charts is to generalize this concept to be more realistic in some important practical applications. For example, some generalizations account for the autocorrelated data common in process industries or the several components of common cause variability found in semiconductor manufacturing. In other applications, charts based on regression-adjusted variables are needed. Much of this research has been initiated by industrial statisticians. Box and Kramer (1992), Rowlands and Wetherill (1991), Montgomery (1992), and Woodall and Faltin (1993) summarize these and other recent directions of research on process monitoring.

It must seem strange to mathematical statisticians that the use of statistical models with control charts is an item of considerable debate. Even though Deming (1986) recommends control chart rules, he rejects statistical models. He states that operating characteristic functions and alarm probabilities, for example, have no meaning because no process is steady and unwavering in practice. Even though the assumptions of a statistical model are never met exactly, it is a mistake to reject modeling. If we do, then meaningful discussion of the merits of competing methods is impossible and one has no logical arguments against such questionable, ad hoc methods as PRE-control. Theory can never correspond exactly with reality, but it can lend insight into the solutions of practical problems.

RESEARCH TOPICS

In my opinion, there is a continuing need for research on process monitoring. Methods must be adapted to changing production processes and measurement systems. One should not put much weight on whether or not any one individual sees profoundly new ideas on the horizon here or in the theory of designed experiments. In addition, research which makes incremental gains can be very helpful in leading to a better understanding of existing methods and to more effective implementation. The direction of research in the traditional areas clearly needs some reorientation, but these areas will continue to be important due to the profound effects they can have in practical applications.

There are some points regarding Banks' discussion of high-dimensional response surface analysis that need further explanation. It appears that this approach is based on observational data from the process. Because many important variables will be controlled to targeted set points, it will not be possible to study main effects or interactions involving these variables. Thus, it is not clear how better set points could be obtained. It is very difficult, in general, to establish cause and effect relationships using observational data.

I disagree that research statisticians can make little contribution to stable processes. Even stable manufacturing processes that have been in operation for years can sometimes be improved with a corresponding increase in profit and a strengthened competitive position. In some industries, such improvement is necessary for survival.

To add to Banks' list of important new topics, I encourage readers to investigate the use of fuzzy methods and neural nets. These methods are becoming widely used in industry and often compete directly with traditional statistical methods. The performance of fuzzy methods and neural nets have not been adequately studied, however, and thus these areas present numerous opportunities for valuable research topics. Laviolette and Seaman (1992) provide an insightful perspective on the evaluation of fuzzy methods.

INDUSTRIAL PRACTICE

I agree with Banks that U.S. industry could benefit from the more widespread use of simple statistical methods. There is an important role, however, for more highly trained statisticians to focus on the more challenging applications. These applications may be rarer, but can provide opportunities for substantial payoffs. In these cases, the statistician must not only know the relevant statistical methods, but also must be able to map these effectively to the real processes. This skill is difficult to teach, but it can be demonstrated through the use of well-written case studies.

ACADEMIC ENVIRONMENT

Academic statisticians are rewarded primarily for publishing papers. (As Banks states, in some departments the more abstract results are, the better.) It is not realistic to hope that research contributions will become more directly applicable in industrial applications until there is a change in the reward structure. Of course, it should be clear from my discussion of Banks' article that there can be a considerable difference of opinion over what is practical research and what is not. Unfortunately, there is also little incentive for academic statisticians to collaborate with those in industry to write case studies. Case studies are needed to show the rewards of resolving the often challenging practical issues required to apply statistical quality improvement methods.

TEXTBOOK REVIEWS

I have taught several courses using editions of Montgomery's (1991) textbook and one course using Ryan's (1989) textbook. Montgomery's book was preferred because Ryan provides insufficient background on some important topics, referring the reader too often to outside sources. Montgomery (1991) also provides better exercises. The material on control charting in Montgomery's book could benefit, however, from some updating. For example, the simple CUSUM chart design method of Johnson (1961) could be replaced by a much more accurate method using the results of Siegmund (1985, p. 27).

Montgomery (1991) covers acceptance sampling in detail, but it is unlikely that one would want to emphasize this area in an introductory course. Vardeman (1986) gives a thorough discussion of the role of acceptance sampling in modern industrial practice.

Comment

C. F. J. Wu

In this paper, the author gives a biased view of industrial statistics. It is a hodgepodge of book reviews, comments on research and Japanese quality practice and an attack on academic statistics. It attempts to do too much and does it poorly. Some of his opinions are not based on thoughtful research. They are incorrect, misleading or superficial and can have a damaging effect. It sends conflicting and confusing messages. I do not recommend this paper for serious readers in industrial statistics. For the unfortunate few who will read this paper, I would like to provide the following comments.

DOES STATISTICS PLAY A SMALL ROLE IN PRODUCT QUALITY?

His opinion appears to be based on the writings of some Japanese economic historians. There is ample evidence to the contrary by many eminent Japanese quality experts such as the late K. Ishikawa. Widespread use of basic statistical tools (which is made possible within the TQM framework) and statistical thinking (which the author chooses to ignore) are some of the key factors in Japan's quality success. The Japanese contributions are not limited to simple tools. Some of the advanced quality methods/tools were developed and successfully applied in Japan; these include robust parameter design and quality function deployment. A comparison between JUSE and ASQC provides additional support to my point; JUSE sponsors many statistics-related activities such as short courses and study groups on emerging methodologies. By comparison the statistical level of ASQC-sponsored activities has remained low for a long time. Many eminent applied statisticians in Japan have been and are active in JUSE. The same cannot be said about ASQC.

COMMENTS ON THE SEVEN TOOLS

Obviously the seven tools are very simple but the author fails to understand or appreciate the Japanese contributions. How and why did JUSE choose and package these seven tools from among a large number of candidates? As great practitioners, the Japanese (in this case, JUSE appointed a special committee to take charge) studied how various tools were used in practice and after several years of study, chose these seven to be widely promoted. It is the process of selection rather than the final product that explains their success.

COMMENTS ON "CONVENTIONAL" TOPICS IN INDUSTRIAL STATISTICS

This is the worst part of the paper. The word "conventional" is misleading. Many of the novel ideas in experimental design including robust parameter design are not conventional. Regarding experimental design, he says that it is "hard to see profoundly new ideas on the horizon." The most notable counterexample to this claim is Taguchi's contributions to robust parameter

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