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ABSTRACT The objective of this article is to discuss the role and use of statistical process control (SPC) in quality systems, especially when there is an automatic process control (APC) in place. SPC, along with APC, can be used as a process monitoring system to signal deviations from the expected behavior of the process. The idea for this article was triggered by the article by G. Vining (2010) entitled "Technical Advice: Statistical Process Control and Automatic/Engineering Process Control."

KEYWORDS automatic/engineering process control, process monitoring, statistical process control

DISCUSSION

In the early 1900s, Fisher (1956/1990), Snedecor (1956), and others were developing the concepts of experimental design and analysis. They concentrated on determining which controlled factors under a fixed, finite number of conditions were having an effect on the selected response variable. They compared the mean square of each factor with the mean square of the "residuals" and developed the F test of several variances to provide for a statistical test of a factor. This approach is known as *analysis of variance* (ANOVA).

Shewhart (1931), in the United States, and Tippett (1931), in the UK, began working in statistical quality control (SQC; now statistical process control, SPC) around 1920. Shewhart and Tippett were interested in determining the stability of an ongoing process. Stability was seen as meaning no jumps in either the mean or the variance of the selected process variables. If there were any such activity going on, the output would have additional variation that might well cause problems with either internal or external users of the product. They developed a scheme that was analogous to ANOVA but concentrated on producing time-oriented charts to display the analytical results. (This SPC approach was later used by Ott [1967] to develop the concept of analysis of means [ANOM].) The idea behind the charting was to make the results easily understood by factory floor people whose mathematical skills were not highly developed. ANOM benefits from the approach of SPC by emphasizing the charting approach to the ANOVA solution.

The SPC approach is to chart both the average and standard deviation of successive small samples (referred to as *subgroups*) from the process on a

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more or less continual basis. Thus, SPC falls more into the area of time series analysis than experimental design. The limits for the charts were set up to include the random variation of the two statistics, provided that there were no changes from their historical levels (the analog to the residual sum of squares of ANOVA). A point outside the limits for the sample averages, for example, was deemed to have wandered too far from what was to be *expected*, given the past history point (the analog of the "between" sum of squares of ANOVA). A point outside the limits would indicate that something unexpected had happened that would cause excess variation in the system. This event, known as "out of control", is an analogous situation to the ratio of "between mean square" to the "residual mean square" of ANOVA being significant. In the ANOVA world, the conclusion would be that the variable "time" has a significant effect on the average of the response variable. In the SPC world, the proper thing to do is to explore what was going on when the unexpected average value occurred and capitalize on that information – do more of what happened if it would result in process improvement; do less of what happened if it would lead to process deterioration.

The name of this activity was changed from statistical quality control to statistical process control to broaden the use to problems other than the quality of manufacturing operations. Those suggesting this change missed the opportunity to change *control* to a term—for example, *monitoring*—that is more in line with the job that SPC was designed to do. The use of the word control not only encourages the misuse of SPC but aggravates the process control community greatly: "We're already doing control, stay out."

To summarize the situation: statistical process control is applied to the activities of those engaged in hunting for the causes of unexpected results in the sample data that, if identified, might lead to process improvement. SPC is not meant to provide any sort of automatic process control (APC).

On the other hand, APC has, generally speaking, the task of making the process average achieve some target value for the process. As such, it is constantly moving the average value should the indication of the process average fall outside a "dead band." Extensive studies are done on comparing and integrating SPC and APC. For example, there are several articles on this topic in Volume 34 of *Technometrics*, including those by Box and Kramer (1992), Hoerl and Palm (1992), and Vander Wiel et al. (1992). Hoerl and Palm (1992), for example, reiterated that the fundamental issue is not choosing SPC or APC but how to integrate them effectively. Deming (1944) also suggested that "good engineering control of the process" (p. 173–177) must be part of any quality control system. Other selective references on this issue are Montgomery et al. (1994), Box et al. (1997), Tsung et al. (1999), and Jiang and Tsui (2002).

APC is thus moving the process average deliberately, whereas SPC is simply looking to see whether the process average is changing from its expected value. Thus, if one were to apply an X-bar chart to an APC process, the answer would almost invariably be "yes." If you understand the question being addressed by SPC, i.e., is the process average changing from its intended value, you would not apply an X-bar control chart to answer the question to which you know the answer without an X-bar chart, would you?

Now lest you think that APC people are unique in this type of activity, think of the Six Sigma program that takes as one of its basic tenets that a process average can be expected to vary ± 1.5 times the short-term standard deviation. Thus, a foregone conclusion from using an X-bar chart on a Six Sigma project is very clear: the chart will show process average shifts because you allow it to shift.

What is missing is that the SPC question is "Has something unexpected happened that we may capitalize on to improve the process?" The question being addressed is not "What corrective process action must be taken based on the data?"

Now that leads to an interesting question: "What is the place of SPC in an APC plant?" The answer is rather simple. You must determine what you expect from APC and then use SPC to monitor it for changes from what was expected. What to expect from an APC process is readily obtained, in the sense of SPC, by using autoregressive integrated moving average (ARIMA)-type models to determine what the expected process performance is and then perform an SPC type of analysis on the difference between what you expected and what you got; see, for example, works by Holmes and Gordon (1992), Alwan and Roberts (1988), Alwan (1991), and Montgomery and Mastrangelo (1991) and some articles in the 1997, 29(2) of the *Journal of Quality Technology* on this issue.

An example might help. A process has as one of its elements a very large starch tank. The viscosity of material in the tank is being controlled by a well-developed APC system. In some fashion, a frozen carp gets thrown into the tank. The APC system responds as best it can to maintain the target value for the viscosity; being an excellent system, it digests the carp and the process continues. The APC system does its job. The SPC system, however, would signal that the APC is having trouble, and a study would be undertaken to find out what might have happened and, in this case, eliminate the cause—find a way to keep the carp out of the tank in the first place.

EXAMPLE

We will try to demonstrate our point with a numerical example that was used in one of our papers (Holmes and Mergen 2008). The data (given in the Appendix), which are disguised to maintain confidentiality, are on the diameter of sequentially machined hubs from a machine shop producing brake drums (collected maintaining the time order). The control chart's application indicated that the time series data are not in control; that is, not stable. This was tied to the fact that there is an automatic control mechanism in the shop that adjusts the process automatically. This, in return, creates an autocorrelation in the data. The autocorrelation function shown in Figure 1 supports this.

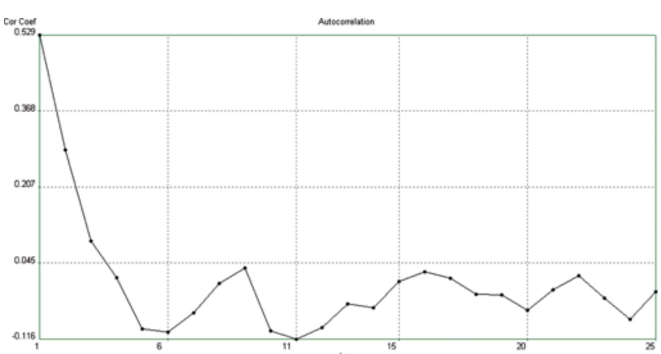

FIGURE 1 **Autocorrelation function for the data. (Color figure available online.)**

Thus, we fit a first-order autoregressive (AR) model to model the autocorrelation in the data and calculated the error terms, e_t, (i.e., the residuals) as follows:

$$\widehat{X}_t = 1.395 + 0.53X_{t-1}$$

$$e_t = X_t - \widehat{X}_t$$

where X_t is the actual observation and $\widehat{X}_t$ is the estimate at time t.

A significance test, such as the Durbin-Watson test, showed that this is a good fit. Thus, the process behaves according to the AR model given above. Then the correct question to be checked by the control chart should be "Does the process deviate from its expected behavior, that is, in this case, from its AR model?" Thus, when an X-bar chart and R chart are applied to the residuals, the results show that the process is in control; that is, behaving as expected.

SUMMARY

In summary, the question to be checked by the SPC should be "Does the process deviate from its expected behavior?" SPC, despite the existence of word control, should therefore not be seen as a control system but rather as a monitoring system that signals deviations from the process's expected behavior, whatever that may be.

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APPENDIX

Data on hub diameter

2.966	2.966	2.974	2.970	2.960	2.958
2.966	2.960	2.988	2.959	2.950	2.977
2.964	2.966	2.981	2.953	2.964	2.982
2.953	2.967	2.979	2.940	2.968	2.977
2.953	2.963	2.981	2.959	2.971	2.981
2.958	2.983	2.980	2.980	2.983	2.976
2.965	2.986	2.972	2.981	2.968	2.986
2.973	2.960	2.944	2.976	2.986	2.972
2.978	2.982	2.958	2.969	2.981	2.981
2.987	2.979	2.958	2.961	2.998	
2.977	2.978	2.952	2.953	2.974	
2.964	2.976	2.975	2.951	2.982	
2.966	2.976	2.976	2.948	2.987	
2.976	2.952	2.970	2.971	2.981	
2.967	2.973	2.968	2.960	2.976	
2.981	2.967	2.955	2.979	2.958	
2.983	2.980	2.944	2.972	2.950	
2.989	2.973	2.944	2.979	2.960	
2.979	2.970	2.973	2.976	2.964	
2.966	2.980	2.963	2.971	2.968	
2.965	2.983	2.960	2.976	2.978	
2.961	2.968	2.956	2.965	2.980	
2.968	2.955	2.965	2.967	2.984	
2.976	2.942	2.961	2.960	2.978	
2.973	2.955	2.968	2.962	2.966	
2.967	2.960	2.972	2.963	2.972	
2.964	2.962	2.973	2.961	2.975	
2.976	2.974	2.964	2.953	2.974	
2.965	2.968	2.966	2.964	2.977	
2.968	2.963	2.957	2.968	2.979	
2.968	2.967	2.968	2.959	2.978	
2.987	2.966	2.985	2.960	2.973	
2.976	2.963	2.976	2.972	2.971	
2.963	2.967	2.988	2.968	2.962	
2.964	2.964	2.984	2.990	2.956	
2.990	2.966	2.981	2.979	2.973	
2.995	2.964	2.967	2.964	2.968	
2.975	2.966	2.969	2.967	2.972	
2.980	2.987	2.978	2.978	2.969	
2.980	2.991	2.975	2.952	2.986	
2.966	2.975	2.964	2.962	2.977	
2.965	2.983	2.958	2.953	2.965	