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HAPPILY it is not necessary to be acquainted with the underlying basis for the Shewhart control chart in order to use it profitably. Here we shall take up a number of ideas, including discussions of the following statements:

(a) Shewhart charts are a graphical way of applying a sequential statistical significance test for an out-of-control condition.

(b) Control limits are confidence limits on the true process mean.

(c) Shewhart charts are based on probabilistic models.

(d) Normality is required for the correct application of an X chart.

(e) The theoretical basis for the Shewhart control chart has some obscurities that are difficult to teach.

Contrary to what is found in many articles and books, all five of these statements are incorrect.

Shewhart control charts are used to indicate the presence of causes that produce important deviations from the stable operation of a process. These causes have been called by Shewhart (1931, p. 14) "assignable" causes and by Deming (1986, p. 310) "special" causes. Signals of special causes indicate that a process is doing something which a stable process would not be expected to do. The analyst may find and act on causes giving rise to such signals.

When the existence of special causes is no longer indicated, the process is said to be "in statistical control". This implies an economic condition. In principle it would be possible to reduce the variation of the process, thereby revealing additional special causes. Initially, this may not be an economic option; but eventually competition may force it to be. It seems apparent from the preceding that being "in control" does not imply that only random causes remain; nor does it imply that the distribution of the remaining values is normal (Gaussian). More on these points later. What it does indicate is that the process is stable and, as a most useful consequence, predictable within limits.

Wheeler (1997) makes the following points. "As long as people see a Shewhart chart as a manual process-control algorithm, they will be blinded to its use for continual improvement. In keeping with this I have been using 'predictable process' and 'unpredictable process' rather than the more loaded phrases 'in-control process' and 'out-of-control process'. I find this helpful in two ways--predictability is what it is all about, and many people use 'in-control' as a synonym for 'conforming'."

It is all too frequently said that when a process is in control, all that remains is random variation. The fact that this statement is not true is clearly brought out by John Tukey (1946) who wrote of the confusion of control (in the sense of Shewhart) with randomness. He points out that the Shewhart control chart is not a means for detecting deviations from randomness.

He wrote, "This was not Shewhart's purpose, and it is easy to construct artificial examples where non-randomness is in control or randomness is out of control. A state of control, in Shewhart's basic sense, is reached when it is uneconomic to look for assignable causes, and experience has shown that the compactness of the distribution associated with a good control chart implies this sort of control."

Tukey then goes on to say, "There seem to be two reasons for this common confusion between control and randomness. First, bringing a process into control almost inevitably brings it measurably nearer randomness. Second, randomness is easily discussed in a simple model by a mathematical statistician; while economic control requires a complex model without any interesting or beautiful mathematics."

Shewhart did not base his choice of the 3sigma limit on any particular statistical distribution. It did not matter whether the underlying distribution was normal or binomial or Poisson or any other. Said another way, Shewhart charts are not based on any particular probabilistic model. In the words of Shewhart (1939, p. 54), "... we are not concerned with the functional form of the universe, but merely with the assumption that a universe exists." Even though Shewhart (1939, p. 142) says that once assignable causes have been eliminated, "... we can find a mathematical probability model upon the basis of which we can make valid predictions." He does not say that an assumed probability model is required for the operation of a control chart.

Shewhart's criterion for a special cause was simply a point beyond either the lower or upper 3sigma limit. Examination of 3sigma limits for various theoretical distributions shows that the probability of a point falling beyond the lower or upper 3sigma limit varies somewhat with the distribution. An extreme example: if process data are exactly normally distributed (a practical impossibility), the chance of a point lying above the upper 3sigma limit is 0.00135 for the X chart and 0.00915 for a range chart using subgroups of size two. Note that the corresponding average run lengths are 1/0.00135 = 741 and 1/0.00915 = 109. Shewhart was not, nor should we be, concerned with such exact calculations because the distribution of the process being controlled cannot be precisely known.

When additional tests for special causes were introduced for the X chart (Western Electric (1956) and Nelson (1984)), advantage was taken of the fact that the distribution of the subgroup means is approximately normal by virtue of the central limit theorem. Thus, the approximate statistical behavior can be found for those tests requiring normality. In this special case it could be argued that we have treated this as a probabilistic model; but due regard must be given to the rough way in which this, or any other model, approximates process data. Probabilistic models played no important part in Shewhart's general view of control charts.

Regarding statement (a) in the first paragraph, Shewhart (1939, pp. 30-31, 39-40) explained that a control chart cannot be correctly viewed as a statistical significance test. I believe confusion on this point can be traced to the fact that in using a control chart, one is looking for causes that produce "significant" effects. Nevertheless, the basis of a control chart test for an effect that is of practical significance is quite different from that of a statistical significance test despite the fact that the word "significance" can be used for both.

Some think that an in-control condition is indicated if the individual values of a control chart form a distribution that is not significantly different from a normal distribution. Shewhart (1931, p. 158) graphically indicates the falsity of this. He shows how a 50-50 mixture of two normal distributions with a common standard deviation, differing only in that the averages are separated by 1.5sigma, results in a distribution that is almost perfectly normal. There is no certainty in using a histogram of individual values to conclude that a state of statistical control exists. Remember too that a histogram has no time dimension. Nevertheless, it may prove useful to examine the distribution of individuals to get information on the source of a special cause.

Occasionally, it is suggested that data can be improved by applying a transformation to make it behave as though it came from a normal (Gaussian) distribution. This makes sense provided that the non-normal distribution to be transformed is known (see, e.g., Nelson (1994)). But if it has to be estimated from preliminary data, danger abounds.

I have found that the origin of a great many skewed distributions can be traced to a mixture of data from two sources each with a normally distributed output, but with different parameter values. Of course, the objective should be to identify the sources, not conceal them by transforming the mixture into an approximate normal distribution.

If one thinks of a control chart as a statistical significance test being applied to each point in succession, what then is the significance level of such a test? The question becomes "What is the significance level of a test that is carried out repeatedly until a significant result is obtained even though no special causes are present?" If one is certain (as here) eventually to reject the "null hypothesis" of being in control, then the significance level alpha must be equal to 1. Because this result is nonsensical, this viewpoint must be incorrect. Regarding statement (b) in the first paragraph, if a control chart is not a statistical significance test, then the difference between its lower and upper limits cannot be viewed as a confidence (or tolerance) interval. Statement (e) comes from wrongly assuming that Shewhart derived the control chart by mathematical reasoning based on statistical distribution theory. His writings clearly indicate that he did not do this. Shewhart developed the control chart empirically, and its excellence rests soundly on that basis. The experience of the last two-thirds of a century has firmly fixed its premier place in the toolbox of the process engineer as the device for process stabilization, the first step in subsequent process improvement.

ADDED MATERIAL

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