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AUTHOR:Lloyd S. Nelson
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PROCESS capability expressions are sensitive to more than just the process capability. When a capability index requires normality of the individual items produced and stability of the process, as do the most widely-used indexes, it is essential to have evidence that these conditions exist. In practical terms this means that a test for normality is not failed and a control chart shows good evidence that the process is stable. It is also assumed that the observations are independent and identically distributed. Although these characteristics are no less important, violations usually arise only in special cases and will not be treated here. Detailed information on process capability analysis when data are autocorrelated is given by Shore (1997).

Consider the normality assumption. That this is critical has been well explained by Gunter (1989). Normality refers to the distribution of the individual values, not the distribution of the subgroup means. Some useful procedures follow. No fewer than fifty observations should be used.

1. The last (say) N = 100 observations (not means) can be plotted on normal probability paper. The observations are ranked and labeled X[subi], where i is the rank and the percentage plotting positions are either 100(i - 1/2)/N or 100i/(N + 1). If a straight line fits the points well, it indicates that the population is not nonnormal.

2. Michael's stabilized normal probability plot gives a plot to examine as well as a quantitative test (Nelson (1989)).

3. The Anderson-Darling test is a powerful omnibus test. (Nelson (1998a)).

4. The Lin-Mudhollkar test for lack of symmetry might be useful (Nelson (1981)).

5. To address the specific problem of the possible presence of either fast or slow oscillations, the mean square successive difference test is appropriate (Nelson (1998b)).

The importance of rational subgrouping for a control chart should be appreciated. Such subgrouping involves organizing the data into subgroups in such a way as to maximize the homogeneity of the data within a subgroup. This will provide greatest sensitivity in the effort to stabilize the process and reduce its variability.

It is tempting to think that a control chart showing no special causes is indicating that the output of the process is both stable and normal. In fact it indicates only that the special causes remaining are not large enough to be economically worth removing. Thus, what remains after "control" is achieved is a process that can be thought of as rumbling along with small enough rumble to be ignored. This "rumble" can be composed of undetected special causes and/or mixtures of distributions. As long as it remains essentially constant, the process can be judged to be stable. However, judging a process to be stable in no way implies the presence of a single distribution, much less a normal one. Also, Burr (1972) pointed out that variability over an eight-hour shift is likely to be larger than that for a one-hour period. He suggested that, for a long period, plus/minus four sigma would be a more realistic estimate of capability than plus/minus three sigma.

Control charts should indicate that at least the last fifty points show no evidence of being out of control. Of course, any signal indicating an out-of-control condition can be ignored if the condition causing the signal has been identified and corrected. The objective is to establish and maintain a process for which the output is predictable.

Many rules for judging an out-of-control condition exist. A battery of eight tests was given by Nelson (1984). Test 1, a point outside a three-sigma limit, is the original Shewhart test. The remaining tests, used together in any combination, will introduce more power but, of course, will also increase the chance of falsely indicating trouble.

Transformation can sometimes be used to make a distribution approximately normal. Suppose that an item being produced has a characteristic that is skewed to the right. Further suppose that a logarithmic transformation yields essentially normally distributed values. The data may now adequately meet the assumption of normality for a process capability index. But remember that the specification(s) on the product must also be transformed in the same way, here expressed in terms of logarithms, before calculating the capability index.

Nonnormality can arise from truncation. If inspection discards all items greater (and/or less) than the specification(s), then the distribution of the out-put will not be normal. Clearly, no test for nonnormality is required here. Knowledge of the inspection procedure is enough to rule out the use of a capability index requiring normality.

Finally, an important consideration is the procedure for estimating the standard deviation of a process for use in calculating a capability index. The phrase "standard deviation of a process" refers to the standard deviation of the individual items produced by the process. Consider the following three methods one might use to get an estimate of the standard deviation of a process (Remember: The process is deemed to be "in control."):

1. Use the individual observations from which the control chart was made. As in testing for

normality this is the proper way to calculate the standard deviation estimate.

2. Use the subgroup averages that constitute the X chart. If the subgroups are each of size n and the standard error of these subgroup averages is s[suba], then the estimate of the standard deviation of the individuals is s[suba][square root]n. This method should be used only when the individual values are not available.

3. Use the average range (or average standard deviation) from the control chart. As we shall see, this is inappropriate.

For a perfect process all three procedures would give (essentially) the same result. But processes are not perfect. Their stability is not rock solid even though a control chart may show no evidence of lack of stability. This is to say a process cannot be held absolutely steady. Further, a control chart will reveal instability only when it is beyond a threshold level. Therefore, even when a process is in control, there will be some subgroup-to-subgroup variation. Procedures 1 and 2 will give approximately the same result; both will take account of variations from subgroup to subgroup that the control chart does not signal. The average range (or standard deviation) in Procedure 3 reflects only the variation within the subgroups. It does not take into account the inevitable variations from subgroup to subgroup (the "rumble") and should not be employed to estimate the standard deviation to be used in calculating a capability index.

The October 1992 issue of this journal was a special issue devoted to capability indices. Anyone who uses such indices should be familiar with these articles. Numerous references are also given there to other articles on this subject.

ADDED MATERIAL

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