Wysowl Pty Ltd
ACN 010 677 022

10 Jacksonia Drive
WARNER QLD 4500
Ph: Intl+ 61 7 3882 1822
Fax: Intl+ 61 7 3882 1800
wysowl@msn.com.au

Wysowl Pty Ltd
Newsletter Number 2
August, 1998

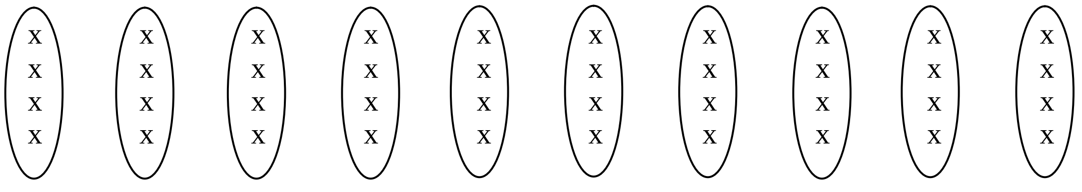
Some Thoughts on
CONTROL CHARTS FOR CONTINUOUS OPERATIONS

DEFINITIONS
For the purpose of this newsletter, the sampling method will be used to define a continuous operation. Strictly speaking, continuous operations are those that do not manufacture discrete items. Rather the production method involves a continuous flow of material. Petrochemical, metallurgical and pharmaceutical processes provide some examples. However, batch processes and even some processes that produce discrete items suffer the type of sampling related problems noted in continuous operations. Because these problems are closely associated with the sampling method used, I will define the processes examined by the sampling methods chosen.

TYPES OF SAMPLING
For control chart purposes, we can break approaches to sampling into two types; instantaneous sampling and sub grouping, and continuous or serial sampling.

INSTANTANEOUS SAMPLING
This type of sampling is used whenever we can take (say) 4 items at a time from the process, which then becomes the sub-group. This method is most common when manufacturing discrete items. We can illustrate this type of sampling as noted at Figure 1, where "X" is one product or measurement, and where each group contained within an ellipse is a sub-group. We then plot the average and range of each sub-group to build an average and range control chart.

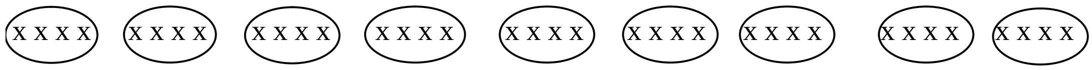
FIGURE 1
SUB-GROUPS FOR INSTANTANEOUS SAMPLING



SERIAL SAMPLING

This type of sampling is more common in service industries and in continuous manufacturing processes. Samples are drawn on an hourly, daily or similar basis. Data generated in this way are in serial, one follows another. We can still sub-group the data as shown in Figure 2, and produce an average and range control chart.

FIGURE 2
SUB-GROUPS USING SERIAL SAMPLING



SOME FUNDAMENTALS OF CONTROL CHART THEORY

All control charts for variables develop all control limits from the average of the ranges. Therefore we can say that the control limits are as reliable as is the average of the ranges. Put another way, if the estimate for the average of the ranges is sound, so too are the control limits. By extension, if the average of the ranges is corrupted, so too are the control limits for both charts. It is for this reason that the elimination of special causes in the ranges chart is so critical. If special causes are included in the calculation of the average of the ranges, the control limits on both charts will be spread too far apart. This then can give the illusion of a controlled process, even though a state of chaos might exist. It is worth emphasising that such an illusion is quite common. (See page 75 of *Analysis and Control of Variation.*)

In particular, this problem can be found in single point and moving range control charts. If a special cause exists in the individuals chart, two will be found in the moving ranges chart. It only takes a couple of special causes in the individuals chart to significantly corrupt the position of the control limits. (See page 78 of *Analysis and Control of Variation.*) Also, in single point charts, if the process shows a “step” up or down, in most cases a single special point will be found in the moving ranges chart. Again, to avoid the corruption of the average of the ranges, this point should be eliminated from the calculations. Because single point and moving range control charts are more common in service and continuous processes, it is here that this problem is most common. Clients have furnished plenty of examples of control charts where the control limits have been so corrupted by special causes that the distance between the control limits has been more than doubled.

SUB-GROUP INTEGRITY

Shewhart’s control charts for variables are remarkably robust. However, there is one aspect that they demand of us in order to develop reliable charts...sub group integrity must be maintained. Put another way, all the data in one sub-group must come from the same essential technical conditions. Usually, this is not too significant a problem where instantaneous sampling is being used (discrete items). However, if serial sampling, such as is common in continuous processes, is being used, it can be difficult to maintain sub-group integrity. Often, as serial data are grouped we will find that data from different shifts, for example, will be combined into the one sub-group. If the process is reasonably well controlled, this is not a significant problem.

However, if the control chart is being used to determine whether the process under examination is stable, and it is not, loss of sub-group integrity can lead to similar problems that exist when special causes are not removed from the ranges charts. There are many things that can cause loss of sub-group integrity. The most common are:

1. Combining multiple systems on the one chart. If there are two suppliers of raw materials or components, two shifts that operate differently or two machines operating at different levels, combining the data on a single chart can cause loss of sub-group integrity.
2. Processes that have a “noisy” signal; that is they exhibit regular but small special causes will nearly always have a special cause in each sub-group. This increases the

range of each sub-group and expands control limits. Noisy signals are common in cement and metallurgical plants.

3. Over-control when serial sampling is being used.

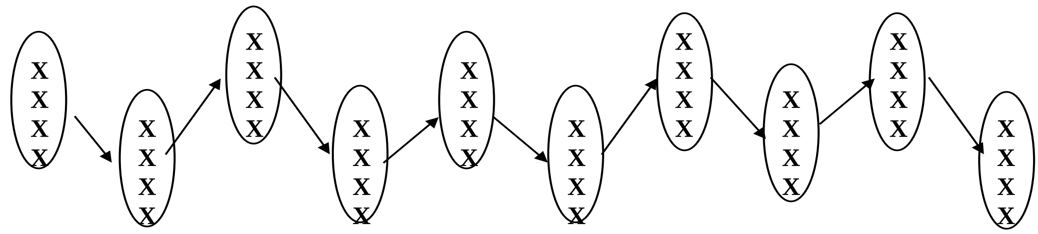
Here I wish to focus on a common problem found amongst clients operating serial sampling, over control.

DETECTING OVER CONTROL

Both instantaneous and serial sampling methods work in a similar fashion when using an average and range control chart, **providing that for serial sampling adjustments are made only *between* sub-groups and not *within* sub-groups.** When this is not the case, and particularly when over control occurs, the two sampling methods will display such disturbances in very different ways. In fact they are exact opposites. Over control using Instantaneous sampling appears as shown on pages 74 and 119 of *Analysis and Control of Variation*, with many points falling beyond the control limits as the process is unnecessarily adjusted. However, when serial sampling is in place, the points "hug the centre line" when over control is present, as illustrated at page 73.

This difference in the way over control is revealed is caused by the effect on the average of the ranges of the different sampling methods. With instantaneous sampling it is unusual to find the process being adjusted **within** a sub-group. Nearly always, adjustments will occur **between** sub-groups. Even though the averages chart exhibits chaos, the ranges chart display stability because sub-group integrity has been maintained, as illustrated at Figure 3. (Each arrow indicates an adjustment or change.)

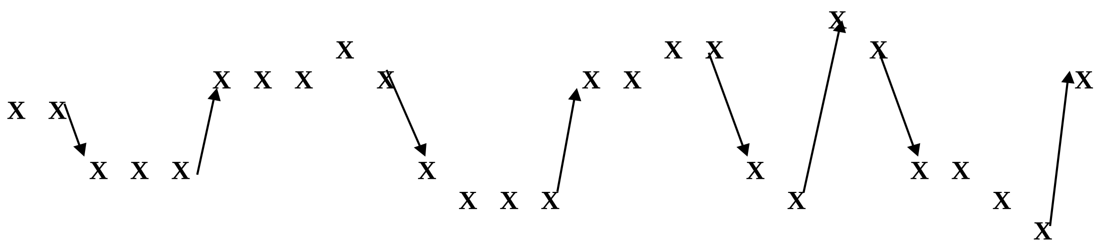
FIGURE 3
OVER CONTROL - INSTANTANEOUS SAMPLING



OVER CONTROL - SERIAL SAMPLING

However, with serial sampling, it is common to find adjustments **within** subgroups, as noted in Figure 4.

FIGURE 4
OVER CONTROL - SERIAL SAMPLING



To illustrate the different effect of over control using serial sampling, draw an ellipse around each sub-group of four data. Note how the range of the subgroups is increased by the adjustments made **within** the sub-groups, something that did not happen with instantaneous sampling. As the range of the sub-groups increases, so too does the average of the ranges. Because all control limits are calculated from the average of the ranges, as it increases the control limits become more widely spaced around the centre line. This causes the "hugging the centre line" effect.

Please again note that over control in charts using serial sampling creates the opposite effect to over control in charts using instantaneous sampling.

CONTINUOUS PROCESSES

For service industries and for continuous manufacturing processes, it is common to use a single point and moving range control chart. However, such charts sometimes fail to detect over control when it is present. The charts at Figures 5 and 6 come from a continuous process. Both use the same data. Note how easy it would be to interpret the single point chart as fairly stable (the control limits for Figure 5 are at 45 and 80). The average and range chart, however, displays "hugging the centre line", warning of possible over control when serial sampling is being used. Note also that the average chart is superior at detecting slight but sustained shifts in the mean.

FIGURE 5
PLOT OF INDIVIDUAL DATA

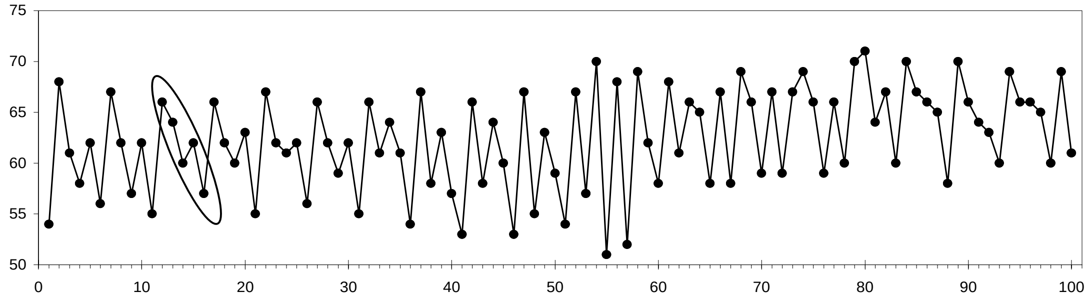
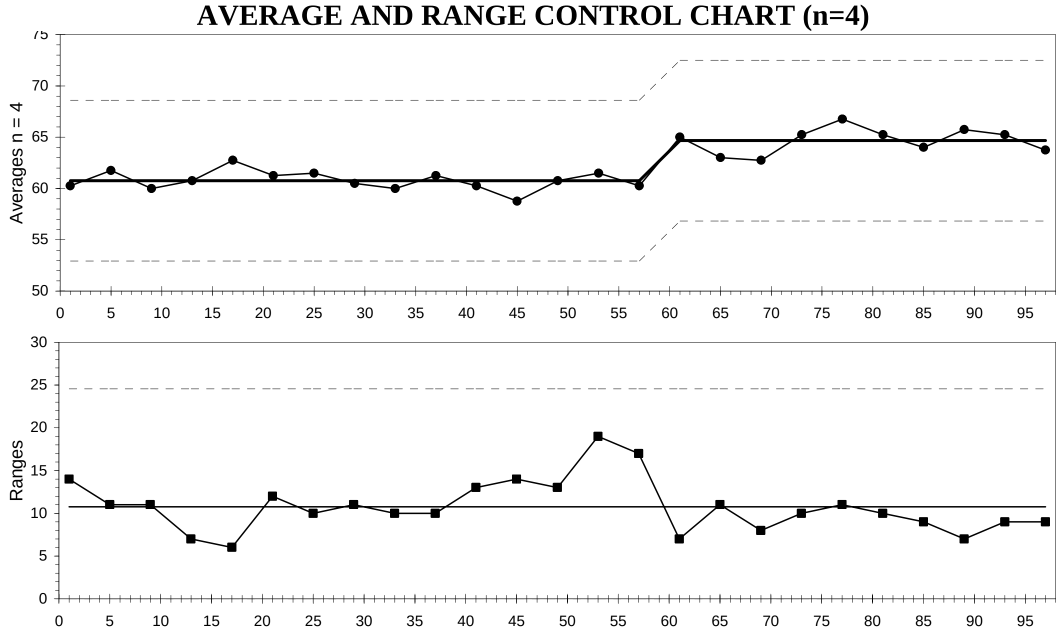


FIGURE 6
AVERAGE AND RANGE CONTROL CHART (n=4)



In this case, an automatic process controller was "hunting", or over controlling. The instrumentation had been in place for many years, but initial statistical studies had failed to identify the problem. If you look carefully at the individuals chart, a five point pattern can be seen (one such pattern is contained in an ellipse). Starting with the second point, break the points into groups of five. Note how the first point in each group is high, and the fifth is low. Towards the middle of the chart, this pattern is replaced by the characteristic "saw tooth" pattern of over control (Nelson Funnel Experiment, Rule 3). Then towards the end of the chart, the five-point pattern re-emerges.

When the mean rose about halfway through the chart, the controller went beserk as it tried to control the process. As the process drifted back down, the controller settled back into its original pattern. Once the control engineers were alerted to the problem, it was fixed in short order and variability was more than halved. The first test was simply to turn the controller off, and to manually control the process using a control chart to indicate when a change was necessary. Very few adjustments were made.

SUMMARY

Continuous processes, and others where serial sampling is used, have the potential to destroy sub-group integrity and to create the illusion that all is well, even though a state of chaos exists. However, if we are aware of this, and know what to look for, the characteristic "hugging the centre line" in an averages chart warns us of trouble. Actually, this pattern is nice to find because over control is generally easy to fix (at a rational level, the emotional aspects can be tough), resulting in rapid improvement. It is for this reason that for processes that use serial sampling, I will routinely run both an average and range control chart and a single point and moving range control chart. When confronted with the question: "Which type of chart should I use?" the better answer is often: "Both". We need not be trapped in an "either - or" mindset.