Taking advantage of statistical process control

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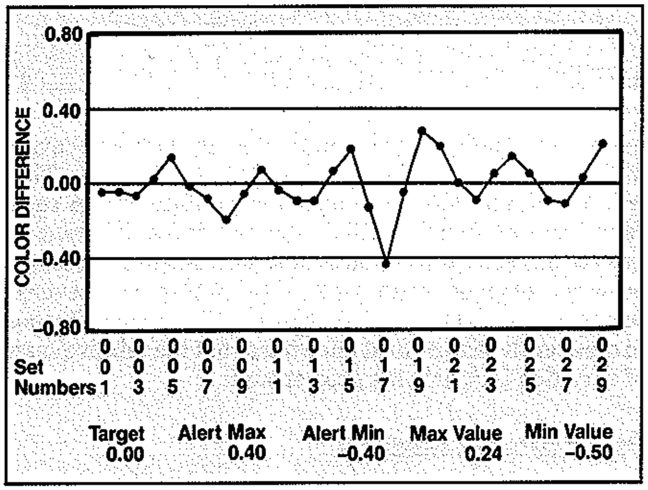
We need not limit analysis to measuring the overall variation of properties against specifications. With relevant recording, we can relate results to grades and operations, to origins and sources, to patterns of production and to known changes. We can learn how much of the variation is contributed by which factors.

The latest upsurge of interest in statistical methods has sprung from successes in other parts of the world and other industries. Those of us who witnessed the drive for statistical quality control (SQC) in the 1950s and 1960s may have some concern about repeating our earlier mistakes. We must not fail this time to take full advantage of the objectivity and process understanding that the use of statistical process control (SPC) now affords us. The third time around, within a new climate of quality awareness, we need to take SPC as a serious contributor to business. As such, it requires our attention to detail to secure better understanding both in breadth and depth.

The emphasis of SPC in this industry, quite rightly, has been on control at the point of manufacture. Here test and evaluation results are monitored and presented in simple chart form to the process "driver" to enlist his skills in more objective control. Findings are compared with realistic criteria based on actual variability as well as the defined intentions. As illustrated in **Fig. 1**, stabilization and working to target are encouraged with clearer distinctions between usual and unusual variation.

Although Statistical Process Control has appeal for its direct applicability to control within manufacture, much additional benefit can be obtained from wider use of the process knowledge generated. With more information about variation, it is possible to plan, organize, and manage our quality effort with the same objectivity we seek to apply in control. The cumulative evidence from SPC and other systematic fact-gathering is much too valuable to be limited to short-term use.

1. Comparison of measured readings against predetermined ranges



Background

The metal cutting industries have long used limits to define the extremes of permissible variation of dimensions. This practice accepts the concept of tolerable discrepancies and implies recognition of the inevitability of variation. Engineers learned to compare the spread of results of measurements with the limits set by designers and came to express this spread as the process capability. It became usual to quote six standard deviations as a percentage of the tolerance band and call this the process capability. This simple comparison is useful but tends to perpetuate a naive concern with the width of distributions irrespective of the pattern of variation.

In many businesses, multi-head operations produce parallel streams of output at the same time. Each stream, therefore, is likely to give rise to a separate and slightly different—yet similar—pattern of results. These individual distributions are called machine capabilities, reserving the term process capabilities for their collective effect. The same kind of interpretation and wording can be applied where there is a characteristic pattern of variation in a process which is inconstant from one occasion to another. Here the changes from time to time add to the inherent machine capability to produce the overall process capability.

In the injection molding production of plastic compo-

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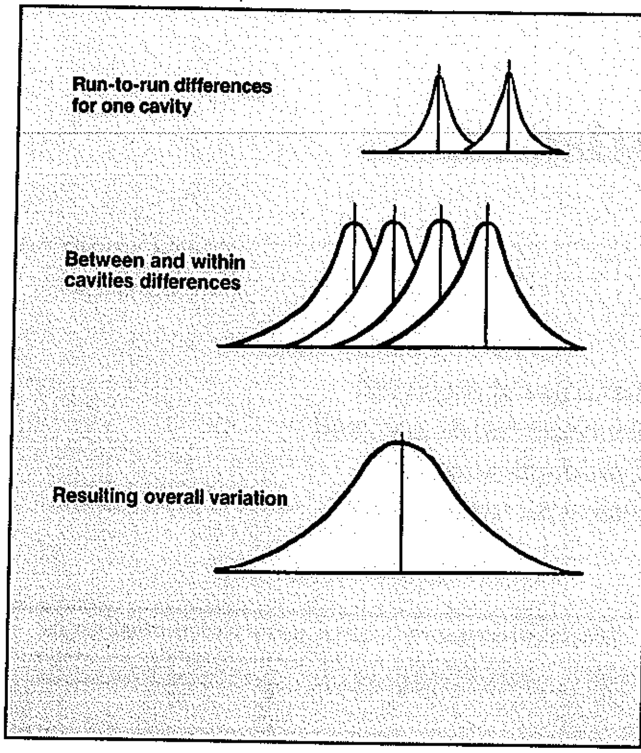
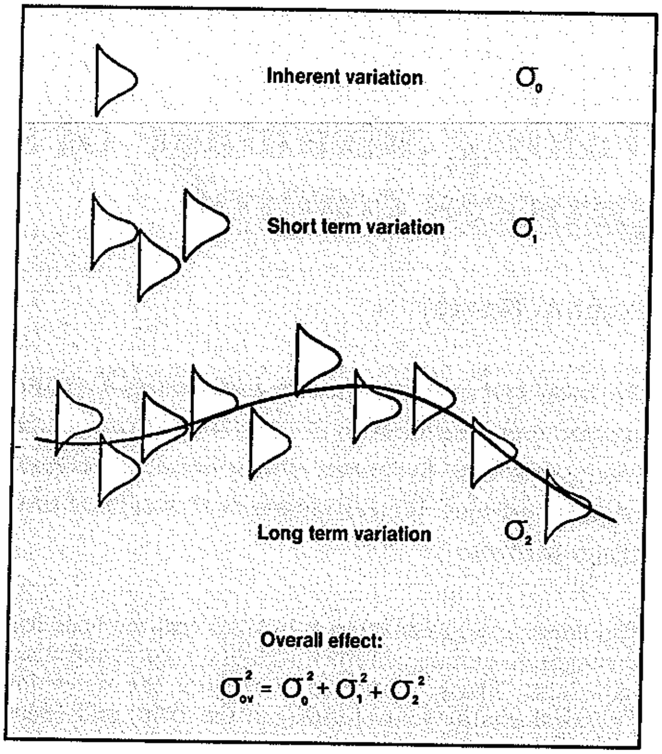
2. Measurement of components of variation



3. Duncan's model of variation



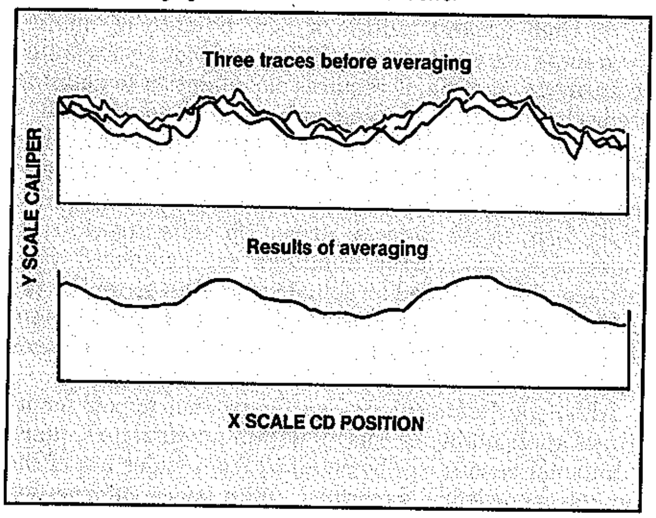
nents, for example, variability due to cavity-to-cavity differences may be built in at the mold making stage. This will add to the inherent machine capability within each cavity and be further inflated by any extra differences, associated perhaps with materials, temperature, pressure, or other changes with time. Here there are several "components of variation," as shown in **Fig. 2**, contributing to the overall picture. Just knowing about the relative span of variation is clearly not good enough.

Paper process analysis

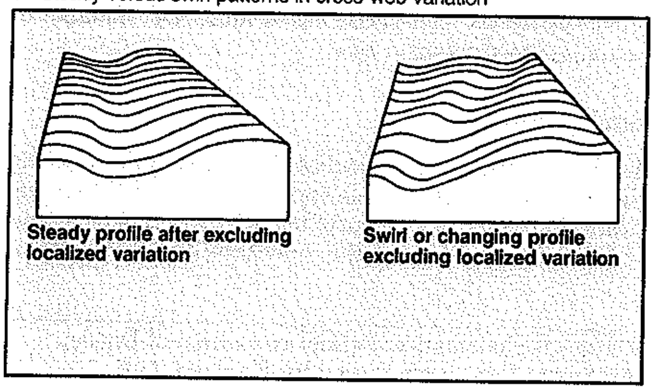
For paper and related industries, we need to know much more about our processes and how they behave. For us, process capabilities should not only relate the pattern of results to machine, grade, and basis weight but also to the causes that we may be able to influence. We need to learn for each property how much of the variation is really measurement error which can be countered by averaging, thereby improving discrimination for control and decision making. We need to expose the relationship of process variability to the origins and sources of variation, to production schedules, and to known changes—that is, to the combinations of machine, furnishes, and process conditions. Real process knowledge can be distilled from the evidence we already collect in exercising control of our processes and products.

There are also some essential statistical questions. Which standard deviation is being quoted? Does it include cross and down machine effects? Is the sample base a square inch or an acre? Has normality been assumed or confirmed by examination? The process capabilities will be quite different as a result of the answers to these questions. It is important to have adequate statistical guidance available and sufficient training to be able to

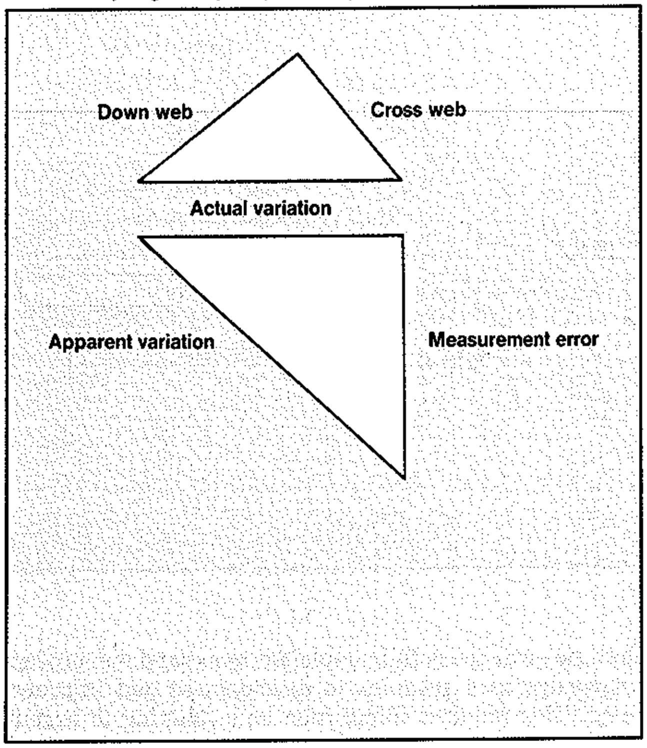
4. Use of averaging to reduce measurement error



5. Steady versus swirl patterns in cross-web variation



6. Use of Pythagorean principles to explain variation



ask the questions as well as apply the techniques. Practical statistics needs to become a subject for everyone, not just the technical specialists.

Given good disciplines of fact-gathering and recording, it is possible to get useful control and decision intelligence from retrospective analyses. Historical data are now being requested by large paper purchasers, creating new demands for data handling. Some mills will be using this to commercial advantage. The accumulative evidence is even more valuable in showing what changes have occurred and in providing clues to possible reductions in variation.

Improvement opportunities

In seeking treatments for excessive variation, we invest our management skills, together with the paper science and technologies of engineering, electronics, and even SPC. Surely we need diagnosis to guide our efforts ahead of investment. Traditionally our process capability studies asked only about the magnitude of the variation experienced. Of greater interest is the question, "Where does the variation come from?" The evidence is there to be picked up, interpreted and used, if only we can adapt our process capability studies to this purpose.

The model for combinations of variability, developed by Duncan, can be adapted to papermaking to provide a useful structure for examining process capability. It is illustrated in **Fig. 3**. This model interprets variability as the sum of a series of components, each contributing to the overall variability. These components are additive by their squared values, i.e., 3^2 and 4^2 equals 5^2.

Taking, for example, a large number of measurements of caliper over cross-web strips, from a plotting or trace we would see the combined effects of the actual profile overlaid with the noise of measurement inconsistency. By taking a series of three such traces and averaging positionally, the noise of measurement error is dampened out by about 40%. This leaves a clearer impression of the true profile, as shown in **Fig. 4**.

Looking at the results of cross-web measurements over reels from several makings, we can identify the persistent cross-web profile and expose additional effects, as shown in **Fig. 5**. We may use the term "swirl" to denote the extra contribution to cross-web variation due to inconsistent profile.

By applying analysis of variance as the mathematical isolation of effects, it is possible to quantify all the contributions to variation included in our model. Typically we may look for the machine direction effect of making-to-making differences compared with the variation within makings. We may separate cross-web from down-web variation and learn how much of the spread is attributable to long-term and how much to short-term differences. This extent of understanding of the variation of processes can be very important in determining priorities and direction of action for control and for improvement projects.

Interpretation

The usefulness of this knowledge may be somewhat dependent on our ability to communicate the findings effectively to those responsible for action and investment decisions. Graphics can help. The use of right-angled triangles on the Pythagoras principle, that is, 3^2 and 4^2 equals 5^2, provides a convenient form of presentation of combined variabilities.

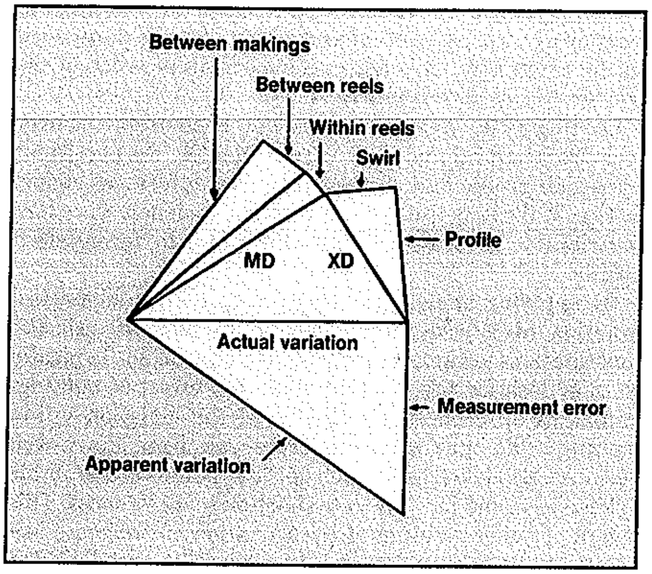
The following example from basis weight measurement on reel-end samples shows the use of Pythagorean presentation of process capabilities. In this case, by deducting from the apparent overall variation the effect of lack of repeatability of measurement, quantified from differences between replicate readings, the extent of actual variability can be derived. The actual variation is also subdivided by the analysis of variance into cross-web and machine direction variabilities, as indicated in **Fig. 6**.

The cross-directional variation is in turn split into profile and swirl, as discussed earlier, to form a further triangle. Similarly, the machine direction variation is partitioned into between- and within-making effects, adding another triangle. Finally, the within-making effect is analyzed into sequential sample-to-sample differences and the remaining time-to-time difference within-makings unexplained by reel-to-reel variation. In the resulting diagram, shown in **Fig. 7**, it can be seen how the components of variation around the perimeter of the figure add up to the actual variation.

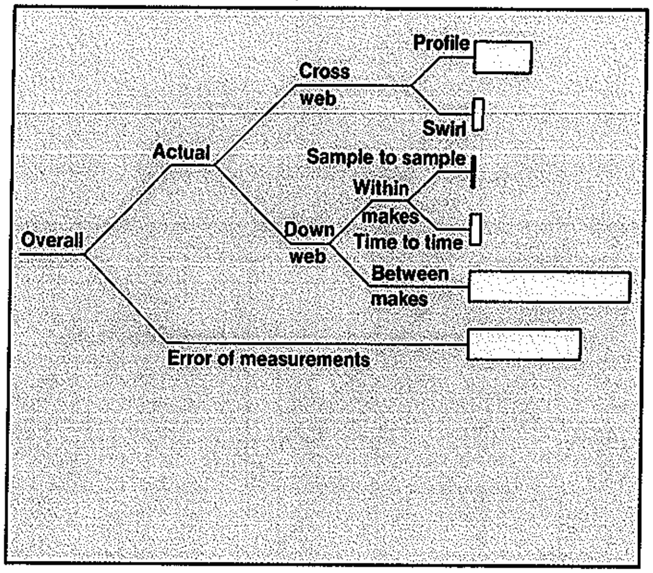
To make any impact at all in reducing variation, it is evident that the bigger components have to be tackled first. In this example, which is not atypical, auto-control so complete that it could totally eliminate machine direction differences could make no appreciable improvement in the actual variation. With the squaring involved, the effects of making and profile differences swamp the other sources of variation. In this case, it would take better procedures for targeting and investment in profile stabilization to make real reductions in variability.

It is sometimes appropriate to present the relative

7. How components contribute to total variation



8. Comparison of different components of total variation



contributions to variation in bar chart form, with bar lengths proportional to the squared standard deviations. Such a presentation is shown in **Fig. 8.** Where computerized capability analysis is available, these and other options for exposing improvement opportunities and priorities can be prepared.

We need fast responding on-line control where short-term effects contribute most to the variation. Better furnish management may be a priority where run-to-run differences are the main source of variation. Such situations reinforce the argument for using analytical process capability studies for diagnosis before investing in remedies. Fashionable technology can be accepted too readily as treatment for sicknesses we do not actually suffer.

Handling the evidence

Even without electronics, the practice of accumulating evidence in a simple histogram has great virtue in creating pictures that are readily understood and help communicate the findings. With the advantage of computers, of course, we can have easy access to past data by segments of interest. Now, at the press of a key, we can see the accumulated evidence for any combination of grades, machines, or conditions. In creating computer-based analysis, we should not be content with the facility to file and retrieve electronically. We should demand the fast statistical analysis and effective graphical presentation computers can offer to make all the knowledge derived both evident and intelligible.

However, we have to be cautious about the way things are developing. Though much of the quality data has been laboratory-based, we now get facts that can contribute to our process knowledge from several different sources. The growth of automatic testing and extensive use of on-line measurement, together with the recorded variables of the process, materials, and settings, all expand our fact-gathering. Facilities already exist to bring these together for direct control of the process. Now we need to ensure that the evidence is fully exploited to expand our process knowledge as a stimulus to development and improvement. This requires integration and planning to permit common, or at least compatible, timings, periodicity, and data frame to enable comprehensive analysis.

Benefits of process capability studies

We can think of process capability studies as a form of continuous process analysis from which we can determine the most economical controls and focus attention on the greatest needs and improvement opportunities.

The advantages of analytical studies which enable fact-based decision making can be summarized as follows:

- Recognition of actual variability
- Comparison of performance with specification
- Generating realistic control criteria
- Relating variation to combinations of causes
- Identifying priorities for improvement
- Diagnosis ahead of treatment.

Let us gear up to capture, use, and exploit the readily available evidence as a business asset—a fund of process knowledge.□