Process Improvement Using Evolutionary Operation
by Gerald J. Hahn

Is your process operating at optimum conditions?

If not, maybe Evolutionary Operation (EVOP) can help you. EVOP involves a deliberate program of replacing the static operation of a plant by a scheme whereby some of the important process variables are perturbed slightly. The effect of these perturbations upon product performance is noted and the process is shifted to obtain product improvement. The procedure is then continued to yield further gains.

This column provides a brief description of EVOP and the processes for which it is suited. A subsequent column will deal with a variation of the standard approach, known as simplex EVOP.

Example of use of EVOP

Consider a molding process for which the process yield—i.e., the percent product within specifications, is to be maximized. Laboratory experiments have shown that ram speed and mold temperature affect yield and have resulted in the decision to run the process at the standard condition of a ram speed of 4 ft/s and a mold temperature of 200 °F. This condition, however, is not optimum in the plant since the scaled-up production environment differs from that in the laboratory. Assume that, unknown to the process engineer, the effect of ram speed and mold temperature on average yield, with other variables held constant, is actually as shown by the contour plot in Figure 1. For example, this diagram indicates that a long-term average yield of 90% results at each of the following conditions:

- Ram speed, 5.5 ft/s; mold temperature, 210 °F
- Ram speed, 6.2 ft/s; mold temperature, 220 °F
- Ram speed, 9.0 ft/s; mold temperature, 220 °F

The optimum average yield of 93% is obtained with a ram speed of 7.2 ft/s and a mold temperature of 213 °F. The current standard condition (ram speed 4 ft/s and mold temperature 200 °F) results in a yield of only 85%.

EVOP is to be used to learn how to improve process yield; that is, to move from the current 85% yield point in the contour plot to a more favorable condition. This is done by running repeat iterations involving slight perturbations of ram speed and mold temperature around the current standard condition, as well as the standard condition. These iterations are continued until a statistically significant result is determined. Each such iteration involves the standard condition (ram speed 4 ft/s and mold temperature 200 °F) and the following four added conditions (see X's in Figure 1):

- Ram speed, 4.5 ft/s; mold temperature, 195 °F
- Ram speed, 4.5 ft/s; mold temperature, 205 °F

As can be seen from Figure 1, an iteration involves the corners of a rectangle (perturbed conditions) and the point in the center of the rectangle (standard condition). The long-term yield at some of the perturbed conditions is slightly better than at the current standard condition and slightly worse at other conditions. This, of course, is not immediately evident due to chance fluctuations. However, after a sufficient number of iterations, a statistically significant difference will be established between the responses; at that time, the fact that the highest percent yield is obtained with a ram speed of 4.5 ft/s and a mold temperature of 205 °F will also be noted. The process center is then shifted from the current standard condition to this new condition (which results in a long-term yield of 87%).

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A new cycle of iterations is then conducted around the new process center. In addition to the center condition of ram speed of 4.5 ft/s and mold temperature of 205°F, this involves a rectangle consisting of the following four perturbed conditions (Figure 2):

- Ram speed, 4 ft/s; mold temperature, 200°F
- Ram speed, 5 ft/s; mold temperature, 200°F
- Ram speed, 4 ft/s; mold temperature, 210°F
- Ram speed, 5 ft/s; mold temperature, 210°F

This second cycle of iterations should eventually reveal a new best condition, which is established as the new process center, and the preceding sequence is repeated. This procedure is continued until no further improvements appear to result. In the example described here, this happens after a total of seven EVOP cycles (Figure 2).

By this time, the center condition has moved to a ram speed of 6.5 ft/s and a mold temperature of 215°F, resulting in a yield of about 92.5% which is very close to the true (unknown) optimum yield of 93%. Thus, the EVOP program has succeeded in improving the process yield from 85% to 92.5%. At this point, no important improvements appear to be attainable by further perturbations of ram speed and mold temperature. These variables are now held constant at the center condition and the EVOP program is continued by introducing perturbations in other process variables to attain further improvements and information.

**Basic viewpoint**

Evolutionary Operation was introduced about 20 years ago by Professor George Box, with the viewpoint that a manufacturing process, in addition to providing a product, should yield information to improve that product. The basic philosophy is that the process engineer need understand the effect on performance of changes in the process variables. This helps him improve performance immediately. It also enables him to move more rapidly to counteract the effect of fluctuations in uncontrolled manufacturing variables that might occur at a later time.

An important requirement is that EVOP be simple to use by production personnel on a routine basis. Thus the required calculations and procedures are very elementary (1).

**Evolutionary operation and the design of experiments**

Evolutionary Operation differs from planned statistical experimentation (2) in several ways. An EVOP program is conducted on the manufacturing floor during actual production. In contrast, a planned experiment is usually performed in a laboratory during product development, and often a scaled-down version of the product line is involved. A planned experiment thus can involve relatively large perturbations of the process variables to determine their effects most rapidly. The economic consequences of poor performance at some conditions in an experimental program are not generally of great concern.

Evolutionary Operation and quality control charts

Evolutionary Operation differs from standard quality control chart procedures in that control charts are designed to detect out-of-control situations: in contrast, a purpose of EVOP is to prevent the occurrence of such situations in the first place. Both approaches can be used profitably for many production lines.

**EVOP for tracking moving processes**

An important use of EVOP is for applications where the relationship...
between the process variables and the process response changes with time (Figure 3) due to fluctuations in raw material properties, changes in operator practice, variability in ambient conditions, etc. The effect of such process fluctuations whose true causes may be unknown, might be compensated for by appropriate adjustment of the process variables via EVOP—as long as the process does not move more rapidly than the EVOP scheme’s capability to react.

**What processes lend themselves to EVOP?**

Evolutionary Operation is applicable for some processes, but not for all. The following characteristics favor the use of EVOP:

- High-volume production
- The potential benefits of process improvements are large (the process is an important one and not already operating at optimum conditions)
- Important process variables can be identified
- The identified variables can be perturbed readily
- The process stabilizes rapidly after a process change
- The process response can be rapidly obtained and measured

**Some pros and cons**

For those processes for which it is applicable, EVOP can lead to important product improvement. The resulting better understanding of the process, in addition to protecting against later deterioration, may also lead to improvement of related or future processes. A further benefit is the increased awareness and sense of involvement with process performance by operating personnel, which comes with the use of EVOP.

A first disadvantage of EVOP is that its implementation costs time and money in training personnel, keeping and analyzing simple records, making process changes, etc. These costs might be quite modest relative to the potential gains, but, like most investments, they precede the returns. Moreover, since these returns are always uncertain, the investment is speculative in nature. Therefore, to break even, the monetary gains resulting from EVOP must at least balance out the costs involved in its administration. Second, in perturbing a process from its current condition, there is always the chance of incurring some losses. If the process is already operating at an optimum, performance can deteriorate but cannot improve. Few processes, however, actually operate at optimal conditions. It might also be argued that errors or misjudgments are more likely to occur when process changes are made than when such changes are not undertaken. For example, due to a reading error, temperature may inadvertently be changed by 100°F instead of by the intended 10°F. A recent survey (3) indicated that “reluctance to perturb the manufacturing process” was the most salient reason for not using EVOP.

**Sources of further information**

This column provides an introduction to evolutionary operation. A recent book (1), directed principally at engineers and production supervisory personnel, provides a detailed and very readable in-depth discussion of EVOP, including a description of the technical details of implementation. Numerous articles describing successful EVOP applications, principally in the chemical industry have also been written; many of these are referenced in the extensive bibliography in Reference 1. References 3 and 4 provide a more detailed discussion of many of the points of this column; the results of a national survey, which evaluates how extensively EVOP is being applied and how it is being used, are also given.

Most EVOP applications have been in the chemical industry. However, the concept might equally well apply to other high-volume production processes. One common point appears to characterize all the successful applications of EVOP. The statistician, the research scientist, and others can provide important technical guidance in an EVOP program. Active management support and encouragement are also important and necessary requirements. However, these ingredients alone are not sufficient. Most crucial to the success of an EVOP program is the active commitment, participation, and

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leadership of those with the direct day-
to-day responsibility for the manufac-
turing process.

My next column will review simplex
EVOP, a dynamic alternative to the
scheme described above, and will pro-
vide further illustrations of the use of
EVOP.

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Membership
Report—Second
Half of 1986

As of the end of 1986, membership
in the ASQC Statistics Division stood at
7937 versus 7919 as of June, 1986.
This apparent negligible increase is
actually due to two counterbalancing
effects. The Division obtained 1334
NEW members (a growth of 16.8%)
during the second half of 1986, while
there are still about that many current
members who have not renewed their
membership as of yet.

Finally, a quick update, now that the
January, 1987 totals have arrived. With
178 additional new members, the Sta-
tistics Division has now passed the
8100 mark in membership. This means
that one out of six ASQC members also
belong to the Statistics Division. We
feel that you get a lot of benefits for
the incremental $3.50 extra per year it
costs to be a new or continuing mem-
ber of our division.