An EVOP Teaching Game Using a Simulated Process

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An EVOP Game is an efficient means of teaching Evolutionary Operation. An in-company training procedure which uses desk-top computer simulation of an actual process is described. The approach should help bridge the gap between learning and on-the-job application.

Introduction

EVOLUTIONARY Operation (EVOP) has been found to be a successful means for increasing process yield in a large number of companies. To achieve the benefits which EVOP offers it is necessary that members of technical staff be familiar with its principles and techniques. To assist in the training of its personnel, the Texas Eastman Company has conducted an EVOP teaching game using a simulated process. The enthusiastic response from the technical people to the game was convincing evidence of the usefulness of the approach. Thus, with the EVOP game it was possible to teach the important principles of EVOP in a realistic and enjoyable manner. The approach taken here is recommended to bridge the gap between learning and on-the-job application.

The old proverb, "learn by doing", is the basis of the approach. The procedure is a modification of the one described by A. H. Bobis [1] in which a single remote terminal to a large digital computer was used to simulate a process, perform all calculations, and print out all results from a predetermined number of cycles[1].

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[1] The approach used by Bobis is particularly suitable for demonstrating EVOP to a large group in a relatively short time (45–60 minute presentation) whereas our approach is suitable for practical training of several small groups in the actual use of EVOP for studying and improving a process. (Several hours are necessary.)

To allow the technical personnel to gain experience in performing the EVOP calculations, a small desktop computer (the Olivetti-Underwood Programma 101) was programmed to give responses (like any real process) which were used by the participants to calculate the experimental effects and significance tests. Several teams competed to optimize the same process independently; the members of each team had their own computer (process), performed their own calculations and made pertinent decisions for improving the process. The photograph in Figure 1 shows three technical people engrossed in the task of optimizing the simulated process with EVOP.

The Programma 101 program with annotations is available upon request from E. R. Russell. Explanation of the program, instructions for using the program, and a table of program modifications for different EVOP games can be supplied.

Process Simulation

A process described by Lend, Goldin and Hickman [5] was used as the model for the simulation. This process was concerned with isolating and purifying an antibiotic product. The solvent extraction step of the process was studied by the authors since this was one of the most fertile areas for cost improvement in the plant operation. Their study involved three process variables, usage levels of two complexing agents and the pH at which the extraction takes place. The effects of these variables on yield were studied.

In order to simplify the process for training purposes, it was decided to use only two of these three process variables, namely the usage levels of the two

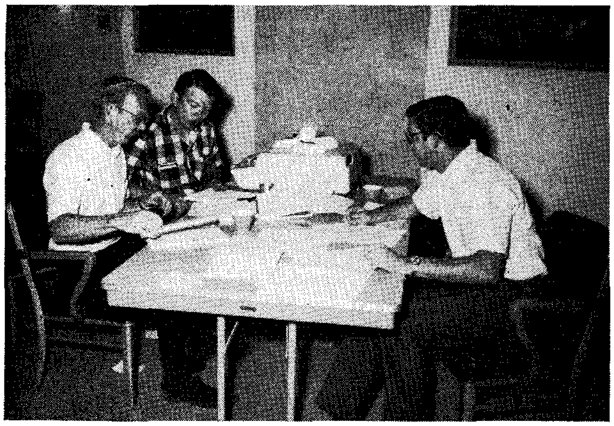

FIGURE 1. Technical People Optimizing a Simulated Process.

complexing agents. The pH was held constant at its initial level because it was reported that changing this variable did not significantly improve the yield.

The prediction equation, derived by the authors from their experimental results, was

$$Y = 65.05 + 1.63\,X_1 + 3.28\,X_2 + 0.93\,X_3 - 2.93\,X_1^2 - 2.02\,X_2^2 - 1.07\,X_3^2 - 0.53\,X_1X_2 - 0.68\,X_1X_3 - 1.44\,X_2X_3$$

where

$$X_1 = \frac{\%A - 1.5}{0.5}, \quad X_2 = \frac{\%B - 1.5}{0.5}, \quad X_3 = \frac{p\mathrm{H} - 5.0}{0.5}$$

A and B are the usage levels of the two complexing agents, Y is the process yield.

Letting $p\mathrm{H} = 5.0$ (the initial condition) causes all terms involving X_3 to vanish from the prediction equation. Then, since it was of interest to make the simulated process as realistic as possible, it was decided to have the participants enter values of the process variable more closely resembling the actual usage levels. This was accomplished by modifying the above equation, expressing the yield as a function of A and B only. The following equation is the result.

$$Y = 1.00 + 41.60\,A + 33.98\,B - 11.72\,A^2 - 8.08\,B^2 - 2.12\,AB$$

The mathematical model used for the simulation of the process is the last equation with a random normal component added to introduce an experimental error in the yield data. The programming of this model allows the use of a different constant term (instead of 1.00), different transformations of A and B and different standard deviations of experimental error, σ_E. This is done to permit some variation in the game for different groups of trainees and is included in the available instructions.

The random normal component is incorporated into the program by first generating uniformly distributed random numbers between 0 and 1 by a power residue method [6] and converting these numbers to a standard normal distribution through sums of size four[2] as follows.

Let U_i be independent uniformly distributed random variables between 0 and 1 with means, $E(U_i) = \frac{1}{2}$, and variances, $\mathrm{Var}\,(U_i) = \frac{1}{12}$.

Let $S = \sum_{i=1}^{4} U_i$, then $E(S) = 4 \cdot E(U_i) = 4(\frac{1}{2}) = 2.0$ and $\mathrm{Var}(S) = 4 \cdot \mathrm{Var}(U_i) = 4(\frac{1}{12}) = \frac{1}{3}$

Let $e = (S - 2.0)/\sqrt{\frac{1}{3}}$, then $E(e) = 0$ and $\mathrm{Var}(e) = 1$

The random variable, e, will be approximately normally distributed, $N(0, 1)$. With multiplication of e by σ_E, i.e., any desired value of the standard deviation of experimental error, a suitable random normal component is obtained. Exhaustive statistical tests have not been conducted on this random normal component. However, from several operations of the EVOP game it appears to be completely adequate.

Conducting the Game

All the participants were scheduled to attend a session of approximately two hours in the morning of the day preceding the actual game. This session was devoted to instruction in the techniques of EVOP, some of the underlying statistical principles, experiences in its use and an explanation of how the game was to be conducted on the following day. A notebook of related material was distributed to each participant. (This material was also made available several days in advance of the game for those who wanted to get a head start on reading the various papers). The material included the following.

1. An explanation of the EVOP game—its purpose, how it was to be conducted, and advice to participants in preparing for the game.
2. A brief description of the simulated process with an explanation of the experimental variables and the objectives for EVOP to improve the yield.

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[2] Usually sums of size 12 are used for this type of transformation since the variance of sums of twelve is equal to unity i.e. $12 \cdot (1/12) = 1.0$. The standard normal variable is then simply $\sum_{i=1}^{12} U_i - 6.0$. Sums over four were used to save computation time.

3. Copies of the calculation work sheets.
4. The paper by A. H. Bobis on "The Use of Simulation in Teaching EVOP" [1].
5. The paper by G. E. P. Box on Evolutionary Operation [2].
6. The paper by R. E. DeBusk on "Experiences in Evolutionary Operation at Tennessee Eastman Company" [4].
7. The paper by Box and Hunter on the "Condensed Calculations of Evolutionary Operation Programs" [3].

The participants were advised to read as much of this material as possible. Particular attention was placed on their learning how to make the calculations and the pertinent decisions based on the calculations. Each team was advised to prepare their first two-factor EVOP design by selecting the levels of the two factors to be used in the first phase.

For conducting the game, two groups of five teams consisting of four or five members per team were formed. The game was conducted in the morning for one group and in the afternoon for the other group. An Olivetti-Underwood Programma 101 was provided for each team. A competitive atmosphere was created by having the teams in each group competing with each other in arriving at the process optimum. The following items were developed for scoring the performance of the teams.

1. 1000 points were given for each percent yield increase after EVOP.
2. Points were subtracted for out-of-control conditions in the yield based on a control chart, as follows:

Yield Values Out of Control	*Points Subtracted from Score*
1st	0
2nd	100
3rd	200
4th, 5th and 6th	300
7th, 8th, etc.	400

3. Points were given after each phase for significant effects found: 200 points for main effects and 150 points for interaction.
4. 500 points were given to the team with the highest yield.
5. 15 points were subtracted for each yield observation obtained during the game.

The questions which this scoring system was designed to exploit are as follows.

1. Is the process making more money now than before EVOP?
2. Were the EVOP conditions selected in such a manner that loss in yield was a minimum?
3. Did the EVOP show the true effects of the variables?
4. Were the final conditions near the optimum?
5. How long did it take (in observations) to reach the final level of yield?

Control Chart Monitoring

One idea that proved to be an outstanding feature while conducting the game was to display the progress of each team on a large control chart. This turned out to be more or less the control center. Participants were constantly referring to the chart. It was obvious that this chart guided many of their decisions. (In conducting the game, if your participants have never used a control chart, this is a fairly good, practical way to show its use and value.) One of the displays is shown in Figure 2. Actual size was $3' \times 15'$. A single team's control chart is shown in Figure 3. Separate limits were obtained for each phase. The center lines were the averages of all values from each phase. The limits were set at $2\sigma_E$ using the known (not by the participants however) standard deviation of the process and not the one determined by the EVOP work sheets. The standard deviation used to obtain the EVOP game data shown in Figures 2 and 3 was 6.3. The limits shown are $\bar{X} \pm 2\ (6.3)$ where $\bar{X}$ is the average of all observations in a particular phase. It is a good idea to have two or more people who are not playing the game collect and plot the data.

Some Reflections on the Game

As mentioned, each time the game was conducted there were some five teams consisting of four or

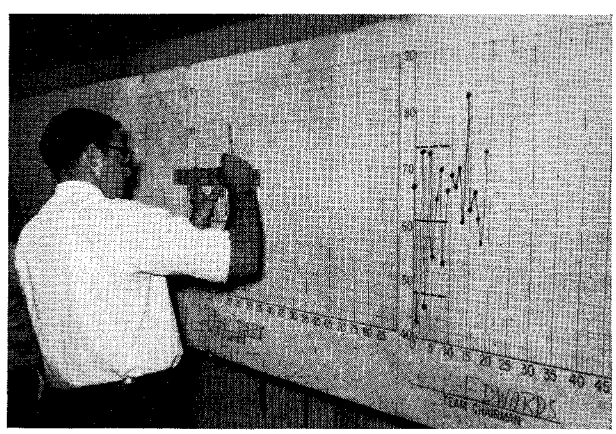

FIGURE 2. EVOP Game Control Chart Display.

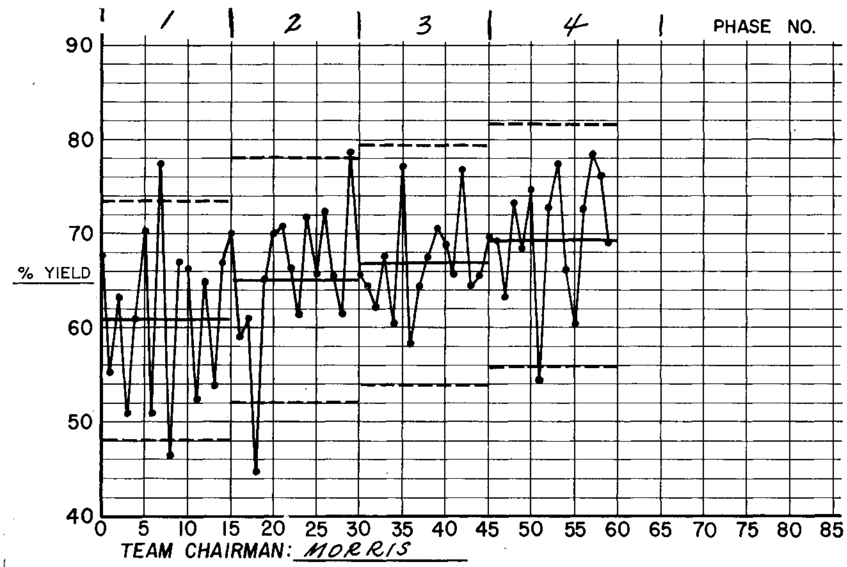

FIGURE 3. Control Chart Showing One Team's Results for a Complete Game.

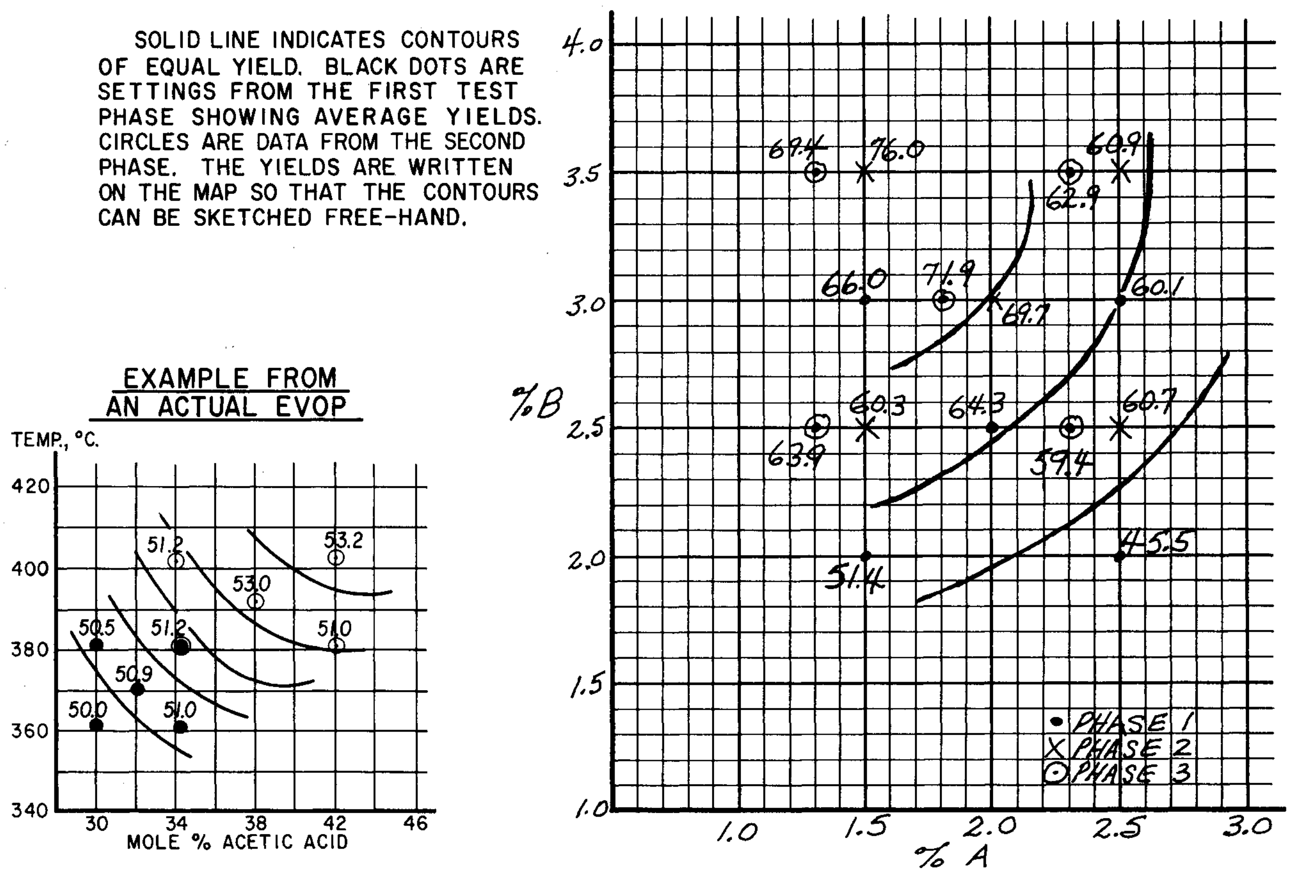

FIGURE 4. Contour Map Shows Team Way to Optimum.

five members each. Each team had a chairman who organized the team. Many teams had an organizational meeting the day before the game. This appears to be an excellent practice, for these teams were able to get started well ahead of the others during the game. Other teams didn't seem to be able to get under way for about 15–20 minutes after the start of the game.

TABLE 1. Summary of EVOP Game Score Sheets

Optimum Reported by Each Team	Teams A	B	C	D	E
% A	1.6	1.4	1.6	1.8	1.7
% B	3.1	3.0	2.9	3.2	3.3
Important EVOP Aspects					
1. Yield Increase	7,759	6,348	6,166	7,984	8,637
(Average Yield After EVOP)	(68.759)	(67.348)	(67.166)	(68.984)	(69.637)
2. Yields Out of Control	−600	−100	−600	−300	−2,400
(Number)	(4)	(2)	(4)	(3)	(9)
3. Process Information from EVOP	800	600	0	400	200
4. Optimum	0	0	0	0	500
5. Improvement Time	−1,050	−1,350	−825	−1,425	−1,425
(Total No. Observations)	(70)	(90)	(55)	(95)	(95)
Grand Total	6,909	5,498	4,741	6,659	5,512

Note: Yields are calculated from model equation modification No. 1 given with the program listing (available on request).

A few instructions were needed at the start of the game on how to operate the computers to make use of the stored program to obtain yield values as well as in using the keyboard for routine calculations. The Programma 101 offers the capability of being used as a desk calculator along with, and independent of, a stored program.

At the start of the game, the participants were given a recommended range for changing the levels of the factors. The size of this range was a function of the size of the experimental error. This appears to be necessary since otherwise they have no feel or prior knowledge about the simulated process, such as they would have about their "own" process. The magnitude of the error variation used in the game is very important. A small standard deviation would allow for very rapid process improvement. A larger standard deviation would tend to slow down the improvement by requiring more cycles. It was found for this simulation that a standard deviation between 3.5 and 6.5 would be suitable—permitting the participants to reach a reasonable degree of improvement in the process in a three-hour game period.

The game was conducted during company hours. Three hours of actual playing time was allowed. This seemed to be enough to demonstrate most of the essential aspects of EVOP. However, some teams wanted more time which seemed to be related to the fact that they were really getting the feel for the EVOP technique and realized that further improvement was possible.

One significant outcome of the game was that every team improved the process with EVOP. It is interesting to note that the process variation was fairly large compared to the improvement that could be made. In one game the standard deviation, σ_E, was 3.5 percent and the improvement that could be made was 5.5 percent in yield.

Most of the teams appeared to exercise caution in the selection of the levels of the factors. This is evident from the very few points out of control on the control chart.

The team whose control chart is shown in Figure 3, had several points out of control. However, with 2σ limits some are expected. Figure 4 is a contour map of this team's average yields from the first three phases. The map shows clearly the way to the optimum. Yields are calculated from model equation modification No. 1 given with the program listing upon request. Each team constructed its own map during the game using the form (with blank coordinate grid) shown in Figure 4. The example given in the lower left corner is used as a guide. To illustrate the scoring for one game, a summary of results is shown in Table 1.

Conclusions

EVOP can be one of the most significant process improvement techniques available for general use if one knows how to use it. The EVOP Game is a method which teaches its application in a realistic manner. The engineer gets practical experience with a situation very much like an actual process. He is therefore more experienced in its use and more confident in its results when he applies it to a real process.

It is believed that sufficient material is presented in this article and the supplementary instructions available upon request to enable the reader to develop and use an EVOP game for teaching its principles and techniques.

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