The demand for some American products is beginning to ebb as foreign competition increases. Quite the opposite is occurring in Japan, where in many cases higher quality products are being produced at lower cost. How do the Japanese do it? Many business leaders today are trying to find the answer to this question. One of the more important factors seems to be the widespread use of quality control techniques. American businesses are beginning to see that pairing these techniques with statistically designed experimentation provides a key to increasing the productivity of our processes.

The computer also has an important role in business today. Its speed and accuracy could be of great help in applying quality control methods. For instance, an interactive, prompt-driven system to produce control charts could be a very useful application. This paper discusses the development of such a system.

CONTROL CHARTS

Perhaps the best-known quality control device is the control chart. Control charts are graphical tools based on statistical theory that allow us to monitor the performance of a process. The process can be anything from the baking of bread to the production of parts for nuclear weapons to the generation of paperwork in an office.

While the process may be complex, starting a control chart on the process is very simple. Whatever the product, consecutive samples (generally of fixed size) are taken. If some feature of interest can be measured on a continuous scale, then the average and range of each sample are obtained. The average of the sample ranges and the average of the sample ranges are calculated, and are used to compute upper and lower limits. We then plot the sample averages and ranges with their respective limits. If any of the values fall outside of these control limits, the process is said to be "out of control." In other words, the process is not behaving in a consistent and predictable way. Our goal is to discover which variables affect the process and to control those variables so that the process itself becomes predictable or "in control." Once this is achieved, we may make some additional changes to optimize the performance of the process.

If the process is in control, we can predict its future performance accurately. This is generally very valuable information. If it is out of control, prediction is virtually impossible. A complete discussion of the rationale behind control charts and the necessary calculations can be found in Grant and Leavenworth (1980).

Since control charts are simple to produce, it is usually recommended that the workers themselves be responsible for keeping them. A short training program can teach the basics for creating and interpreting these charts. However, when a process has many variables which need to be monitored, creating the control charts can become a full-time job itself. In such a data-rich situation, using the computer is the most efficient solution. Software can calculate the control limits, test for out of control conditions, and produce the charts. Relieving the worker of these tedious tasks allows him to spend more time using the charts to control the process.

The process that stimulated this effort is one which produces large metal ingots. These ingots are cut into smaller pieces which are machined into parts for use in nuclear weapons. Continuing problems with ingot quality signaled the need for closer monitoring of the process. The variables of primary interest have been the amounts of niobium and of carbon in the ingots. However, we also wanted to monitor the many variables that affect the process. For this reason, our first step was to create a data base which contained all necessary information.

The second step was to develop software that would generate control charts. Several important features were required. In addition to control charts, we wanted to plot charts of individual ingot data and have access to more complex analysis techniques. All tasks needed to be done interactively under TSO, since the long turnaround time of batch jobs was considered unacceptable. This interactive work would be done by process personnel and managers with limited computer experience, so the software needed to be easy to use. Most importantly, we wanted all of these capabilities to be combined into a single system. Having seen the new features available in SASH2, I decided to use it as the basis for our system.

THE SYSTEM

Three SAS macros and a CLIST comprise the structure of the system. One macro does the prompting, another handles calculations and plots, and the third is a command macro. The command macro passes control back and forth between the prompting and charting macros in a continuous loop. The CLIST allows easy entry to the system.

The entire program is written using SAS and SAS/CRAPH. However, no knowledge of SAS is...
needed to use it. In fact, experienced SAS users may not be aware that the system is written in SAS.

The system is designed to be specific to a process and yet be reasonably portable. While the prompting macro is tailored to an individual process, the charting and command macros are very general and can be installed on another process without change. In moving the prompting macro to a new process, a number of minor changes must be made. Most of these are the changing of variable names to those used in the new process.

While the system described here is currently limited to control charting, its structure was designed with expansion in mind. The other features mentioned above may be added in the form of new macros. Any new prompts that are necessary are easily added. The user's responses will then trigger the command macro to pass control to the proper macro.

### CONTROL CHART FEATURES

In addition to the overall system requirements, the control chart routine needed to be very flexible. The features detailed here are all supported by this system.

*Since the primary task of control charts is to detect process changes, the program must be able to show such changes. Separate limits are calculated and displayed for the time periods before and after a specified change in the process. Up to four such process change points may be entered.*

*Limits on a control chart are calculated when the chart is started and after each process change. Generally, twenty-five samples are considered sufficient for these computations. When this system calculates limits for old periods, it uses all of the data in that period. The user has the choice of basing the latest (current) limits on all of the samples collected so far or on only the first twenty-five. In this way, he may mimic the manner in which the chart would be done by hand.*

*While the amount of available data may be large, any subset of the data can be selected. The subset is selected by specifying the beginning and ending points for any one of a number of variables.*

*The previous feature selects the section of data available for calculations. Another feature allows the user to specify that only the last $k$ samples from this section be plotted, where $k$ is any integer.*

*Control charts display the samples ordered by their sequence through a process. However, the product items may pass through several processes using a different sequence for each one. Changes in one process may cause the data taken from a later process to appear out of control. For this reason, the system makes it possible to order the data from a given process using the sequence of an earlier process.*

*The user may choose any sample size up to twelve. Beyond twelve, the range is not the recommended estimator of variability.*

*The occurrence of runs of length eight or greater is reported. A run is a series of sample values that, when plotted, all appear on one side of the median value, where the median value is computed from all the samples. The location of the eighth sample in a run is listed on the chart.*

*The total number of runs of any length is given.*

*The last eighteen out-of-control points are listed on the chart. The total number of out-of-control points found is given as well.*

*Missing values are checked for and are deleted before any calculations are performed.*

### PROMPTING FEATURES

Though not documented in the 1982 SAS manuals, a %INPUT statement is available. TPUT can be used to print the prompting messages while %INPUT allows the user to type a response which is then placed in a macro variable. This method was used to create a macro that guides the user through a series of questions which define the type of chart desired. The prompts may be repeated by responding "AGAIN" to any prompt. The user can exit from the system and return to TSO by responding "END" to any prompt.

Several options are seldom changed and have been grouped together. The user is first asked if any changes to this group are necessary. If no changes are desired, several prompts are skipped. However, if the user wants to make a change, the prompts are given one at a time, allowing changes to be made.

### EXAMPLES

One variable is charted in these examples. This is the niobium content at a particular location in the ingot. Both the average and range charts are used to determine if this process is in control. However, for purposes of illustration, only the average charts are shown. Figure 1 shows a typical prompting
sequence. Figures 2 through 4 were all based on a sample size of four as indicated by the vertical axis label.

The first time a chart is made, a single set of limits is typically chosen. In figure 2 those limits were based on all available samples. In the upper right hand corner is printed the date on which the chart was made. Below the date is an indicator showing that the control limits were calculated using data from all samples. If only the first twenty-five are used, then "EXT" (extension of limits) is printed. The "3039" in the title is the part designation of these ingots. At the bottom of the chart, the last line shows the mean and standard deviation estimates for the population of individual ingot values. When the process has more than one period, estimates are calculated for each period.

There are some very clear process shifts and trends in this example. We recalled that an adjustment to the initial niobium level occurred on May 8. Figure 3 resulted from entering 5/8/82 as a process change point. The limits after this point are calculated from all remaining samples. The points out of control on June 16 and July 7 have not yet been fully explained. If the factors that caused them can be removed from the process, then these points may be deleted and the control limits recalculated. Another problem is the sinusoidal curve in the data that is detected by the runs test. This pattern was the result of some work that varied a number of factors in the process. After about two months, the process became more stable.

With the work done we are now interested in a chart showing only samples from the modified process. Figure 4 accomplishes this by selecting 10/8/82 as the beginning point for calculations. Using only the first twenty-five samples will hold the latest limits fixed as new data comes in. The plot shows that our modified process is in control. Since these charts are produced and distributed weekly, it is not necessary to show a long history of the process. For example, it may be adequate to show only the last twenty samples. Figure 1 shows how this chart would be obtained.

FIGURE 1

The user has logged on to TSO. He types "ex chart" to execute the CLIST that starts the system. The example that follows is from the middle of his session. That is, he has gone through the prompting sequence at least once before.

 summary

Anyone familiar with the use of control charts can operate this system to his advantage. In doing so, he is saved the time and tedium of plotting by hand. The possibility for error is eliminated as is the need for repetitious calculations. Should a change to the plot be required, a presentation-grade chart can be produced in minutes.

Use of this system benefits both the worker and the statistician. With it, the worker needs to take only a few minutes away from his other duties to obtain an up-to-date control chart. The statistician is spared from helping to set up yet another control chart on a process. This gives him more time to design and analyze experiments that will point the way to further improvements of the process.

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References

Grant, E. L. and Leavenworth, R. S.
Statistical Quality Control. 5th ed.
ENTER NUMBER OF VARIABLE YOU WISH TO CHART.
(1) 3036 TOP CARBON  (2) 3036 BOTTOM CARBON
(3) 3036 TOP NIOBIUM  (4) 3036 BOTTOM NIOBIUM
(5) 3039 TOP-CENTER CARBON  (6) 3039 TOP-EDGE CARBON
(7) 3039 TOP-CENTER NIOBIUM  (8) 3039 TOP-EDGE NIOBIUM
(9) 3039 BOTTOM-CENTER NIOBIUM  (10) 3039 VAR RUNTIME

ENTER NUMBER OF CHART YOU WISH TO PRODUCE.
(1) CONTROL CHART FOR RANGE
(2) CONTROL CHART FOR AVERAGE
(3) CONTROL CHARTS FOR BOTH RANGE AND AVERAGE

ENTER NUMBER OF ORDERING (LOWER AXIS) VARIABLE.
(1) 3039 INGOT NUMBER
(2) ARC-MELT DATE
(3) SKULL MELT DATE

SPECIFY ANY KNOWN PROCESS CHANGES RELATIVE TO THE
CHosen ORDERING VARIABLE. UP TO FOUR MAY BE ENTERED.
THEY MUST BE IN INCREASING ORDER. DATES ARE ENTERED
AS 4/21/82 FOR EXAMPLE.

DO YOU WANT TO RE-SELECT ANY OF THESE OPTIONS?
AMOUNT OF DATA
EXTENSION/CALCULATION OF CURRENT CONTROL LIMITS
SAMPLE SIZE
(1) YES  (2) NO

IF YOU DO NOT WISH TO USE ALL AVAILABLE DATA IN THE
CALCULATIONS CREATING THE CHART, CHOOSE THE VARIABLE FOR
WHICH YOU WANT TO SPECIFY THE BLOCK OF DATA TO BE USED.
(1) 3039 INGOT NUMBER  (2) 3036 NUMBER
(3) SKULL RUN NUMBER  (4) ARC-MELT DATE
(5) SKULL MELT DATE  (6) USE LAST X OBSERVATIONS
(7) USE ALL DATA

ENTER THE STARTING VALUE FOR THE SELECTION ABOVE.
ENTER DATE AS 4/21/82 OR 10/2/82 FOR EXAMPLE.

ENTER DATE AS 4/21/82 OR 10/2/82 FOR EXAMPLE.

IF YOU WISH TO PLOT LESS DATA THAN WAS SELECTED FOR THE
CALCULATIONS, ENTER THE NUMBER OF SAMPLES BACK FROM
PRESENT THAT YOU WANT PLOTTED. IF YOU WANT ALL DATA
USED IN THE CALCULATIONS TO BE SHOWN, JUST PRESS RETURN.

SHOULD CONTROL LIMITS FOR THE MOST RECENT PORTION OF THE CHART BE:
(1) EXTENSIONS BASED ON FIRST 25 SAMPLES
OR (2) CALCULATED FROM ALL AVAILABLE DATA

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PRESS RETURN FOR SAMPLE SIZE OF 4, ELSE ENTER DESIRED VALUE (< 13).

... plotter instructions from SAS/GRAPH

*************************************************
* TYPE: END TO TERMINATE SESSION *
* OR: AGAIN TO REPEAT PROMPTS *
*************************************************

ENTER NUMBER OF VARIABLE YOU WISH TO CHART.
(1) 3036 TOP CARBON  (2) 3036 BOTTOM CARBON
(3) 3036 TOP NIUMIUM  (4) 3036 BOTTOM NIUMIUM
(5) 3039 TOP-CENTER CARBON  (6) 3039 TOP-EDGE CARBON
(7) 3039 TOP-CENTER NIUMIUM  (8) 3039 TOP-EDGE NIUMIUM
(9) 3039 BOTTOM-CENTER NIUMIUM  (10) 3039 VAR RUNTIME

END

READY

LOGOFF

3039 TOP-EDGE NIUMIUM

FIGURE 2

XBAR CHART

PREPARED
12JAN83

ALL

03/08/82 04/05/82 05/05/82 06/04/82 07/04/82 08/03/82 09/02/82 10/02/82 11/01/82

ARC MELT DATE

RUNS TEST FAILURE POINTS: 03/26/82 07/11/82 07/24/82 09/02/82 09/15/82 10/18/82 11/02/82
NUMBER OF RUNS= 47
36 POINTS OUT OF CONTROL: 08/03/82 08/05/82 08/06/82 08/07/82 08/08/82 08/09/82 09/02/82 09/04/82 09/05/82 09/06/82 09/07/82 09/08/82 09/09/82 09/10/82 09/11/82 09/12/82 09/13/82 09/14/82 09/15/82 09/16/82 09/17/82 09/18/82 09/19/82 09/23/82 10/07/82 10/13/82 10/14/82 10/15/82 10/16/82 10/17/82 10/18/82 10/19/82 10/20/82 10/21/82 10/22/82 10/23/82 10/24/82 10/25/82 10/26/82 10/27/82 10/28/82 10/29/82 10/30/82 11/01/82
XBAR=6.859 SIGMA=0.158

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FIGURE 3

3039 TOP--EDGE NIOBIUM
XBAR CHART

PREPARED
12JAN83

ALL

03/02/82 04/05/82 05/08/82 06/04/82 07/04/82 08/03/82 09/02/82 10/02/82 11/01/82

ARC MELT DATE

RUNS TEST FAILURE POINTS: 07/11/82 08/03/82 08/31/82 09/18/82 11/06/82
NUMBER OF RUNS = 74

0 POINTS OUT OF CONTROL: 06/18/82 07/07/82 07/31/82 08/08/82 08/07/82 08/10/82 08/31/82 09/01/82
08/02/82 08/15/82 09/10/82 09/10/82 09/21/82 09/23/82 10/07/82 10/13/82 10/28/82 11/03/82
XBAR=5.745 SIGMA=0.141 0.182

FIGURE 4

3039 TOP--EDGE NIOBIUM
XBAR CHART

PREPARED
12JAN83

EXT

10/07/82 10/12/82 10/17/82 10/22/82 10/27/82 11/01/82 11/06/82 11/11/82 11/16/82

ARC MELT DATE

RUNS TEST FAILURE POINTS:
NUMBER OF RUNS = 10
0 POINTS OUT OF CONTROL:
XBAR=5.808 SIGMA=0.184

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