Section III

Shop Applications

PART A
Process Control Charts

This part of the Handbook covers the planning, installation and use of Operating process control charts. Process control charts are the hub around which the whole program in the Shop revolves.

Designed Experiments are an aid in making process capability studies. Process Capability Studies are helpful in obtaining information about the process. Sampling Plans, as used by Inspection, are a useful means of checking on the adequacy of the process controls.

However, unless the Designed Experiments are translated into process capabilities, and the process capabilities are in turn translated into tangible results in the Shop, all the improvements brought about by experiments and capability studies will be just so much paper. In the same way, unless the shop is controlling its processes, it is not possible to realize the economies and advantages of sampling inspection.

For this reason the Shop Section is in many respects the most important part of the Handbook.

Shop objectives

In starting process control charts in a given area, or on a given job, it is necessary to have in mind some tangible objective. This objective may be:

a. To improve quality.
b. To reduce losses or re-work.
c. To make the process more stable—that is, less subject to unpredictable trouble.
d. To find the cause of some difficulty which is currently being experienced.
e. To discover which operations or characteristics are capable of changing or influencing other operations.
f. To check on the importance or suitability of specifications, etc.

All of these are in line with the general quality control objective of improving quality and at the same time reducing costs.

The details of planning, installing and using the shop control charts should be handled jointly by a Quality Control Team.

A-1 PLANNING THE CONTROL CHARTS

A-1.1 Where to put the first charts

Almost any shop will need a certain number of shop control charts. The charts should be set up in such a way that they will show the significant "causes of variation" affecting the particular job. There are three ways of discovering these causes of variation.

(1) *Process capability studies.* These studies frequently end by showing the proper places for shop charts. See pages 47–63 for the method of making such a study, and pages 63–65 for the method of using the information to set up a chart in the shop. Process capability studies are the best foundation for process control charts.

(2) *Performance studies.* It is possible to use performance studies in place of process capability studies in any of the following cases:

a. Where the shop is having difficulty in meeting a requirement.

b. Where there are large amounts of re-work.

c. Where it is necessary to adjust, re-adjust or do selective assembly.

d. Where someone is performing 100% inspection.

Follow the directions for performance studies on page 74. Work gradually backward into the earlier operations until you discover the most important sources of trouble.

(3) *Nature of operation or characteristic to be studied.* The following situations will almost always benefit from charts, whether or not there is any apparent indication of trouble:

a. Cases where the individual operator directly controls important results.

b. Cases where the machine setter has to keep the machine centered within narrow limits.

c. Cases where it is desirable, for economic reasons, to hold the distribution in some specific place.

d. Cases where it is desired to study or question the specifications.

In certain cases the engineer may set up charts in the shop for the purpose of gathering engineering information. These charts should be marked "experimental chart" or "engineering study" to distinguish them from the regular shop control charts.

A-1.2 How to decide on the proper type of chart

Three types of control chart are commonly used in the shop:

a. $\bar{X}$ and R charts.

b. p-Charts (or other attributes charts such as np-charts, c-charts, and u-charts).

c. Charts for individual measurements with control limits based on the moving range.

The following are appropriate situations in which to use each type of chart.

$\bar{X}$ and R charts

Use these charts for:

(1) New jobs, or jobs where there are unsolved engineering problems.

(2) Jobs that have been in production for some time but are chronically in trouble.

(3) Cases where it is difficult or expensive to obtain data, as in destructive testing.

(4) Cases where there are difficult assembly problems, including overlapping tolerances, small clearances and interference fits.

(5) Cases where the chart is needed for diagnostic purposes: the job is in trouble and we have not discovered why.

(6) Cases where it is desired to obtain changes in specifications.

(7) Cases where it is desired to reduce acceptance inspection to a minimum and where the job is in good control.

(8) Cases where the shop must determine when to adjust a machine or process and when to let it alone. This includes cases where the shop must determine whether a set-up is satisfactory.

(9) Cases where attributes control charts have been in use but the shop has been unable to bring the charts into control.

$\bar{X}$ and R charts may be plotted on (a) a critical quality characteristic, (b) a characteristic which is important for economic reasons, or (c) a characteristic which is frequently in trouble.

p-Charts (or other attributes charts)

Use these charts for:

(1) Cases where a chart can help the operators to do better work.

(2) Cases where it is desired to reduce repairs, re-work and scrap, and the causes for these are known to, or controlled by, the individual operators or the Operating group.

(3) Cases where it is desired to obtain a historical picture or summary of the job. p-Charts can be more useful for this

purpose than $\bar{X}$ and R charts, since it is possible to combine many characteristics into a single *p*-chart.

(4) Cases where it is desired to study trends in individual defects or groups of defects.

(5) Cases where some means of detecting assignable causes is needed and it is not economically feasible to obtain variables data for $\bar{X}$ and R charts.

p-Charts may be plotted on (a) the percent defective, (b) the percent good, or (c) the percent lost or spoiled at the operation. On complex types of apparatus or equipment, where it is possible for many defects to occur on the same unit, it is customary to use *c*-charts as a substitute for *p*-charts.

Charts for individual measurements with control limits based on the moving range

Use these charts for:

(1) Operations where it is not possible or convenient to obtain more than one measurement per sample: for example, furnace temperatures, gas pressures, chemical analyses of a quantity of powder or liquid.

(2) Cases where the data must be obtained from accounting figures, etc., which are not available until the end of a week or month.

(3) Any case where it would not be possible or practical to use the regular variables or attributes charts.

A-1.3 How to determine the correct number of charts

It is seldom possible to determine, at the beginning, how many charts will be needed. However, this can be determined over a period of time as follows:

(1) At the beginning, put charts on any characteristics or operations which you believe to be important. The charts themselves will give information as to whether they are actually needed.

(2) As time goes on, take off charts that are found to be unnecessary. Add others that are found to be necessary. More charts will usually be required at the beginning than after the job has become more stable.

(3) Keep up-to-date records of the number of charts on the job. It is best to keep separate records of the variables and attributes charts. In general, for a number of months after the charts are first installed, you should find that the number of charts tends to increase rather steadily until it reaches a maximum. After that it may stabilize at the maximum point or it may even decrease. After the job stabilizes it is quite common to find that it has the same number of charts from one year to the next. However, they are not necessarily the same charts.

(4) If the charts are being used effectively and if new knowledge is being gained about the controlling variables, you should find the proportion of $\bar{X}$ and R charts gradually increasing as compared with *p*-charts.

(5) All decisions having to do with the removal or addition of charts should be joint decisions of the Quality Control Team.

A-1.4 How to make sure that the charts are set up correctly

Shop charts are not designed to be interpreted in the same manner as process capability studies. When a chart used in a process capability study is out of control it means, "Here is additional information." It may even be essential for the chart to go out of control in order to solve the problem.

Process control charts, however, are deliberately set up in such a way that "out of-control" is synonymous with trouble. On a process control chart an out-of-control condition should mean:

a. Part of the product will be outside of specifications.
b. There will be an increase in assembly difficulties.
c. Some later operation will suffer.
d. Yields will go down.
e. There will be too many repairs,

or some other undesirable and uneconomical result. If a chart can go out of control without meaning trouble, the chart is not set up properly for shop use.

Among the conditions which may result in having charts set up incorrectly are the following:

(1) The cause of trouble may be too far removed from the point where the chart is located. In that case it will be too difficult for the shop to trace the trouble causing the out-of-control condition.

(2) The product may have been screened or 100% inspected prior to the place where the samples are taken. In that case the information needed for control is probably being thrown out along with the defectives.

(3) The chart may attempt to cover too many characteristics at once. This is often true of *p*-charts. When the chart shows trouble the shop may have no way of knowing which characteristic is out of control.

(4) Even when the chart covers a single characteristic, there may be too many causes which can affect that characteristic. For example, one engineer was very impatient with the shop for failing to take action on a chart. When the engineer was asked to make a list of all the causes which could throw that characteristic out of control, he found there were 47!

No one in the shop should be expected to investigate an unreasonable number of causes. The Quality Control Team should provide charts on some of the causes back in the process where it will be practical to check them.

The Team should make sure that all charts are statistically correct as well as correctly planned and used.

Scales are important on process control charts, since unsuitable scales may diminish the readability or usefulness of the charts. If fluctuations are made to look very large as a result of the choice of scale, a machine setter may have a tendency to over-adjust the machine. On the other hand, if the scale is such that the fluctuations are very small, shop people may delay in taking action because they have an impression that the fluctuations are unimportant.

As processes come into better control, the fluctuations on the control charts may tend to become smaller. In such cases, it may be necessary to expand the plotting scales from time to time, in order to obtain more readable patterns.

If specification limits are to be indicated on the chart, it is necessary to set up the scales with this in mind. Specified limits should be indicated only as arrows in the margin, so they will not be mistaken for the centerlines or control limits.

A-1.5 Operations which may not need to be charted

It is not necessary to plan control charts on every operation. Some operations may not need to be checked at all. On other operations it may be sufficient to have the operator check one or two parts informally at specified intervals during the run. Informal checks of this kind, which are not plotted or subjected to statistical tests, are called "casual checking."

Too much reliance on casual checking should be avoided. Small samples without statistical limits can only distinguish between conditions which are about 100% good and those which are about 100% bad. If the shop is expected to discover moderately defective conditions, or to tell whether the product is meeting a dimensional limit, this will ordinarily require a control chart.

A-2 DETAILED PROCEDURES IN SETTING UP THE CHARTS

A-2.1 General

The following steps should be taken in setting up charts for shop use.

(1) *Decide where the process should be checked, and how and where the samples should be selected.* Checking for process control should be performed as soon as possible after the operation which is to be controlled. The sample should be selected in such a way as to detect changes in the process as rapidly and economically as

SUMMARY OF DETAILS IN SETTING UP CHARTS FOR THE SHOP

Chart	*Recommended Sample Size*	*Remarks*
$\bar{X}$ & R	(a) For the usual shop charts, or engineering studies of a going process, use samples of 4 or 5. (b) For experimental work, or for any kind of chart for which the data are extremely limited, use samples of 2 or 3.	(a) Samples for $\bar{X}$ and R charts should be small rather than large, and should rarely exceed 10. (b) For samples of 2 and 3, the control limits on the R chart are noticeably unsymmetrical. This makes the R pattern more difficult to interpret. See pages 182–183.
p	(a) Where the size of the sample can be specified in advance, try to use samples of 25, 50 or 100. It is advisable to keep the sample size constant for the entire series of samples. (b) p-Charts are easiest to interpret where the product of n x p is approximately 4 or 5. However, if the fraction defective is small, this would frequently call for uneconomically large samples. (c) In some cases it is convenient to plot the results of 100% sorting, considering each lot or quantity as a "sample."	(a) If the sample size varies from sample to sample, the chart will require special interpretation as shown on pages 18–19. (b) If the sample size is very small and $\bar{p}$ is also small, the control limits will be unsymmetrical. Special tests for such charts are given on page 183. (c) If the sample size is very large (hundreds or thousands) it may be advisable to use "moving range" control limits for the p-chart as explained on pages 196–197.
np	Same as for p-chart except that the sample size must be constant throughout the series of samples.	(a) If the product of n x p is small, the control limits will be unsymmetrical. See page 183. (b) If n is very large (hundreds or thousands), interpret the chart as explained on pages 196–197.
c	The sample should consist of some constant unit or quantity such as (a) A piece of wired equipment of a particular type. (b) A square foot of rubber or cloth. (c) A certain number of feet of wire, etc.	(a) The sample for a c-chart may consist of a number of separate units, provided the group of units are handled as if they were one. For example, we might count the number of loose connections in groups of wired panels containing 8 panels in each group. The sample in this case would be "a group of 8 panels." (b) For further information, see remarks under "np-charts."
u	The sample may consist of any convenient number of units or quantities of product, each unit or quantity being of the type that would be used for a c-chart. It is not necessary for the number of units to be constant. For example, the sample may consist of ten radar systems the first month, eight radar systems the second month, etc. However, the term "radar system" should have essentially the same meaning from month to month.	(a) If the number of units varies much from point to point, calculate separate control limits as explained on page 18. (b) If the number of units does not vary from point to point, this type of chart should be converted to a c-chart. (c) For further information, see remarks under "p-charts."
Individual measurements with control limits based on moving range.	Since individual measurements only are plotted, the sample size is 1.	Care should be taken that the meaning of "individual" is essentially the same from point to point. For example, if accounting figures are being plotted, the point should represent a week's data consistently or a month's data consistently, etc. If monthly points are used, five-week months should ordinarily be converted to a four-week basis.

possible. Care should be taken to make sure that the samples are truly representative of the process. Ordinarily, the best kind of sample for process control purposes is the "instantaneous" sample obtained by taking a small group of successive units at regular intervals from the process.

In planning the selection of samples, it is often helpful to list the various known changes in the process which may be able to affect the characteristic or characteristics being plotted. The samples should be selected in such a way as to detect those changes. It is possible that more than one control chart will be needed to control a particular operation.

(2) *Decide on the sampling interval (or checking frequency).* This depends on (a) the cost of making checks and (b) the rapidity with which the process is likely to change. The necessary frequency of check may be every few minutes, every few hours, once a shift, once a day, once a week or once a month. At the beginning it is usually necessary to take more frequent samples than after the process begins to settle and the charts come into control. One of the important responsibilities of the Quality Control Team is to keep reviewing the checking frequencies on all control charts with the object of increasing the interval between checks wherever possible.

(3) *Decide on the sample size to be used.* Ordinarily, this is determined by the type of chart. The table on page 191 will be helpful. It contains a summary of the information given in Section I of the Handbook.

Do not hesitate to use sample sizes other than those recommended here if there is a good practical reason. However, the possible implications of the chosen sample size should be carefully discussed by the Quality Control Team.

(4) *Decide on the centerline and control limits for the chart.* In a process capability study these are merely calculated from the data. In a process control chart they require an engineering decision. Detailed information on making these decisions is given on pages 64–65 and 193–197.

(5) *Provide what is necessary for obtaining data and plotting and handling the control charts.* This includes the following:

a. Provide gages and other devices for making the checks.

b. Appoint someone in the shop to take the samples, make the checks and plot the charts.

c. Train the process checker in carrying out these duties properly, including the marking of x's on the chart when the pattern is out of control. Make sure that the process checker knows what to do about abnormal data or "freaks."

d. Provide suitable forms for recording the data and other forms for plotting the charts.

e. Also provide suitable chart holders and facilities for mounting the holders. For the sake of appearance as well as usability, these should be standard throughout the plant.

Holders can be designed for mounting on benches, pipes, pillars, walls or whatever is available in the area. The fixtures that hold the charts should be such that the charts can be readily removed and replaced. For durability, the charts should be mounted on a backing in such a way that the shop can easily turn to previous sheets. It should be possible to insert fresh copies of the chart on top of the old ones so that a chronological history of the job is made available by turning a few pages.

(6) *Write a layout giving the shop specific instructions on how to use each chart.* The writing of the layout is the responsibility of the product engineer. It should include instructions on obtaining the samples, making the checks, calculating, plotting, marking the patterns and deciding what to look for when the chart goes out of control. The product engineer is usually assisted in this by the other members of the Quality Control Team. As experience accumulates through the quality control meetings, the layout may be modified to include additional information.

A-2.2 Centerlines

On a process control chart the centerline is located by engineering decision. It should represent the place (or places) where the Team has found it is desirable and possible for the process to run. The considerations on which this decision should be based are discussed on pages 64–65.

Three techniques are possible in setting the centerline on a shop chart.

(A) The centerline may be chosen to represent the *desired average* for the process—that is, some single place where the distribution ought to be held most of the time in order to get the best results. The "best results" may refer to the best quality, the highest yields, the lowest cost or the best balance between any or all of these. The decision to use this type of centerline should preferably be based on a process capability study. In some cases the "one best place" for the distribution has been specified in advance as an engineering requirement.

While this type of centerline is sometimes used on R charts or p-charts, it is used more commonly on $\bar{X}$ charts or charts for individual measurements with control limits based on the moving range.

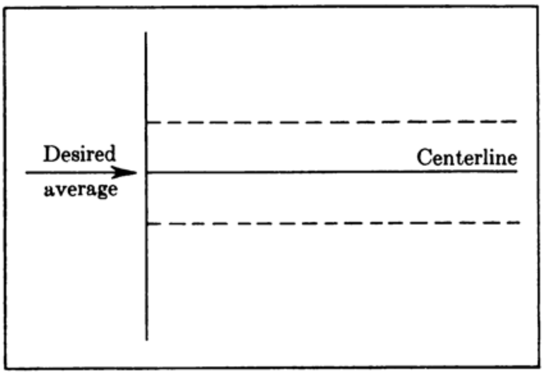

Fig. 204. First method of setting the centerline on a shop control chart: desired average.

(B) In case there is no specific point which represents a desired average, there may still be a high or low limit which the engineer does not want the distribution to exceed. In that case the centerline on the process control chart is made to represent the *highest or lowest permissible average* for $\bar{X}$, R, p or individuals, as the case may be.

This type of centerline can be used for any type of control chart. In the case of a p-chart or R chart it often represents the best the process has been able to do so far. The engineer does not want it to get worse, but he may intend to lower the centerline as soon as the process can be improved. Ordinarily, $\bar{R}$ or $\bar{p}$ should be as close to zero as possible for economic reasons.

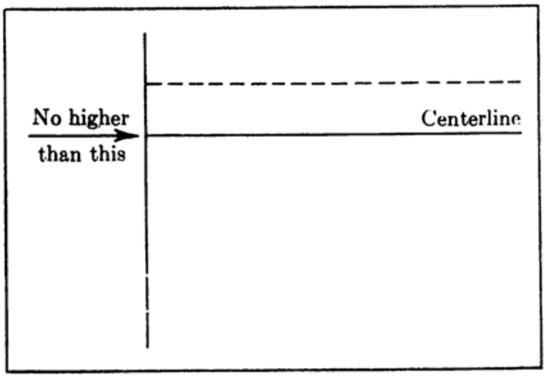

Fig. 205. Second method of setting the centerline on a shop control chart: highest or lowest permissible average.

(C) In many cases there is an area or "band" of acceptable levels within which the engineer is willing to let the process run. For example, we may wish to allow a shift of several thousandths of an inch to take care of toolwear, or unavoidable differences between machine settings or batches of material. We may not care how much the process fluctuates, as long as the distribution does not move outside this permissible band.

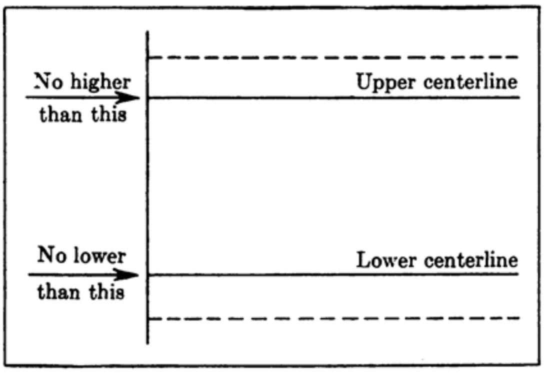

Fig. 206. Third method of setting the centerline on a shop control chart: a band of acceptable averages.

In such cases show two centerlines on the shop chart, one on the high side and one on the low side. This double centerline is used only on $\bar{X}$ charts or charts for individual measurements, never on R charts or p-charts.

Centerlines located by any of the above methods are called "economic centerlines" because they are chosen on an economic or engineering basis. The control limits placed around such centerlines are called "economic control limits."

Precautions to be taken in locating centerlines on shop charts

Never locate a centerline on a shop control chart at a point where it is impossible or impractical for the process to run. Centerlines may, however, be located in such a way as to encourage the process to improve. Sufficient data should be available to show that the improvement is possible. An example is given in Figure 207.

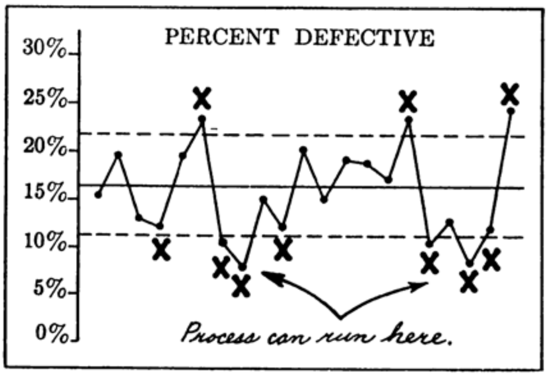

Fig. 207. Shop chart used as the basis for an economic decision.

This chart says it is possible to run the process at about 10% defective even though the current level is about 15% defective. A shop chart on this process could properly be set up with its centerline at 10%. On the other hand, *do not put the centerline on a p-chart at some low percent defective just because you think that such a level would be desirable.* If the chart predicts that the process can run at 10% defective and you want it to run at 2%, improve the process first and then move the centerline down. Also, if you intend to move the centerline down as the process improves, explain this to the operators at the beginning and tell them where it will stop. In the same way, do not put the centerline on an $\bar{X}$ chart, R chart or chart for individual measurements in a place where you have no evidence that the shop would be able to run.

A-2.3 Control limits

In all cases, control limits for process control charts should be located the proper statistical distance from the selected centerline. Once the centerline has been fixed, the control limits follow automatically. The location of the limits is determined by the formulas given on pages 12–21.

The following, however, is one essential difference between the control limits on process control charts and the control limits on process capability studies:

> All process capability studies employ two control limits, one on either side of the centerline. For shop charts it is permissible to omit one of the control limits (on $\bar{X}$ charts or charts for individual measurements) in any of the following cases:
>
> a. Where a double centerline is used on an $\bar{X}$ chart or chart for individual measurements, show only the outer control limit for each of the centerlines. This is because the shop is not required to take action on process shifts that take place between the centerlines.
> b. Where the centerline on an $\bar{X}$ chart or chart for individual measurements is fixed at the highest permissible level, show only the high control limit. This is because the shop is not required to take action when the process is below that level.
> c. For similar reasons, when the centerline is fixed at the lowest permissible level, show only the low control limit.

The lower control limit may be omitted on a p-chart after the process has become stabilized at an economically low level. When this is done it indicates that the shop is not expected to strive for further improvement.

In all cases where a control limit is shown, the shop should be expected to apply tests for unnatural patterns and mark x's where indicated. The presence of x's should always call for some kind of action. If action is not wanted when the distribution moves in a certain direction, this is sufficient reason for omitting the control limit on that side.

A point of special importance on the R chart is that the lower control limit *should never be omitted.* This is because of the great economic importance of the information contained in x's on the low side of an R chart. See pages 168–169.

A-2.4 "Modified" control limits for $\bar{X}$ and R charts

"Modified" control limits are based on a special form of economic centerline, which is designed to let the process run just high enough or just low enough to keep out of trouble with a specification. The restrictions for using modified control limits are as follows:

It is first necessary to make a process capability study and obtain a controlled pattern of R. From this it is possible to calculate the "process spread of individuals," as indicated on page 56. If the process spread of individuals is much narrower than the specification limits, and if product anywhere within specification limits is satisfactory, it is possible to use modified control limits on an $\bar{X}$ and R chart. Do not attempt to use modified limits if any of the above conditions are not met.

Theory of modified limits

When the specified limits are wide and the distribution is narrow, as shown in Figure 208, the distribution can be allowed to move up or down a considerable distance.

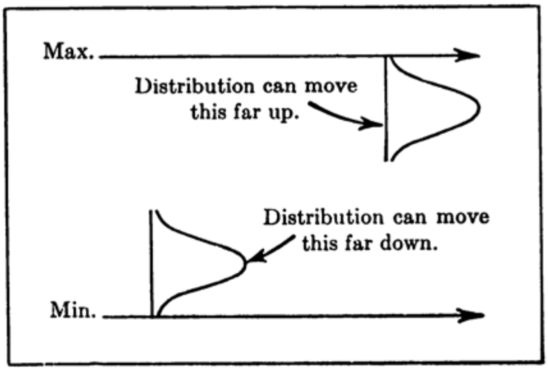

Fig. 208. Conditions for the use of modified control limits.

It is possible to make simple calculations, based on distribution theory, to determine how far the distribution can be permitted to move. The calculations apply to the $\bar{X}$ *chart only.*

Normal distribution

(1) First locate a pair of centerlines on the $\bar{X}$ chart at the highest and lowest permissible point for the center of the distribution. This is done as follows:

a. Find the value of d_2 associated with the sample size to be used on the chart. (See page 131.)

b. Locate the two centerlines for the $\bar{X}$ chart as follows:

Upper Centerline for $\bar{X}$ =

$$\text{Upper Specification Limit} - \frac{3\bar{R}}{d_2}$$

Lower Centerline for $\bar{X}$ =

$$\text{Lower Specification Limit} + \frac{3\bar{R}}{d_2}$$

These two centerlines are shown in Figure 209.

(2) If only one limit is specified (upper or lower), use only the appropriate centerline.

(3) Calculate control limits in the standard way for the size of sample used, by adding $\pm A_2\bar{R}$ to each of the centerline values. The A_2 factors are given on page 12. Show only the outer control limit for each centerline, as indicated in Figure 209.

An example of a chart with modified control limits is shown on page 65.

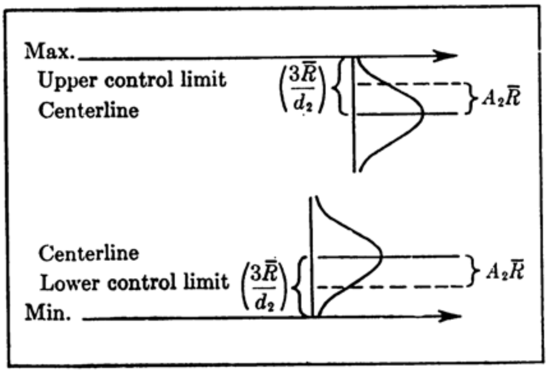

Fig. 209. Determining the location of modified control limits.

(4) Check the location of the modified limits by eye to make sure your calculations are not in error. For samples of 5 the dotted control limit should be about halfway between the centerline and the specified limit (more accurately speaking, about 45% of the distance). This rule is obtained as follows:

Percentage of distance from

$$\text{centerline outward} = \frac{100 \times A_2}{E_2}$$

where A_2 and E_2 vary with the sample size and are obtained from the tables given on pages 12 and 131. ($E_2 = 3/d_2$.)

For samples of 5, $A_2 = .577$ and $E_2 = 1.29$.

$$\frac{100 \times .577}{1.29} = 45\%.$$

Similar calculations can be made for other sample sizes.

Non-normal distributions

Distributions which are not normal may spread more or less than 3 sigma from the average. Consequently it may be necessary to modify the factor "3" in the equations for centerlines in paragraph (1) above. If the distribution is skewed, it may be necessary to use one factor for the side with the long tail and another factor for the side with the short tail. These factors should be estimated on the basis of engineering judgment. A further discussion of non-normal distributions is given in the Engineering Section, pages 56–58.

Corresponding modifications must also be made in the E_2 factors referred to in paragraph (4).

Summary of conditions for using modified limits

(1) If the spread of the process is wider than the distance between specified limits, it is not possible to use modified limits on the $\bar{X}$ chart.

(2) If the spread of the process is just equal to the distance between specified limits, the upper and lower centerlines on the $\bar{X}$ chart will coincide. There is, therefore, no advantage in using modified limits.

(3) It should always be possible to use modified limits on the $\bar{X}$ chart if there is only one specified limit (maximum only or minimum only).

(4) Since the modified limits are derived on the basis of a controlled R chart as determined by a process capability study, it is necessary to maintain a standard R chart at all times wherever modified limits are applied to the $\bar{X}$ chart. If the R chart goes out of control it is no longer safe to use the modified limits on the $\bar{X}$ chart.

(5) No modified limits of any kind are ever applied to an R chart.

A-2.5 Modified limits on charts for individual measurements

Modified limits are sometimes used on charts for individual measurements provided there is adequate knowledge about the shape of the distribution of individuals.

A-2.6 Modified limits for p-charts or c-charts

There is no counterpart for modified control limits which can be used on a p-chart or c-chart. However, when p-charts are used at the end of a production process and where the sample sizes are very large, we sometimes use a special type of control limit on the p-chart which has much the same effect as the modified limits discussed above. The following are the conditions under which the special limits may be used:

> When large amounts of data are combined on an overall p-chart, these data may include many different variations in raw material, part numbers, code numbers, processing batches or inspection lots. These are assignable causes which cannot be studied properly except with individual p-charts at various operations. Superimposed on these ordinary types of causes, however, may be large general shifts or trends which affect the whole shop. The overall p-chart can be used to study these broad shifts and trends by calculating its control limits as follows:

(1) Consider the sample percentages as

individual pieces of data similar to records that might be obtained from accounting.

(2) Calculate control limits for these values using the moving range.

(3) Select as the period on which to base the calculations a time when the shop situation is considered "normal" or free from unusual trouble.

Such control limits will tend to ignore the assignable causes present during the "normal" period but will tend to show up any large general trends. Do not attempt to use these special limits for *p*-charts if the charts are intended for direct process control.

A-3 OTHER METHODS OF CHARTING

Use of "t"-charts and charts for other statistics

In cases where varying sample size is a problem, any of the standard control charts can be plotted as "*t*" charts. The "*t*" chart merely uses a standardized scale for plotting in which "*t*" stands for the number of sigma away from the centerline on the chart. The control limits for the "*t*" chart are drawn at ±3 sigma and the centerline at 0 sigma. If a point on the original control chart would be halfway between the centerline and the control limit, it is plotted on the "*t*" chart at 1.5 sigma. If a point on the original chart would be two-thirds of the way between the centerline and the control limit, it is plotted on the "*t*" chart at 2.0 sigma, and so on. A "*t*" chart always has its control limits the same distance from the centerline, regardless of how the sample size may vary.

The "*t*" chart is useful for certain summary purposes, but is much less useful for process capability studies or process control. The chart is more difficult to interpret correctly than other types of chart. Much information is lost by converting the absolute information into values of "*t*." Out-of-control points, or patterns which are not balanced around the centerline, are likely to be misleading. A "*t*" chart is often more sensitive to the changes in sample size (which are buried in the chart) than it is to the changes in the process which we are trying to detect. A Quality Control Team should therefore use the ordinary types of control chart wherever possible.

The above objections do not apply to control charts for sample maximum values, sample minimum values, sample totals, sample medians or other statistics calculated from samples. It is quite permissible to use control charts for any of these statistics, provided equations are available for calculating the necessary control limits.

Use of the Quality Measurement Plan (QMP) Chart

Quality Assurance (see reference 36) recently changed from the "*t*" chart form of rating to a Quality Measurement Plan based on Bayesian statistics (see reference 37).

Substitutes for $\bar{X}$ and R charts

Engineers sometimes prefer to plot, or have the shop plot, the *total* of a sample of measurements rather than the *average* ($\bar{X}$). This is permissible in the case of constant sample sizes, since the average is derived from the total by dividing through by a constant. Plotting the total instead of the average merely amounts to changing the plotting scale on the $\bar{X}$ chart and has no effect whatever on the statistical analysis. Charts on which totals are plotted instead of averages are known as "total and range charts" or "sum and range charts."

Occasionally some other statistic may be substituted in place of $\bar{X}$. In life testing it is sometimes convenient to use the median of a sample instead of its average. If a sample of 5 units are put on life test the median is known as soon as the third unit has failed. If we were to use the average of the measurements we would have to wait until all 5 units had failed before the point could be plotted. As a rule, however, a Quality Control Team should plan on using $\bar{X}$ unless it has a good reason for doing otherwise.

There are also possible substitutes for the range chart. The most common is the standard deviation of the sample, often designated as "*s*." In general, a Quality Control Team will prefer to use ranges for two reasons:

First, because of the simplicity of calculation.

Second, because the range is a more sensitive indicator of certain types of assignable causes.

Other possible measures of dispersion are the mean deviation, quartile or semi-inter-quartile range, etc. but these are seldom useful for quality control purposes. Other substitutes for the $\bar{X}$ and R chart include charts for "median range" and midranges. See Reference No. 14.

Substitutes for p-charts and c-charts

One possible substitute for the standard p-chart or c-chart is a chart for percentages or counts with control limits based on the moving range. See pages 196–197. Another is the use of standard $\bar{X}$ and R charts for the study of attributes data. While attributes charts are used more commonly for this purpose, it is possible to use $\bar{X}$ and R charts for the analysis of any data, including percentages and other attributes measurements. Merely use the percentages as if they were any other series of numbers.

Charts showing demerits (or other forms of weighted defects) are sometimes used as a substitute for the more usual attributes charts. Demerit charts are much less useful than p-charts or c-charts for detecting and identifying assignable causes. Demerit charts should be used with great care and only where the Team is certain that there is no other practical solution.

Ordinarily, instead of using demerits, the same objective can be achieved by dividing the defects into two groups (major and minor) of if necessary into three groups (critical, major and minor). For purposes of control, plot separate charts for major and minor defects. In some cases it may be sufficient to plot the major defects only.

Major and minor defects are sometimes combined at the end of a process where only a broad general summary is required. The shop, however, usually needs more detailed information, and defects of different seriousness should be kept separate at the point where the process is being controlled.

Substitute forms of the "chart for individual measurements"

Individual measurements are sometimes plotted on a "dot" chart. The process checker merely records a dot or x for each unit in the sample without connecting the points. Individual measurements may also be plotted on a "multi-vari" chart in the form of both maximum and minimum readings on each part. The two readings are connected by a line whose length is proportional to the variability within pieces. If each sample consists of 5 parts, there are 5 lines for each sample. This chart may also be used to record out-of-roundness, eccentricity or out-of-parallel conditions.

The above charts are often used without control limits, and thus can not properly be called "control charts." When control limits are used, they are sometimes located one sigma inside the specification limit. Sigma is obtained from some previous estimate of the process standard deviation.

General comment on non-standard control charts

There is no question that the charts most generally useful for process capability studies and process control are the standard types of control chart. Almost invariably, when an engineer or supervisor feels the need for departing from the standard methods, it is because he does not have a full understanding of what can be accomplished by the regular charts.

In particular, if you constantly find reason to use something other than $\bar{X}$ and R charts or p-charts, it is desirable to deepen your understanding of these two basic tools. This does not mean that non-standard charts should never be used; only that when a decision is reached to do so, one should be certain that he has an adequate reason.

A-4 MAKING CHANGES IN SHOP CONTROL CHARTS

Process control charts are dynamic rather than static, and need to be studied and changed continually. The form of the chart may change with any changes in process, schedules, requirements, product design, etc. The charts in use should be re-evaluated repeatedly in the light of demonstrated results or in accordance with added knowledge. It may be necessary to change the charts from time to time for any of the following reasons:

For ease in interpretation.

For greater readability or usefulness of the scale.

To take advantage of current economic decisions.

To remove charts that are no longer necessary or are not economical.

To consolidate a number of charts into a single chart for economy.

To split a single chart into a number of charts for better analysis.

To reduce or increase the intervals between samples.

To take advantage of improvements.

To incorporate new knowledge gained from process capability studies.

In general, process control charts should change with any changes in the state of knowledge about the job. The charts themselves tend to create the conditions which cause them to be changed.

The need for frequent changes is one of the reasons for having Quality Control Teams. It is also one of the reasons why process control information should be written, if possible, in separate process control layouts.

PART B
Introduction of Charts in the Shop

Most responsibilities in quality control are joint responsibilities, and the introduction of control charts in the shop is no exception. The Quality Control Team, as a whole, is responsible for introducing the charts properly and making sure that they work. However, the supervisor has a special responsibility in this connection, since he is the member of the Team who deals directly with the people. Among the specific responsibilities of the supervisor are the following:

(1) To inform himself on the general principles of quality control as covered in the Fundamental Section of this Handbook.

(2) To understand the workings of all charts in his area.

(3) To explain to all his people who are associated with the charts the following points:

- (a) The importance of the charts.
- (b) How they work.
- (c) The benefits to them of the proper use of the charts.
- (d) The fact that the supervisor, himself, intends to use the charts in running the job.

(4) To make sure that the people who are plotting and reading the charts know how to do it correctly.

(5) To watch the charts, and other process controls, and see that they are functioning as intended.

The following is based on the experience of many shop supervisors in (a) introducing the charts, (b) explaining their benefits and (c) guiding the work of process checkers. Also included for reference is a set of General Instructions for Process Control, and a brief description of a Process Control Layout.

B-1 EXPLAINING THE CHARTS TO THE PEOPLE

It is possible to introduce control charts in the shop without any special explanation. As time goes on and the operators or machine setters begin to ask questions, the supervisor can answer the questions in as much detail as seems necessary. In a short time, the people will become accustomed to the charts and accept them.

In general, however, it is better to prepare the people carefully and in advance for the introduction of charts. Many supervisors do this by holding a meeting with the operators approximately two weeks before they intend to introduce the charts.

All members of the Quality Control Team should take part in this meeting. The discussion should cover the following:

(1) A talk by the supervisor (perhaps 10 minutes in length) explaining that charts are soon to be started on the job. He should give a description of what the charts are for and explain how they have benefited the operators on other jobs. He should also explain how the charts will be made; who will be the process checker; how the samples will be taken and calculated and plotted. He should emphasize that the main idea is to make the product right the first time rather than have to repair it or have it sorted by Inspection.

(2) A demonstration by the quality control engineer (perhaps 20 minutes in length) to explain how control charts work. The quincunx should be used if the first charts to be introduced are $\bar{X}$ and R charts; a box of sampling beads if the first charts are to be p-charts. The quality control engineer should explain the meaning of control limits, the meaning of x's and what should be done when x's occur on the chart.

(3) A talk by the product engineer, in simple terms and at the operator level, explaining how their product is made, why it is important and what are the characteristics that need to be controlled.

(4) A question period (perhaps 20 minutes in length) during which the operators are encouraged to ask questions. The questions may cover the charting, the work of the process checker or the possible effect of the charts on the operators and their jobs.

This meeting should be followed by other meetings after the charts are put into use. At the subsequent meetings, the supervisor should emphasize the charts which are showing improvement and discuss the possible reasons for any which are in difficulty. As the job improves and begins to settle into a state of control, he should see that the operators have the satisfaction of knowing that this is happening. All those connected with the job should feel proud of their share in this achievement.

Importance of these meetings

Much of the success of the control charts in a given area will depend on the way in which these meetings are conducted. Many Quality Control Teams invite not only the operators but also union representatives, maintenance people and members of the wage incentive organization. This leads to a better understanding of the operators' problems.

The key to successful use of control charts in the shop is that the charts must always be used (a) to help the operator or (b) to obtain process information. Control charts must never be used to check up on people.

B-2 SIMPLE EXAMPLES OF THE ADVANTAGES OF CONTROL CHARTS

The following points should be considered by the supervisor in talking with his people about their control charts.

B-2.1 Advantages for machine setters, layout operators, group chiefs and other technical people

The principal benefits for key technical people are likely to be the following:

(1) Quality control involves a new way of running the job. It is possible to determine scientifically just where the process should run.

(2) The charts tend to make the jobs of technical people easier. They can determine the best combinations of operator and machine. They have definite knowledge of the capability of the machine or process. This means that they have better answers to the questions which arise when something goes wrong.

(3) The charts make it possible to work with distributions instead of only with "plus or minus" tolerances. With control charts there are fewer bottle-necks and fewer periods of serious trouble. The beginnings of trouble are picked up promptly so that the whole line does not become filled with bad parts.

(4) When changes are made in a particular operation, the charts will indicate what effect this has on the end product. The chart tells the machine setter which way to adjust the process and also by how much. The charts can be used to separate machine trouble from operator trouble, or to tell when a machine is in need of repair as distinct from when it has a wrong setting.

(5) It is easier to get help promptly from Engineering, and easier to settle difficulties with Inspection, when the job is covered with control charts.

B-2.2 Advantages for operators

The principal benefits for operators are likely to be the following:

(1) The charts show up unsuitable tools, fixtures, gages, piece rates, etc., and this makes it easier to get the conditions corrected.

(2) The operators no longer need to feel responsible for normal process fluctuations or for difficulties which they cannot control.

(3) The charts help the operators turn out more good product in the same amount of time. This tends to increase the operators' earnings.

(4) The charts make the job more interesting. The people can see the progress of the work and follow trends. They also know where the process is running all the time and do not need to be fearful that the product will be rejected by Inspection.

(5) The charts show up the good work which the people are doing. Most operators become very proud of their control charts.

B-2.3 General advantages

Some of the general advantages of control charts are shown in Figures 210–213. The illustrations cover (a) a machine-controlled operation, (b) a manually controlled operation, (c) a case of real specification trouble and (d) a case which appeared to be specification trouble but wasn't. The following is a brief description of the use made of each chart.

Figure 210. Machine operation.

Here the machine setter was able to improve the process by actually doing less work. The machine was originally "over-adjusted." This happens when changes are made on the basis

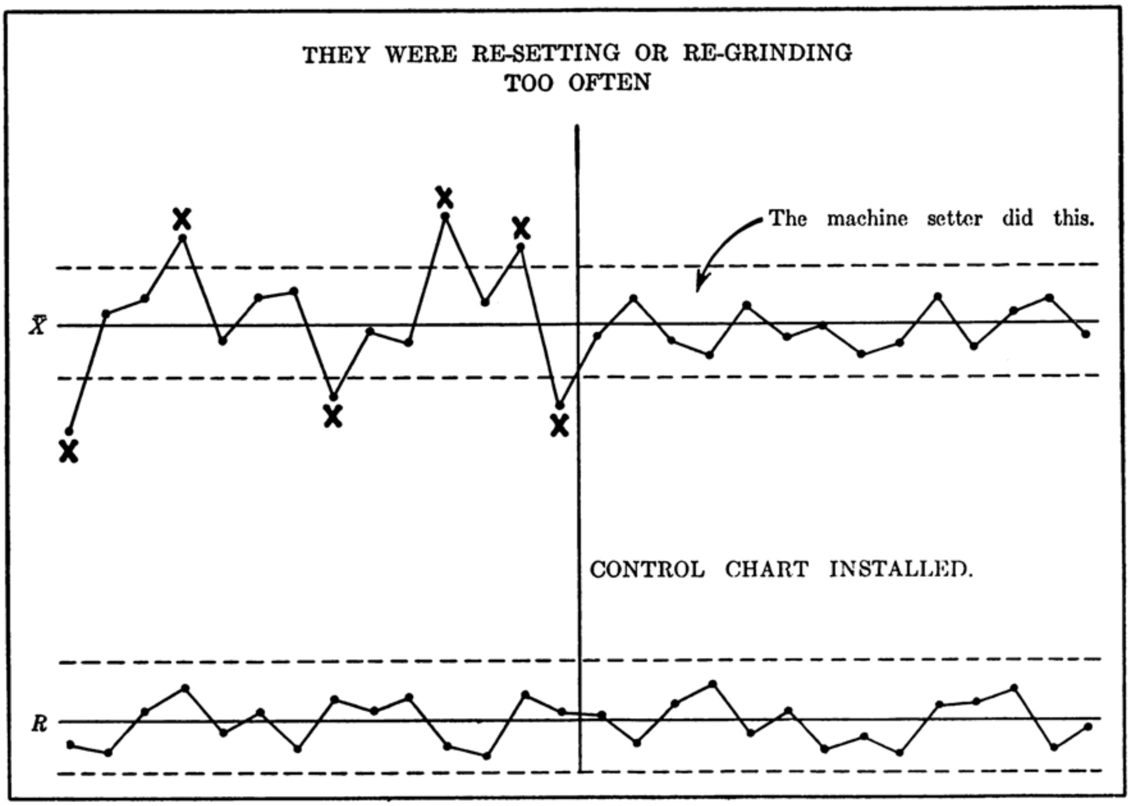

Fig. 210. First example of shop control chart.

of a few isolated measurements. Later the machine setter was given a control chart.

The control chart told him when to re-set and, equally important, when to leave the setting alone. The setting is shown on the $\bar{X}$ chart, the machine capability on the R chart.

Figure 211. Manual operation.

This is an example of a control chart used for operator training. The control limits are based on the work of several experienced operators. Both of the operators shown here were recently hired.

The chart showed that Operator 1 needed further training in the fundamentals of this job (erratic pattern on R chart). Operator 2 was properly trained in the fundamentals (controlled R chart) but there was evidently some bias in her method of working which caused her to work consistently on the low side of nominal ($\bar{X}$ chart).

Both operators were re-trained, but the type of training given in the two cases was very different.

Figure 212. Specification trouble.

In this case the process was running normally (controlled $\bar{X}$ chart, controlled R chart). Still there was product outside of the specification limits. This indicated that the problem might be due to Engineering rather than the Shop.

Figure 213. Process trouble.

This case looked at first like specification trouble, since large quantities of product were found to be out of limits. The patterns, however, were unnatural. Consequently this was not specification trouble but process trouble. Note the change brought about by better maintenance of equipment.

The foregoing examples were based on $\bar{X}$ and R charts. Similar cases could be shown using p-charts or c-charts.

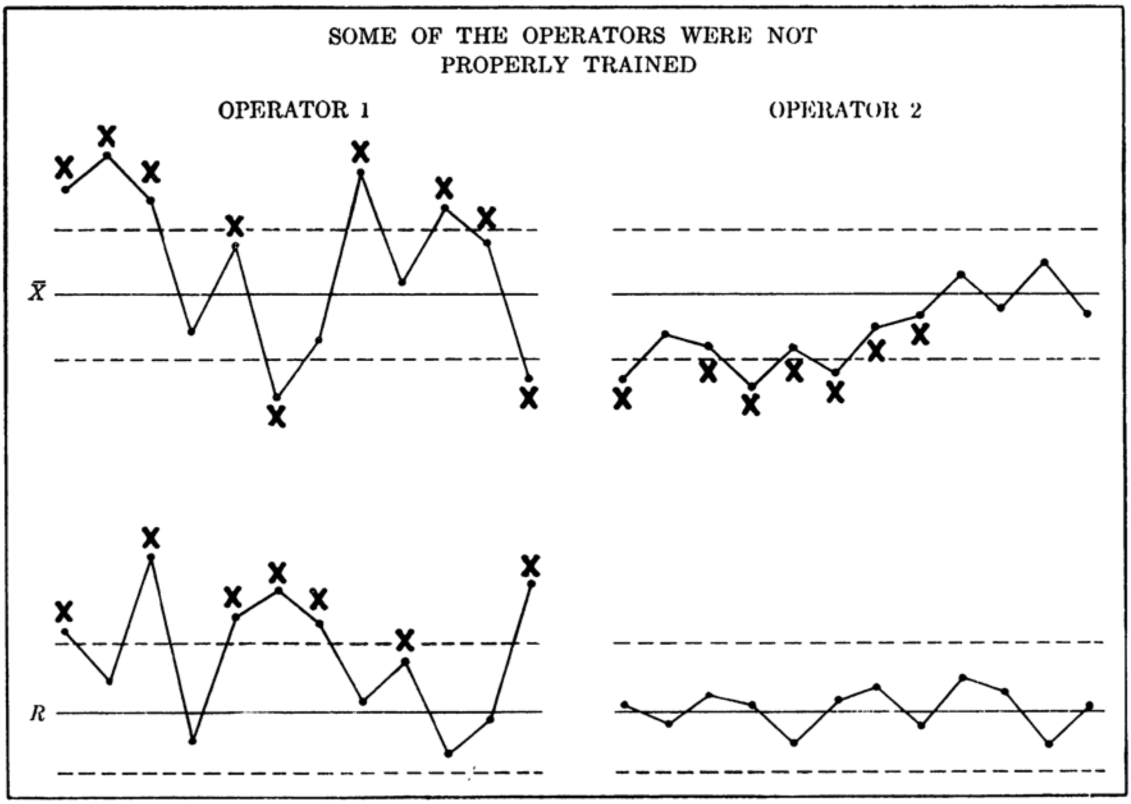

Fig. 211. Second example of shop control chart.

B-3 GENERAL INSTRUCTION FOR PROCESS CONTROL

The following is a general instruction for the use of charts in the shop. The supervisor should make sure that these instructions are understood by all his people who are expected to work with charts.

Instructions for Process Control

1.0 *GENERAL*

1.1 *Purpose*

1.11 The purpose of this instruction is to provide general information on process control procedures and to supplement the process control information given in the Manufacturing and Process Control Layouts.

1.12 All process control activities should be carried out in accordance with this instruction unless otherwise stated in the Process Control Layout.

1.2 *Definitions and symbols*

1.21 Average ($\bar{X}$)
The average is a value obtained by adding up all the individual measurements in a sample and dividing by the number of individual measurements.

1.22 Range (R)
The range is a value obtained by subtracting the smallest measurement in a sample from the largest measurement in the sample.

1.23 Percent Defective (p)
The percent defective is a value ob-

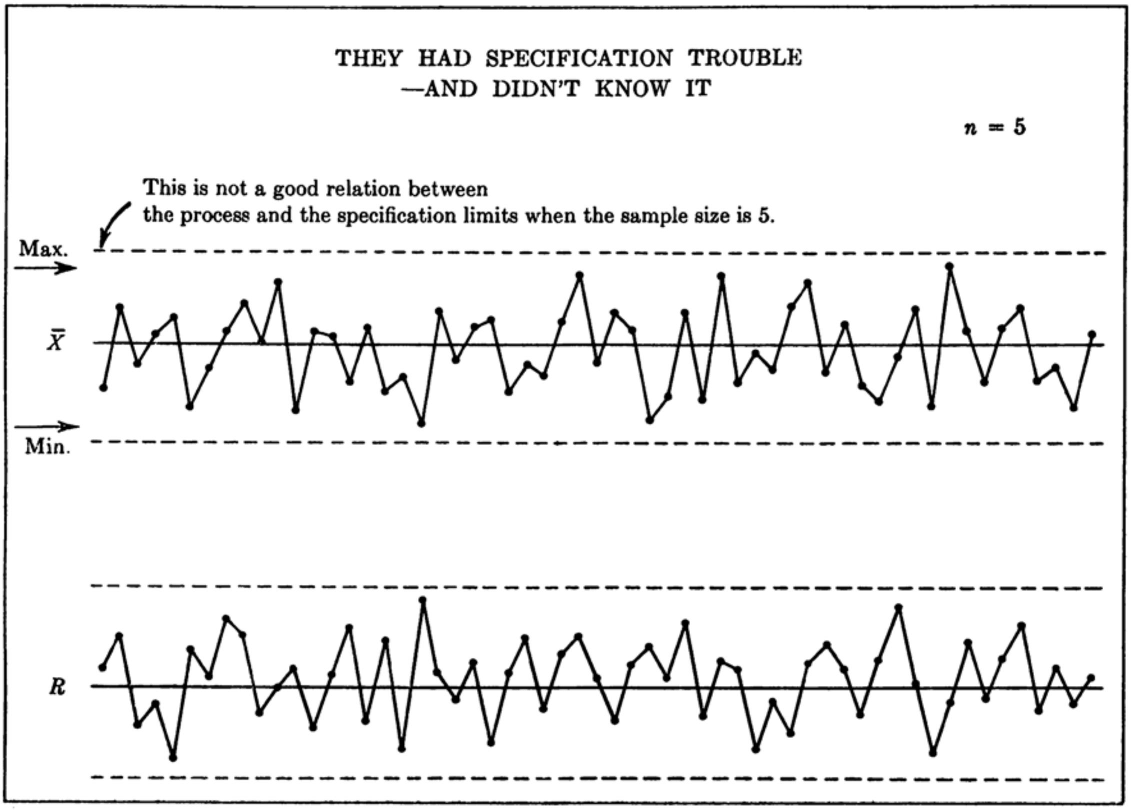

Fig. 212. Third example of shop control chart.

tained by taking the number of defective units found in a sample and dividing it by the total number of units in the sample, and then multiplying the result by 100.

1.24 $\bar{X}$ Chart
A control chart on which a series of averages are plotted.

1.25 R Chart
A control chart on which a series of ranges are plotted.

1.26 p-Chart
A control chart on which a series of percent defective values are plotted.

1.27 np-Chart
A control chart on which is plotted the actual number of defective units in the sample, rather than the percent defective.

1.28 c-Chart
A control chart on which is plotted the total number of defects in a sample rather than the number of defective units.

1.29 Control Chart
A chart consisting of one or more solid centerlines and one or more dotted control limits, which is used to evaluate the state of control of a process.

1.210 Chart with "Moving Range" Limits.
This name is applied to a control chart of individual values for which control limits have been calculated using the moving range technique.

1.211 Sample Size (n)
The sample size is the number of units to be selected and checked in the sample.

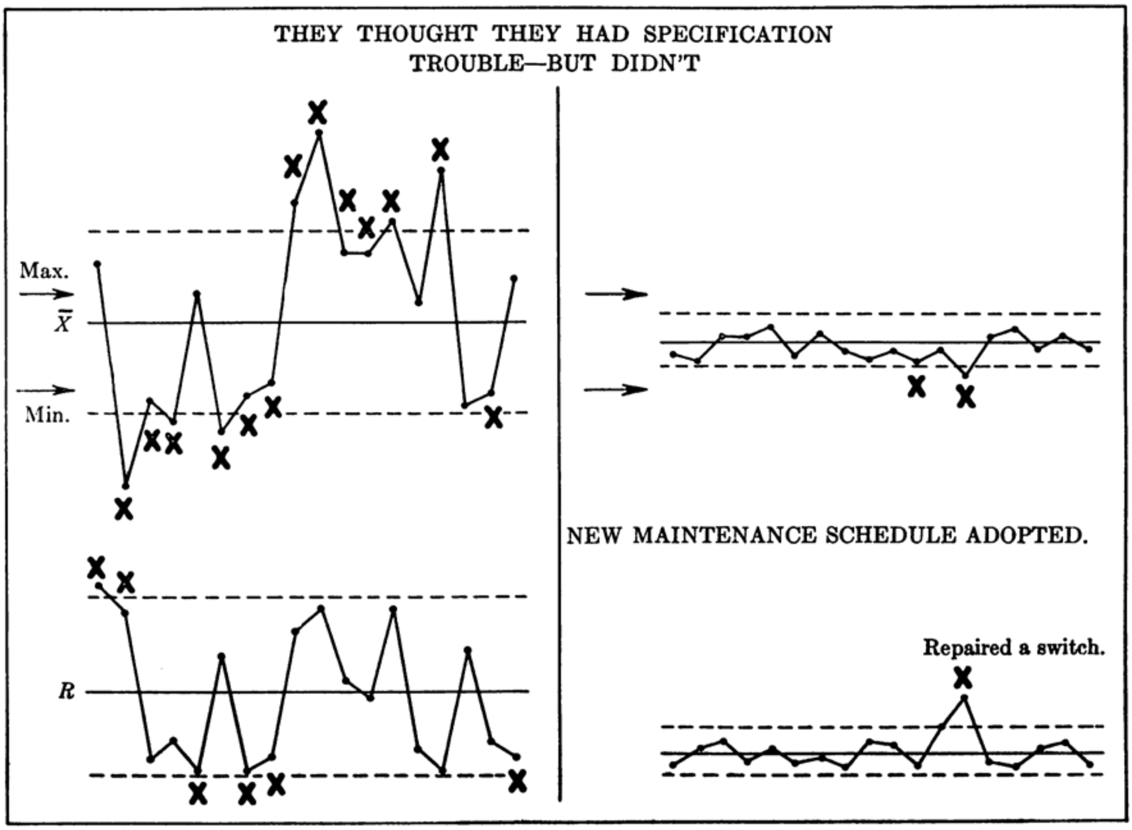

Fig. 213. Fourth example of shop control chart.

1.212 Sampling Interval or Sampling Frequency.
The sampling interval or sampling frequency is the normal spacing between samples. The spacing may be expressed as so many minutes, hours or days, or it may be expressed as so many pieces produced.

2.0 *RECORDS, CHARTS AND FORMS*

The records required for process control consist of (a) data sheets for recording the findings in each sample and making calculations; and (b) control chart forms on which the results are plotted. The data sheets and chart forms are set up specifically for each type of chart.

The process checker should maintain a file of old data sheets for a period of time specified by the product engineer or quality control engineer. This file should also include old copies of shop control charts.

The process checker should obtain blank chart forms and data forms, as required, from the quality control engineering organization or other authorized source.

3.0 *COLLECTING, RECORDING, CALCULATING AND PLOTTING DATA*

3.1 *Selecting the samples*

3.11 Samples should be selected in the specified manner from the process or product.

3.12 If the sample is to be taken directly from a machine or operator, it should consist of the specified number of pieces taken in consecutive order as produced.

3.13 If the layout states that the sample should represent product made over a certain period of time, the sample should be selected at random from all product made during that period.

3.14 The layout should give specific instructions for any cases where a machine has several positions or heads, an operator is using several fixtures or tools, etc.

3.15 The instructions of the layout with respect to checking intervals should be carefully followed. However, care should be taken to avoid regularity in obtaining the sample at exactly the same time each hour or each day.

3.2 *Recording the data*

3.21 Units should be checked as soon as possible after the sample is taken.

3.22 The results of the checking should be recorded on the appropriate data form called for in the Process Control Layout.

3.23 In the case of variables data, a separate data sheet should be kept for each quality characteristic. In the case of attributes data, the information recorded should include sample size, number of defectives and type of defect.

3.24 In recording data for a process control check, it is important to record any supplementary information which will identify the data. For example: machine number, operator's name, shift number, time and date. Also, the process checker should record any known change in the equipment or piece parts as soon as it takes place. For example: new cutting tool introduced, or parts from a new supplier.

3.3 *Making calculations*

The process checker should make all the

necessary calculations called for by the layout. The values of $\bar{X}$, R, p, etc. should be recorded along with the original data.

3.4 *Plotting the data*

The data should be plotted on the appropriate control chart as soon as possible after the calculations are made. All notes identifying the data should be added to the control chart.

4.0 *TESTS FOR UNNATURAL PATTERNS*

4.1 *When to check the pattern*

If the pattern on any control chart no longer appears to be balanced around the centerline, check the pattern for out-of-control indications by making the following tests. The tests should be made as soon as a new point is plotted.

4.2 *How to check the pattern*

In making these tests, consider only one half of the control band at one time.

4.21 Mentally divide the control band into three equal zones. See diagram below.

4.22 Consider the pattern unnatural if it shows any of the combinations listed in the various zones. (If in doubt as to the proper manner of applying these tests, refer to the handbook, pages 23–28.)

4.23 Mark an "x" at the point which contributes the final evidence of unnaturalness. (See page 26.) Mark the "x" above the point if it is on the high side of the centerline. Mark the "x" below the point if it is on the low side of the centerline. Mark all x's about $^{1}/_{8}$ inch from the point being marked.

4.24 Judge the amount of unnaturalness in the pattern according to the number of x's.

4.25 Check whether the background information and notes recorded on the chart seem to be related in any way to the x's.

5.0 *WHAT TO DO WHEN A CHART GOES OUT OF CONTROL*

If out-of-control conditions are observed on any chart, notify the supervisor or his delegate at once.
The reasons for the out-of-control conditions and the action taken should be noted on the control chart at any convenient place near the out-of-control points.
If many such comments are to be recorded, use a code number near the out-of-control points and write the explanations on a separate sheet mounted beneath the control chart, or on the back of the chart.

Upper Half		*Lower Half*	
Single point out			
A	2 out of 3 in Zone A or above		
B	4 out of 5 in Zone B or above		
C	8 in a row in Zone C or above		
		C	8 in a row in Zone C or below
		B	4 out of 5 in Zone B or below
		A	2 out of 3 in Zone A or below
		Single point out	