the number of ranges, which is one less than the number of original measurements. This average range is called $M\bar{R}$.

(5) Multiply $M\bar{R}$ by 2.66 (a constant factor) to get the width of the control limits for the moving range chart. Add this value to (and subtract it from) $\bar{X}$ to get the location of the control limits.

$$\text{Control limits} = \bar{X} \pm 2.66\, M\bar{R}$$

The control limits are shown as dotted horizontal lines. See Figure 25.

(6) Set up a chart on graph paper or a standard control chart form. Be careful not to make the chart too wide. See Figure 25.

(7) Plot on this chart the series of original numbers, and connect the points with straight lines. *Do not plot the moving ranges calculated in Step (2).*

(8) Mark x's on the chart, if necessary, in accordance with the rules given on pages 25–28.

(9) Interpret the chart as explained on page 31. For a fuller interpretation of this type of control chart, see pages 160–161.

B-5.4 Example of calculations for a chart with "moving range" limits

Obtain a set of data as shown in Figure 24.

(1) Centerline for chart:

$$\bar{X} = \frac{\text{total of individuals}}{\text{number of individuals}}$$

$$= \frac{460.4}{15} = 30.7$$

(2) Average moving range:

$$M\bar{R} = \frac{\text{total of moving ranges}}{\text{number of moving ranges}}$$

$$= \frac{53.6}{14} = 3.8$$

(3) Upper control limit

$= \bar{X} + 2.66\ (M\bar{R})$

$= 30.7 + (2.66 \times 3.8)$

$= 30.7 + 10.1$

$= 40.8$

Earnings of a Group of Workers

	% *Earned*	*Change from Preceding Month (Moving Range)*
January (last year)	25.0	...
February	25.3	.3
March	33.8	8.5
April	36.4	2.6
May	32.2	4.2
June	30.8	1.4
July	30.0	.8
August	23.6	6.4
September	32.3	8.7
October	28.1	4.2
November	27.0	1.1
December	26.1	.9
January (this year)	29.1	3.0
February	40.1	11.0
March	40.6	.5
	460.4	53.6

Fig. 24. Typical data for a chart with "moving range" limits.

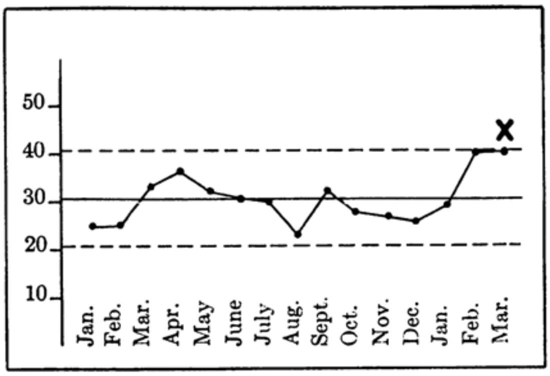

Fig. 25. Example of a finished chart with "moving range" limits.

(4) Lower control limit

$= \bar{X} - 2.66\ (M\bar{R})$

$= 30.7 - 10.1$

$= 20.6$

The completed chart is shown in Figure 25.

B-5.5 Typical uses for charts with "moving range" limits

The following will suggest other applications for this type of chart.

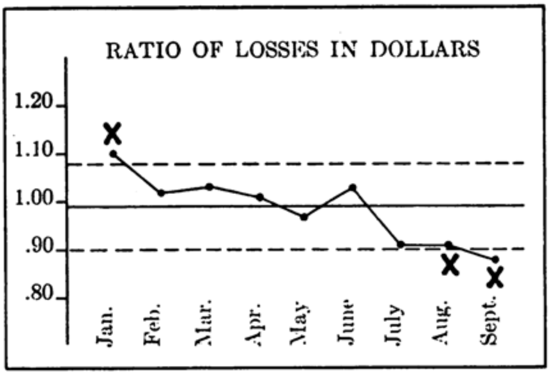

Fig. 26. Chart for merchandise losses.

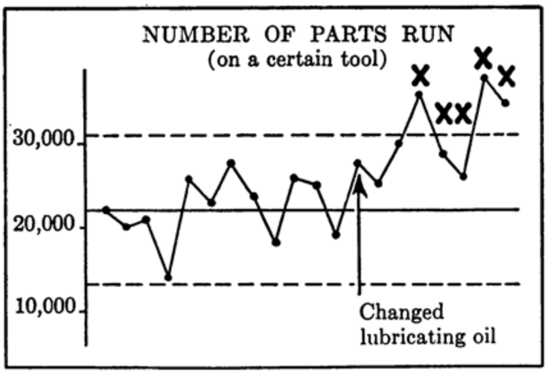

Fig. 27. Chart for length of run after a tool is repaired.

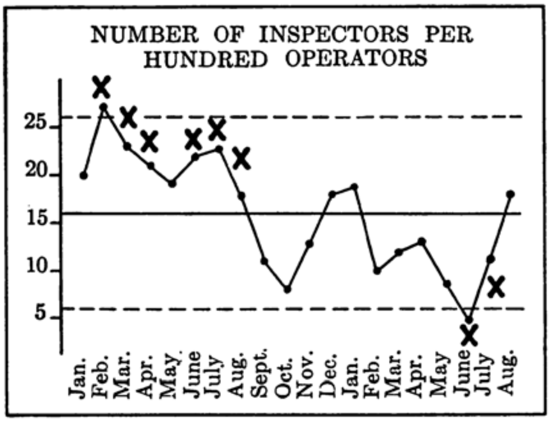

Fig. 28. Chart for inspection ratios.

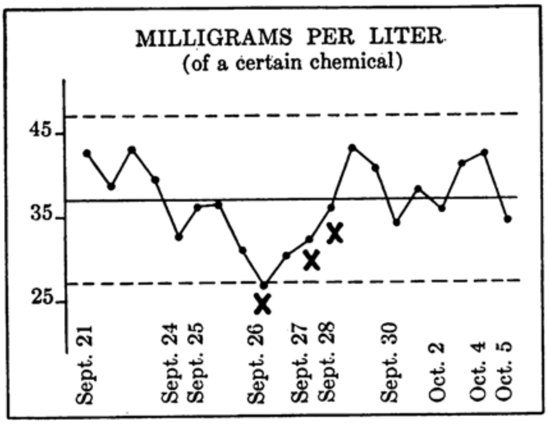

Fig. 29. Chart for chemical analyses.

B-6 TESTS FOR UNNATURAL PATTERNS

The points plotted on a control chart form an irregular, up-and-down pattern which can be classified as "natural" or "unnatural." Ability to interpret the control chart depends on the ability to make this classification.

The following tests are taught in all Western Electric training classes on quality control. They involve (a) making a visual check on each point to see whether it is part of an unnatural pattern, and (b) marking the point with an "x" if it reacts to the visual check. The tests should be memorized and practiced until they can be applied automatically while glancing at a control chart pattern, and *all control charts should be marked immediately with x's in accordance with these tests as the charts are being plotted.*

Failure to mark the x's on a control chart* may make it difficult to interpret the chart correctly.

Theoretical basis for control chart tests

A control chart is essentially a picture of a sampling distribution. That is, it consists of a series of sample values or "statistics" which, if they were gathered together instead of being plotted in sequence, would form a distribution. An example of this is shown in Figure 30.

If the plotted points were gathered together at one end of the chart, they would form a distribution as shown in Figure 31.

There is a large amount of theoretical and practical knowledge having to do with sampling distributions. From this we obtain the following characteristics of natural and unnatural patterns.

* See footnote on bottom of page 25.

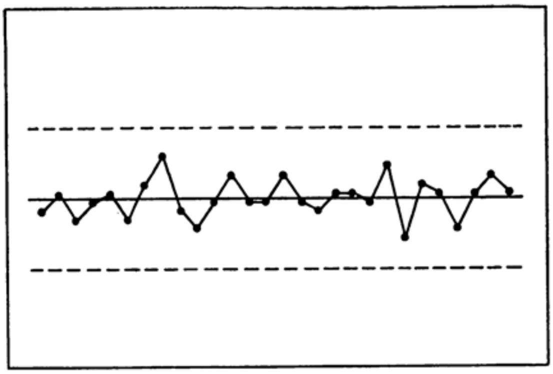

Fig. 30. Typical pattern on a control chart.

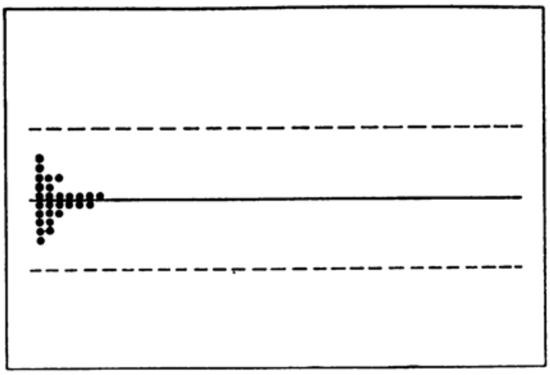

Fig. 31. Grouping of points on a typical control chart.

B-6.1 Characteristics of a natural pattern

The primary characteristic of a natural pattern is that the points fluctuate at random, and obey the laws of chance. This means that they follow no particular recognizable "system" or order. In addition, the following characteristics are found in natural patterns:

> Since most of the values in a sampling distribution tend to cluster about its center, it is natural for most of the points on a control chart to be somewhere near the centerline. Since most sampling distributions tend to be reasonably symmetrical, it is natural for the number of points on one side of the control chart centerline to be about equal to the number on the other side. Since most sampling distributions have "tails" extending as far as ± 3 sigma, it is natural for an occasional point on a control chart to approach or reach the 3 sigma control limits.

These characteristics of a natural pattern can be summarized as follows:

(1) Most of the points are near the solid centerline.

(2) A few of the points spread out and approach the control limits.

(3) None of the points (or at least only a very rare and occasional point) exceeds the control limits.

A natural pattern has all three of these characteristics simultaneously. The pattern will look unnatural if any one of the three is missing.

B-6.2 Characteristics of an unnatural pattern

Unnatural patterns tend to fluctuate too widely, or else they fail to balance themselves around the centerline. A pattern may also be unnatural because it does not fluctuate widely enough. Unnatural patterns always involve the absence of one or more of the characteristics of a natural pattern. For example:

(1) Absence of points near the centerline produces an unnatural pattern known as "Mixture."

(2) Absence of points near the control limits

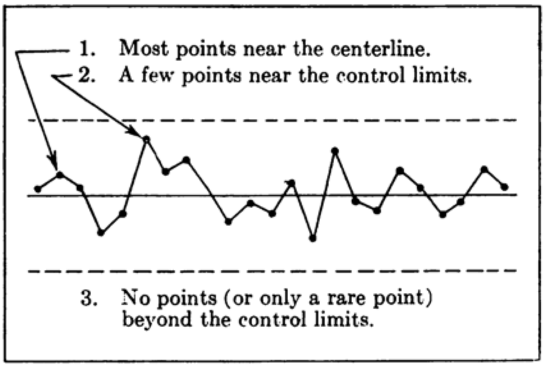

Fig. 32. Three characteristics of a natural pattern.

produces an unnatural pattern known as "Stratification."

(3) Presence of points outside of the control limits produces an unnatural pattern known as "Instability."

Many types of unnaturalness can be recognized informally by glancing at the control chart. When formal tests are available, however, they tend to put the interpretation of patterns on a scientific basis. The tests given below should be applied to all control charts so that everyone will be able to interpret the charts in the same way.

The tests for unnatural patterns are obtained from probability calculations which tell us the "natural" proportion of points that will fall near the centerline, near the control limits, etc. The method of calculating these tests is explained on pages 180–183.

B-6.3 Tests for instability

The most important of the tests for unnatural patterns are the tests for "instability." These are tests to determine whether the cause system is changing.* In applying these tests consider only one-half of the control band at a time; that is, consider only the area between the centerline and one of the control limits. Divide this area mentally into three equal zones.

Since the control limits are 3 sigma limits, each of the zones is one sigma in width. For this reason the zones are sometimes referred to as the "one sigma zone," the "two sigma zone," etc. See Figure 33.

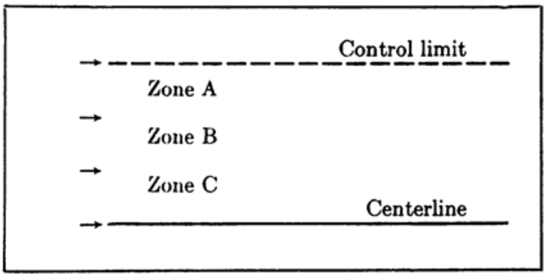

Fig. 33. Method of applying the tests for unnatural patterns.

The pattern is unnatural if any of the following combinations are formed in the various zones:

Test 1. A single point falls outside of the 3 sigma limit (beyond Zone A). See Figure 34.

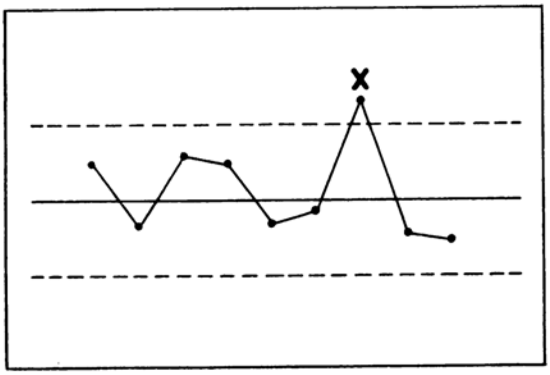

Fig. 34. First test for unnaturalness: a single point outside of 3 sigma.

Mark the unnatural point with an "x."

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* The reader may be interested in the following brief description of the tests used in this book.

The standard control chart test devised by Shewhart (and called by him Criterion I) makes use of 3 sigma control limits as a criterion for indications of lack of control. This criterion is intended to strike an economic balance between the net consequences of two types of error:

(1) Error of the first kind: Looking for assignable causes when no such causes exist; that is, having a point fall outside of control limits when, in fact, there has been no change in the process.

(2) Error of the second kind: Not looking for assignable causes when such causes do exist; that is, having a point fall within the control limits when, in fact, there has been a change in the process.

In extensive process control programs such as those developed at Western, it is generally advantageous to use, in addition, one or more tests based on sequences or runs. At Western Electric three such tests are used in addition to Criterion I.

If assignable causes are present (as they usually are in a process capability study), the multiple tests will detect those causes sooner than will Criterion I alone. If assignable causes are not present (as may be the case in some shop situations), the multiple tests will produce an "x" on the chart more often than will Criterion I alone. The action required to be taken in the shop when an "x" occurs is covered in engineering layouts, which take account of the probabilities associated with the multiple tests. A brief discussion of the multiple probabilities is given on pages 180–183.

Test 2. Two out of three successive points fall in Zone A or beyond.
(Note: The odd point may be anywhere. Only the two points count.) See Figure 35.

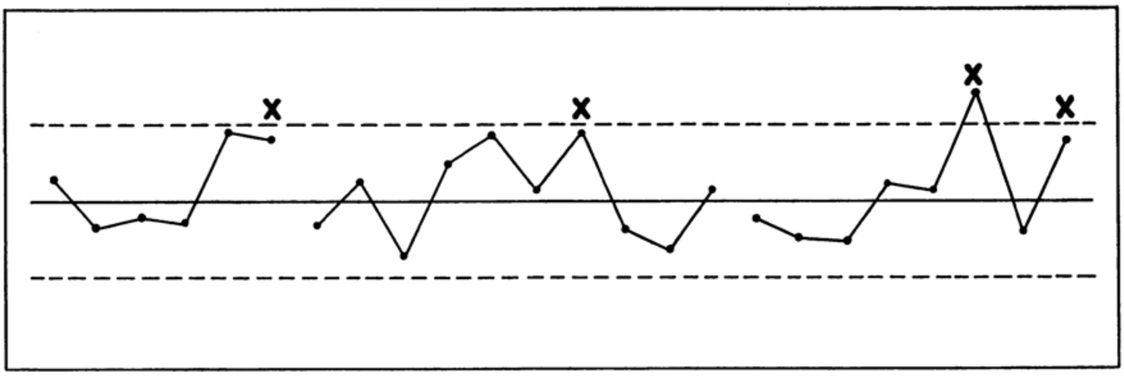

Fig. 35. Second test for unnaturalness: Two out of three successive points outside of 2 sigma.

Mark only the second of the two points with an "x," since the second point is necessary to produce a reaction to the test. In the last example above, the point which is third from the end is marked because it reacted to Test 1, and not because it was part of the test for "2 out of 3."

Test 3. Four out of five successive points fall in Zone B or beyond.
(Note: The odd point may be anywhere. Only the four points count.) See Figure 36.

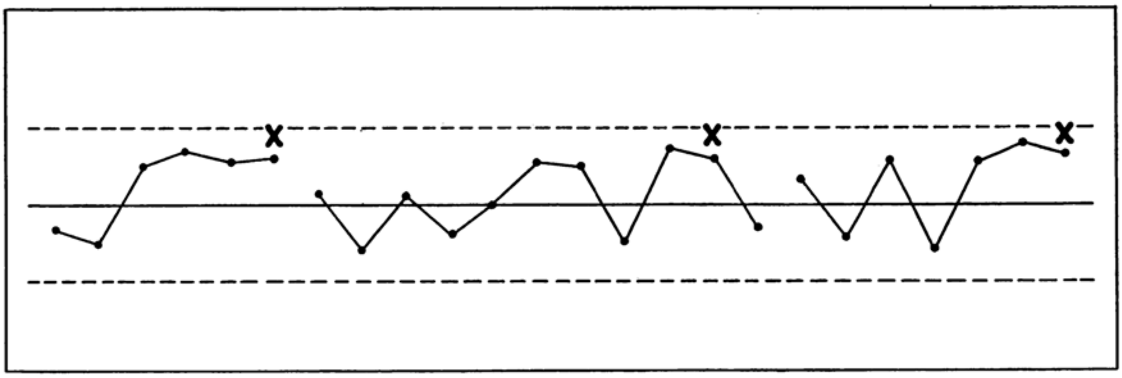

Fig. 36. Third test for unnaturalness: Four out of five successive points outside of 1 sigma.

Mark only the last of the four points with an "x," since there is no reaction to the test until the fourth point.

Test 4. Eight successive points fall in Zone C or beyond.
(This is sometimes expressed as "eight points in a row on one side of the centerline.") See Figure 37.

Mark only the eighth point with an "x," since all eight points are necessary to produce a reaction to the test.

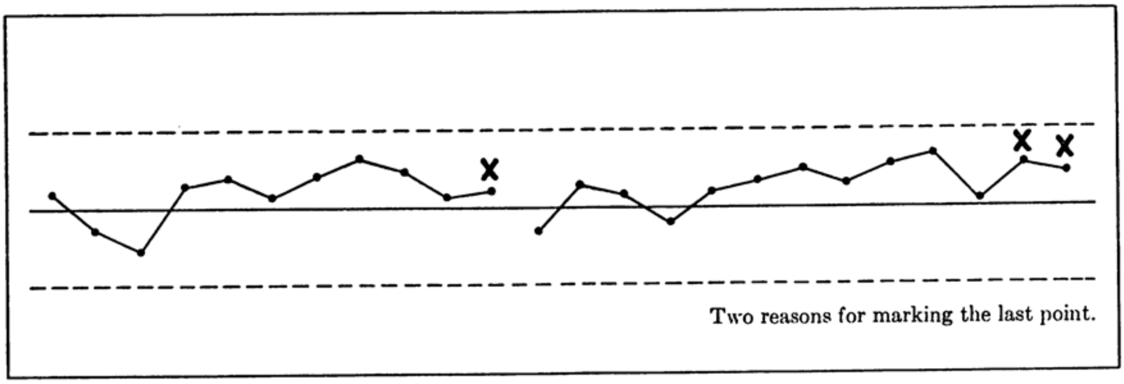

Fig. 37. Fourth test for unnaturalness: Eight successive points on one side of the centerline.

In applying the tests, start with any point you choose (generally the last plotted point) and count backward as many points as are required to make the test. In the second example in Figure 37, the first "x" was arrived at by starting with the twelfth point and counting back to the fifth.

It is possible for the same point to react to more than one test. For example, in the last portion of Figure 37, the final point reacts to the test for "8 in a row" and also to the test for "4 out of 5." In this case there are two reasons for marking the point with an "x." Do not, however, show more than one "x" for the point.

Marking the x's

In marking x's, always put the "x" a uniform distance from the point being marked (preferably about $^1/_8$ inch). Put it directly above the point if the point is in the upper half of the control chart, and directly below the point if the point is in the lower half of the control chart. That is, put the "x" on the side that is *away from the centerline.*

Interpretation of the x's

The greater the instability in the system of causes, the more points will tend to react to these tests and be marked with x's. After the pattern is marked, it is possible to judge the amount of instability by the number of x's.

In looking for the *causes* which are producing the instability, remember that the causes may have affected more points than the ones actually marked. If a point has been marked for being the eighth on one side of the centerline, the cause has probably been in the picture for the whole run of eight points, and quite possibly before.

Applying the tests to the opposite half of the chart

The same tests for instability apply to both halves of the control chart. However, they are applied separately to the two halves, not

Upper 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

Lower Half

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

Fig. 38. Summary of tests for unnatural patterns.

in combination. For example, two points do not count in the "2 out of 3" test if one is in Zone A on the upper half of the chart and the other is in Zone A on the lower half of the chart. Both of the points that count must be in the same half of the chart.

The complete set of tests is shown in Figure 38. Note that Zone A is always next to the control limit, and Zone C is nearest to the centerline.

Other unnatural patterns are discussed in paragraph B-8.

B-6.4 Inconclusive patterns

When a pattern has not yet produced any evidence of unnaturalness, but it appears that one or two more points might complete a certain pattern and produce such evidence, the pattern is sometimes said to be "inconclusive." The following is an inconclusive pattern, because one more point (if it happened to fall in Zone B or beyond) would react and be given an "x".

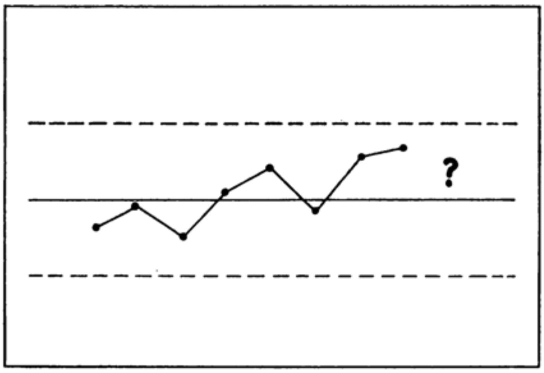

Fig. 39. Inconclusive pattern. Three out of four points in Zone B: one more point could react.

When an inconclusive pattern forms on a control chart, one of two things can be done:

(1) Ignore the pattern until such later time as it may produce an "x."

(2) Obtain more data immediately and give the pattern a chance to complete itself if the cause system has really shifted.

In a process capability study or a designed experiment it is often important to know as soon as possible whether the pattern is going to react. In such cases we try at once to obtain sufficient data to complete or refute the test. In Figure 39, if the next point completes the pattern we say that the cause system has changed. If the next point breaks the pattern we say there is no evidence of a change. Thus the pattern itself can sometimes tell us how much data we need to reach a conclusion.

B-7 TESTS TO BE USED WHEN THE CONTROL LIMITS ARE NOT SYMMETRICAL

The above tests apply when the two control limits on the chart are at reasonably similar distances above and below the centerline. On an $\bar{X}$ chart the control limits are always symmetrical, but on an R chart or p-chart the control limits are sometimes unsymmetrical. Unsymmetrical limits may require a slight change in the application of the tests. For information on this see pages 182–183.

B-8 OTHER UNNATURAL PATTERNS

The following patterns should be watched for in addition to patterns of instability. The ability to recognize these patterns can greatly increase the usefulness of the control chart, by permitting a fuller interpretation of its meaning. These patterns are different from the patterns of instability in that *both halves of the control chart are considered together in looking for the patterns shown below.*

These patterns are marked with *circled x's*

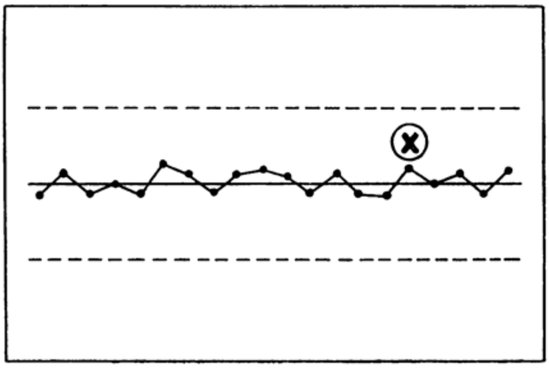

Fig. 40. Pattern of stratification.

to distinguish them from the patterns of instability.

(1) Stratification

If the up-and-down variations are very small in comparison with the width of the control limits, the control chart indicates stratification in the samples. This means that the sampling is being done systematically in such a way that two or more different distributions are represented. See pages 172–174.

Consider that stratification exists when 15 or more consecutive points fall in Zone C, either above or below the centerline.

(2) Mixture

If the pattern shows a tendency to avoid the centerline, with too many points near the control limits, this is an indication of mixture. See pages 169–170, 171, and 179–180.

Consider that mixture exists when the chart shows 8 consecutive points on both sides of the centerline with none of the points falling in Zone C.

(3) Systematic variable

The presence of a systematic variable in the process is indicated if a long series of points are high, low, high, low without any interruption in this regular sequence. See pages 175–176.

(4) Tendency of one chart to follow another

Two variables are likely to be related to each other if a long series of points on their respective patterns move up and down in unison. See pages 176–177.

(5) Trends

Trends may be indicated by:

(a) x's on one side of the chart followed by x's on the other.

(b) a series of consecutive points without a change in direction. See Figure 44 and pages 177–179.

For other information on unnatural patterns, see Part F in the Engineering Section (pages 149–183).

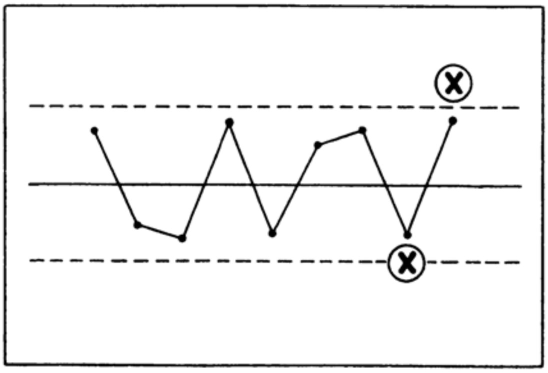

Fig. 41. Pattern of mixture.

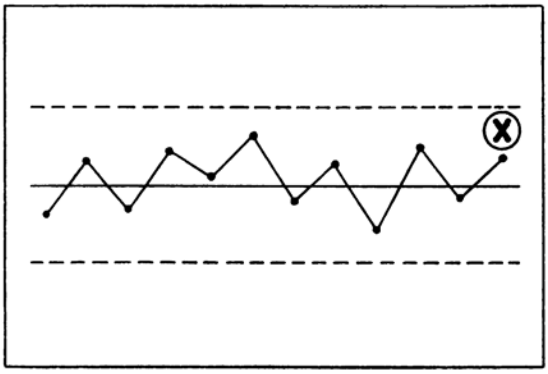

Fig. 42. Pattern showing a systematic variable.

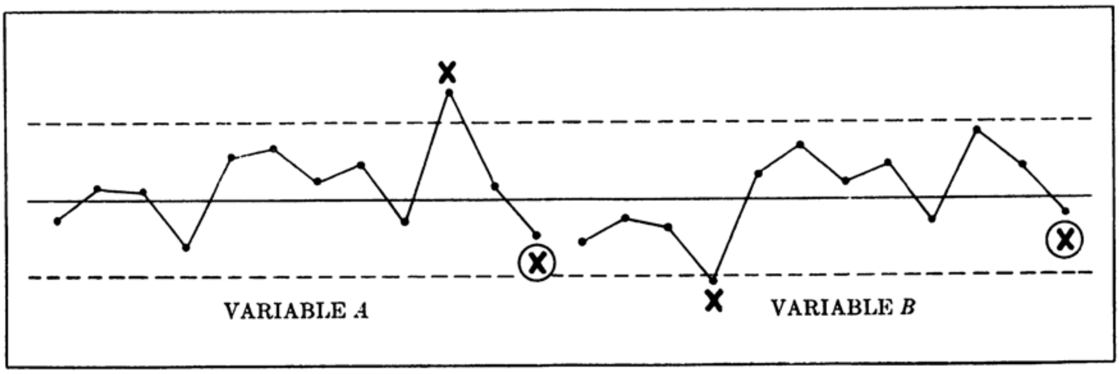

Fig. 43. One control chart follows another.

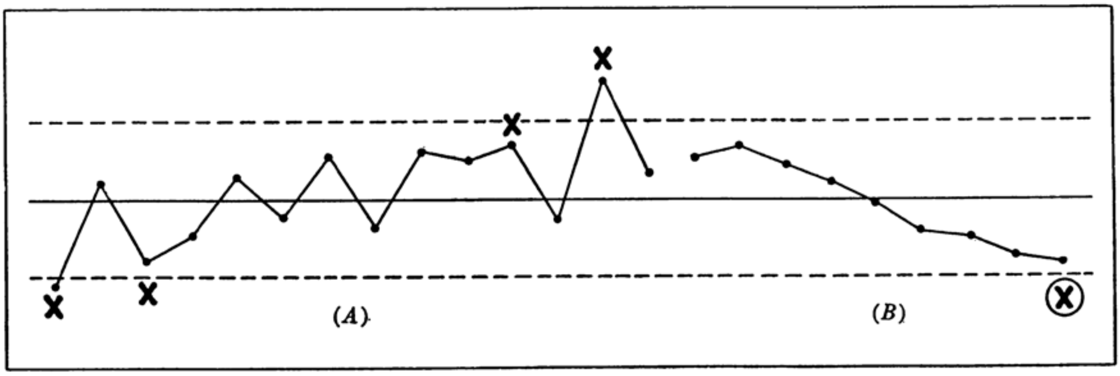

Fig. 44. Trends.

B-9 SIMPLE INTERPRETATION OF CONTROL CHARTS

B-9.1 Meaning of the R chart

Keep in mind that the R chart shows *uniformity* or *consistency*.

If the R chart is narrow, the product is uniform. If the R chart is wide, the product is not uniform. If the R chart is out of control, something is operating on the process in a non-uniform manner.

Machines in good repair tend to make the product more uniform. Carefully trained operators also tend to make the product more uniform.

In looking for causes when an R chart is out of control, look for poor repair or poor maintenance if this is a machine-controlled process. Look for new operators or something disturbing the operators if this is an operator-controlled process.

B-9.2 Meaning of the $\bar{X}$ chart

Keep in mind that the $\bar{X}$ chart shows where the process is *centered*.

If the $\bar{X}$ chart is natural, the center of the process is not shifting. If the $\bar{X}$ chart shows a trend, the center of the process is moving gradually up or down. If the $\bar{X}$ chart is erratic and out of control, something is changing the center rapidly and inconsistently.

Processes are ordinarily centered by:

a. A machine setting.
b. Some other process adjustment.
c. The characteristics of the particular material or piece parts being used.
d. A bias or change in technique on the part of an operator or inspector.

Check these possible causes when the $\bar{X}$ chart is out of control.

$\bar{X}$ charts can also be affected by out-of-control conditions on the R chart. If the $\bar{X}$ chart and R chart are both out of control, look first for the causes affecting the R chart.

B-9.3 Relationship between $\bar{X}$ chart and specification

To find the relationship between the process and the specification proceed as follows. *Both the $\bar{X}$ chart and the R chart must be in control before this check is made.*

(1) In the left-hand margin of the chart, along the $\bar{X}$ scale, draw one or more arrows to represent the specification limits. See Figure 45. The arrows may represent the tolerances specified on a drawing, a proposed specification, or merely some standard we wish to hold for economic reasons. Label each arrow "Maximum" or "Minimum," depending on whether it is an upper or lower limit.

(2) Check the shape of the distribution roughly by plotting the data in a frequency distribution as explained on pages 138–139. If the shape is roughly symmetrical, make the calculation explained in Step (3). If the shape is noticeably skewed, with a long thin tail on one side and a sharp cut-off on the other, proceed as in Step (4).

(3) For a symmetrical distribution, note the distance between the centerline on the $\bar{X}$

chart and one of the control limits. Multiply this distance by $\sqrt{n}$ and note whether it falls outside of the specification. If it does, some of the product from which these samples were taken is probably out of limits.

(4) For unsymmetrical distributions make a similar calculation, but allow more on the long side and less on the short side.

In the case of samples of 5, it is convenient to memorize the following:

a. If the distribution is symmetrical, the space between the control limit and the arrow should not be less than the space between the control limit and the centerline.
b. If the arrow is opposite the control limit, from 5 to 10% of the product is probably out of limits.
c. If the arrow is opposite the centerline, about 50% of the product is probably out of limits.

It is sometimes helpful to sketch the distribution of individuals on the $\bar{X}$ chart as shown in Figure 45. This provides a quick visual means of judging whether there is conflict between the process and the specification.

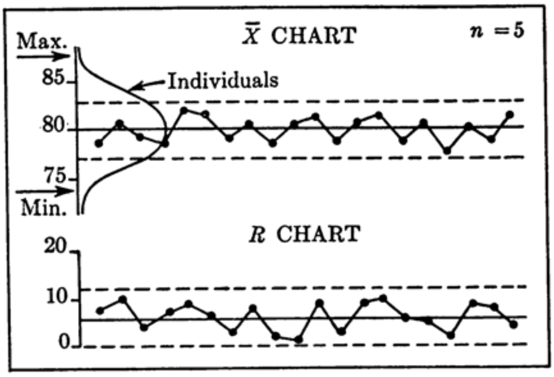

Fig. 45. Showing the probable spread of individuals on an $\bar{X}$ and R chart.

B-9.4 Meaning of a p-chart (or other attributes chart)

Keep in mind that a p-chart shows *proportion:* the proportion of product classified as defective if it is a "percent defective" control chart, the proportion classified as good if it is a "yield" control chart, etc. When the pattern changes on a p-chart, it means there is a change in proportion.

On a percent defective control chart, a change in level may mean:

(a) The percentage of bad product is increasing or decreasing, or
(b) We are not calling the same things defective as before.

Check both of these possibilities in interpreting the p-chart.

If the p-chart is erratic, look for causes which come and go spasmodically. Poorly trained operators and poorly controlled piece parts are two of the most common causes. An erratic p-chart is frequently a sign of need for further process controls.

B-9.5 Meaning of a chart of individual measurements

On a chart of individuals, look first for trends. Trends will appear in the same way, and mean the same thing, as on an $\bar{X}$ chart.

Look second to see whether the fluctuations are becoming narrower or wider. The fluctuations show uniformity or consistency, in much the same manner as an R chart.

Look third to see whether the pattern stays far away from one of the control limits. This may indicate that the distribution is "blocked" on that side, or has a short tail on that side and a long tail on the other.

Look fourth for any obvious peculiarities in the pattern, such as cycles or "bunching." Your knowledge of the process must tell you the probable causes for such peculiarities.

B-9.6 Conclusion

It is possible to go as deeply as we wish into the interpretation of control charts. Some of the less obvious meanings of the charts are explained in Engineering Parts A and F. However, the most important meanings are very simple, and anyone can learn to make these interpretations after seeing only a few charts. Engineers and supervisors who understand the simple principles outlined in this section will be able to make effective use of the charts in a wide variety of problems.

PART C
Essential Elements in a Quality Control Program

Introduction

It is fairly common to find control charts used to solve individual, isolated problems: for example, to determine the capability of a particular machine; to encourage the operators in a given area to be more careful; to solve a particular difficulty having to do with engineering specifications, etc. Such isolated uses of control charts are spoken of as *quality control applications*, but they do not constitute a *quality control program*. A "program" implies the regular, systematic and continuing application of the charts (and of certain other closely related techniques) to the problems in a given area, as the problems arise. The program usually starts with Shop and Engineering problems and is later extended to fields outside of direct engineering and manufacturing—for example, the field of *inspection* or of *scientific management*. A quality control program requires (a) an understanding of the statistical techniques, (b) a plan of development and (c) a series of systematic steps in carrying out this plan. While the details of planning may vary from location to location, the schedule of development at Western Electric normally includes the following:

(1) Management selects a certain area (a Shop, a type of product, a group of operations, etc.) as the place to begin work.

(2) A training program is conducted to acquaint all engineers and supervisors, and all members of management, with the fundamentals of control charts.

(3) Management provides one or more quality control engineers, trained not only in using the charts themselves but also in helping other people to use them effectively.

(4) Management sets up one or more "Quality Control Teams," consisting of a product engineer, an Operating supervisor and a quality control engineer. The Team is made responsible for all quality control applications in its area.

(5) Management states a goal toward which the Team will direct its efforts. The goal may be (a) cost reduction, (b) improved quality, (c) reduction of scrap, rework, repair time, etc., (d) elimination of "bottlenecks" and other interruptions in the shop, (e) increased shop efficiency, (f) reduced inspection, (g) better information about processing variables, (h) more stable production processes. The Team is expected to report its progress at regular intervals.

(6) Management guides the program through its successive stages to make sure it is developing properly.

Normal stages of growth

The program normally develops through several phases, as follows. The time of development varies from location to location, but each phase may require as much as one to three years. The time can often be shortened by good preliminary planning.

Phase I. Initial Development.
This includes (a) training, (b) setting up teams, (c) overcoming the initial resistance to control charts, (d) developing the necessary cooperation between Operating and Engineering.

Phase II. **Shop Coverage.**
This includes (a) making the initial capability studies or performance studies and (b) discovering the proper number and type of charts for use in the shop. During this phase management expects to obtain results in the form of (a) reduced merchandise losses, (b) reduced inspection and (c) greater stability of shop processes.

Phase III. **Engineering.**
This includes (a) renewed emphasis on process capability studies, (b) use of designed experiments, (c) direct attack on fundamental engineering problems. During this period applications may also be started in clerical operations, wage incentives and all areas of scientific management.

Phase IV. **Research.**
The emphasis centers on process capability studies and their use in exploring unknown methods and processes, developing new and improved techniques, eliminating difficult or expensive operations, making improvements in machine, tool and product design. The management program may be extended to include surveys, audits and various forms of research.

Management should note that, throughout this program, the primary emphasis is on Process Capability Studies. These involve the basic use of control charts to detect assignable causes and solve problems. All other parts of the program are based on, and carefully integrated with, the Process Capability Studies.
The Process Capability Studies are reinforced or supplemented, where necessary, by other techniques such as Designed Experiments, Shop Charts and scientific plans for Inspection. The following pages describe these parts of the program in a general way, and show how they can be integrated to make a complete workable system.

C-1 PROCESS CAPABILITY STUDIES TO OBTAIN INFORMATION AND SOLVE PROBLEMS

C-1.1 Definition of the term "process capability study"

In this book the term "process capability study" means the systematic study of a process by means of statistical control charts in order to discover whether it is behaving naturally or unnaturally; plus investigation of any unnatural behavior to determine its cause; plus action to eliminate any of the unnatural behavior which it is desirable to eliminate for economic or quality reasons. The natural behavior of the process after unnatural disturbances are eliminated is called the "process capability."

The information developed from the process capability study is used in two areas as follows:

(1) The immediate information results in the solution of many Engineering problems. It is used for (a) setting up shop processes, (b) investigating shop troubles, (c) establishing or checking on specifications, (d) obtaining new knowledge on cause and effect relationships or similar engineering questions, and (e) determining normal losses, normal wage incentive frequencies and other normal standards of all kinds. For a detailed list of the problems which can be solved through process capability studies, see pages 46–47.

Many of the solutions to these problems result in formal cost reduction. Consequently, one of the objects of a process capability study is to discover opportunities for, and aid in the realization of, cost reduction savings.

(2) If the initial capability of the process is not good enough to solve the problems listed above, the information on the control charts can be used to set up a new process having a different and better

capability. This procedure is continued until the problems are solved, or until the engineer is satisfied that they can not be solved economically.

For a description of the scientific steps in making a process capability study, see page 47. Note particularly the provision for repeating the cycle of steps until a solution is found.

C-1.2 Theoretical basis of a process capability study

The theory of the process capability study is covered in detail in Engineering Part A. The following is a brief graphical summary of the theoretical basis.

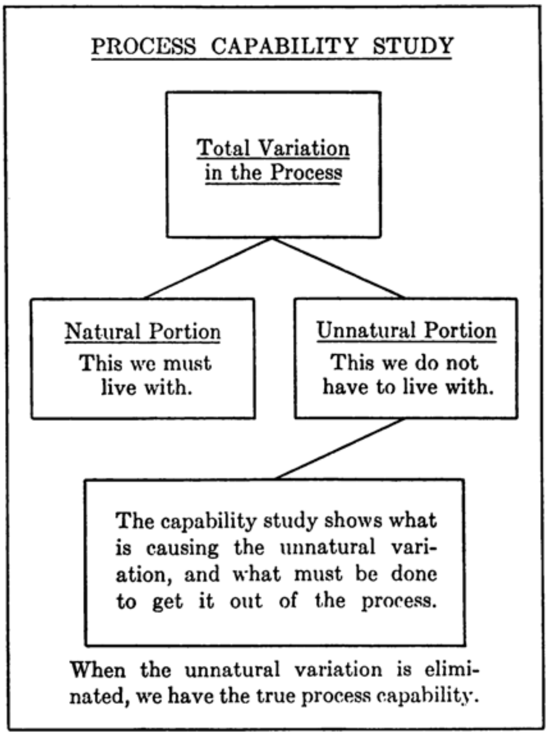

Fig. 46. Theoretical basis of a process capability study.

The essential points for management to keep in mind in connection with these studies are the following:

(1) In most processes, a capability study shows a large amount of initial variation. Some of the variation is natural: it results from the normal variations in people, materials, methods, tools, machines and other process elements. Some of the variation, however, is unnatural: it is due to things that can be changed or corrected. The thing that can be changed or corrected may be a *shop-type variable* (operators not fully trained, machines or fixtures not properly maintained, poor control of plating or heat-treating operations); or it may be an unsuspected *relationship* or *correlation*.

(2) If capability studies have not been made on the process previously, the unnatural variation is likely to be by far the greater part of the total. It may also be the part that gets the shop into trouble, makes engineering experiments inconclusive and causes high manufacturing and inspection costs.

The process capability study will work to detect, and subsequently to reduce or eliminate, the unnatural variation. In the meantime, however, the unnatural variation, in itself, is a rich source of information for both Engineering and the Shop. *Unnatural variations will produce significant patterns on a control chart, and these in turn make it possible to detect and study the significant "cause and effect" relationships.* It is possible for the shop and engineers to take deliberate advantage of unnatural patterns on a control chart in order to obtain (a) quality improvement, (b) cost reduction or (c) new knowledge about the process.

Engineering Part A explains how the *elimination* of unnatural variation can result in

(1) proper standards.
(2) realistic specifications.
(3) good predictions, forecasts and estimates.
(4) a reliable measure of machine capability, operator capability, and the capabilities of tools, materials, methods, designs, etc.

It also explains how *taking advantage* of unnatural variation can result in

(1) an improved process.
(2) lower costs of manufacture.
(3) less inspection.
(4) information about processing variables.
(5) the solution of many perplexing engineering problems.

All these results depend on being able to distinguish between natural and unnatural variation. Process capability studies are a method of detecting, studying and doing something about unnatural variation.

C-1.3 Statistical procedure in the process capability study

The following is a brief summary of the procedures used in making a process capability study.

(1) The person who makes the study is ordinarily a supervisor or engineer. Many process capability studies are made jointly by the members of a Quality Control Team.

(2) The person making the study obtains data from the process and plots it on control charts. The charts show immediately whether the process is operating in a normal fashion.

(3) If the process is not operating normally, the patterns tend to fall into one of a dozen recognizable types, which can then be associated with the causes working in the process. For a detailed discussion of the various types of pattern, see pages 161–180.

(4) In case the disturbing causes are not immediately apparent on plotting the first charts, there are definite techniques to follow in tracing the disturbances to their source. First the study is broken down according to "production paths." That is, the data are split according to operators, machines, shifts, suppliers or whatever is believed to be a controlling element.

(5) If this does not yield the answer, the study is broken down more precisely by using a statistically designed experiment. This makes it possible to study many variables at once, including any interactions between them. It is also possible to determine which variables should be included in a new process, or one under development, and predict its general capability before the process is even set up.

(6) As rapidly as the unnatural disturbances are identified they are

a. eliminated,
b. reduced to an economical level, or
c. deliberately used to advantage as a regular part of the process.

(7) The detection of unnatural disturbances is continued until (a) the process is reduced to its true capability, as shown by long-continued natural patterns on a control chart; or (b) the process reaches an economical point beyond which it is evident that no further large gains will be realized. At this point the demonstrated behavior of the process, as shown by the control charts, is taken to be the "process capability."

C-1.4 Economic significance of the process capability study

Once the capabilities of the process are known, it becomes possible to set up the right shop controls, obtain changes in uneconomical or unnecessary requirements, minimize inspection and set proper standards. Lower inspection costs and lower costs of manufacture are two of the natural by-products of process capability studies.

C-2 PROCESS CONTROL CHARTS TO SECURE TANGIBLE RESULTS IN THE SHOP

C-2.1 Definition of the term "process control chart"

In this book the term "process control chart" means a control chart maintained by, and for the benefit of, the Operating organization in the shop. It is preferably based on a process capability study. The shop chart itself serves as a continuing capability study. It is used (a) to prevent defects, (b) to detect shop troubles at the source and (c) to achieve a stable, smoothly-running process that will combine high quality with minimum cost. For a detailed discussion of the purposes and planning of process control charts, see the Shop Section, Part A. Process control charts, like process capability studies, result in cost reduction if they are properly planned.

C-2.2 Theoretical basis of the process control chart

The theory of process control charts can be explained in three steps, as follows:

(1) The object of charts in the shop is to keep distributions where we want them. The intention is to keep the distributions moving down the most economical path day after day, as shown in Figure 47.

(2) In the absence of shop control charts, unwanted variables creep in and disturb the distributions as shown in Figure 48.

The results of the unwanted variables are quality troubles, poor efficiency, trouble in meeting schedules, excessive rework or scrap, and excessive amounts of product rejected by Inspection.

(3) Process control charts prevent these troubles in the manner shown in Figure 49. The key numbers indicate the information given by the chart and show how the shop is able to make use of this information.

Process control charts are designed to pick up unwanted variables one by one as they enter

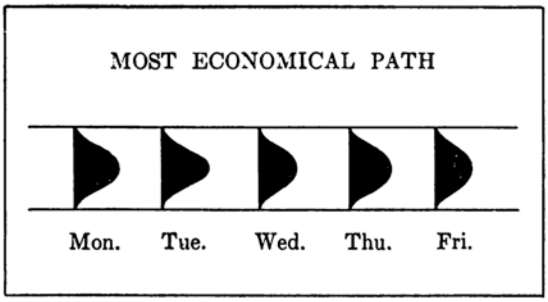

Fig. 47. Desired behavior of a series of distributions in the shop.

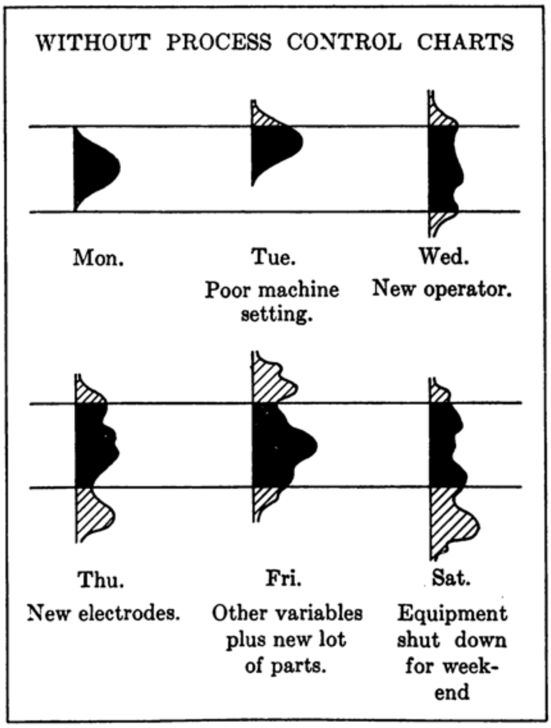

Fig. 48. Effect of unwanted variables in a process.

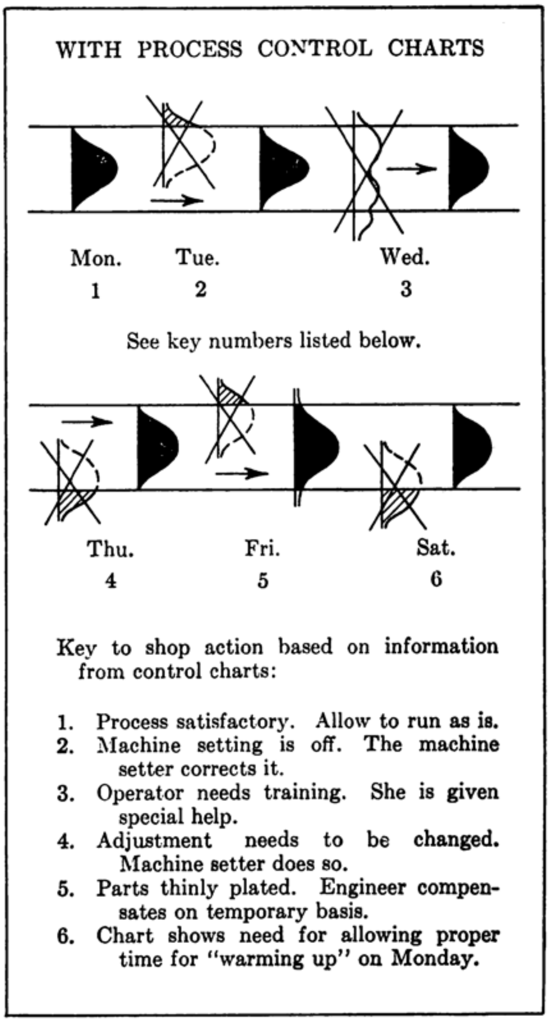

Fig. 49. How shop control charts act to prevent or eliminate unwanted variables.

the process—while their effects are still so simple that the shop can do something about them. In addition, many undesirable variables never enter the process at all, because they are prevented or forestalled by the control charts.

C-2.3 Importance of process control charts in the quality control program

The importance of process control charts can hardly be overemphasized. Without them the most brilliant analyses of capability studies and designed experiments may fail to be translated into increased production, better production and lowered costs. Furthermore, unless the important shop-type variables are kept in reasonably good control, it may not even be possible to plan and conduct successful engineering experiments.

On new processes, where there are many engineering unknowns, process control charts should be considered indispensable. On older products, where there is a great deal of knowledge and experience on the part of engineers and the shop, process control charts are usually necessary to put this knowledge to the most effective use. In any case, process control charts are likely to be needed to make the results of engineering studies effective and permanent.

The statistical procedures used in process control charts are discussed in detail in the Shop Section of the Handbook.

C-2.4 Correct number of process control charts

Process control charts are of two principal kinds: those intended to control the quality of work going to the next operation, and those intended to minimize losses or "dropouts" at the original operation. It may be necessary to have both kinds of chart on a single operation.

The total number of charts that will be needed in a shop varies with the nature of the operations and the number of unknowns. A complicated product does not necessarily require a large number of charts.

The number of charts tends to be small where only the operator's technique is involved, and tends to be larger where the variables include both operators and machines. The correct number of charts is determined for each job by a Quality Control Team as explained on page 189.

C-2.5 Cost of process control charts

A primary objective of each process control chart is to save money. If a particular chart is not saving considerably more than it costs, the chart should be eliminated. One of the functions of the Quality Control Team, as described on page 41, is to review all process control charts continuously and balance the savings against the cost. Charts found to be unnecessary, or not paying their way, are modified or removed.

Properly established control charts in the shop will save money in the following ways:

Fewer defectives.
Fewer operators.
Fewer inspectors.
Less scrap.
Less trouble at the next operation.
Less product rejected by Inspection.
Increased capacity.
Increased shop efficiency.
Fewer facilities needed for making, testing and handling the product.
Savings in time on the part of operators, supervisors and engineers.
Improvements in specifications.
Improvements in design.
Fewer interruptions to production.
Less downtime on machines.
Fewer complaints.
Less difficulty in meeting schedules.

Many formal cost reduction cases have been taken out on the savings resulting from the use of process control charts.

C-3 STATISTICAL SAMPLING PLANS TO REDUCE THE COST OF INSPECTION

Statistical sampling plans are an extension of the quality control methods into the field of inspection. Relatively small samples, and the probabilities associated with certain sampling distributions, are used to provide a scientific basis for acceptance or rejection of product.

The small size of the samples represents a saving as compared with 100% inspection. At the same time, the mechanics of rejection are set up in such a way as to encourage the making of good product and discourage the submission of poor product. Consequently, the use of statistical sampling plans is a proper adjunct to a quality control program.

Most statistical sampling plans are set up in such a way that the inspector uses his sample merely to accept or reject. Comparatively little use is made of the information available in samples (involving trends, patterns, etc.) which is used so extensively in process control. Sampling plans are generally chosen on the basis of a curve known as an "Operating Characteristic" curve which shows the proportion of product that will be accepted or rejected if the product submitted to Inspection is of a certain quality.

By the use of various sample sizes (n) and acceptance numbers (c), sampling plans can be made to reject larger or smaller percentages of product of a given quality. In addition, many sampling plans provide for doing something to improve the rejected product—for example, rework it or sort it. It is then possible to quote a maximum limit of defectiveness (called Average Outgoing Quality Limit, or AOQL) which can exist in the long run in the product leaving Inspection if the provisions of the sampling plan are faithfully followed.

C-3.1 Information to be obtained from inspection samples

In addition to their primary use for accepting or rejecting, inspection samples can be used to furnish certain kinds of information. For example, they can be used to calculate "process averages." The process average is the average percent defective in the product submitted to Inspection by the Operating department or by an outside supplier.

In the case of suppliers the process average can be used to rate the supplier as satisfactory or unsatisfactory. It can also be used to minimize the amount of inspection we must do, since product from a supplier having a good quality record can be accepted safely with less inspection.

While the methods outlined above represent the most common use of sampling plans, occasionally inspection is put on a regular control chart basis, and the inspector makes use of the information contained in levels, trends and patterns in deciding the disposition of the product. In other cases a chart is not actually plotted, but the inspector's action is influenced by the number of lots rejected in the recent series of lots submitted. This is an indirect use of pattern information.

C-3.2 Mistakes to be avoided in connection with sampling inspection

The most frequent mistake made in connection with sampling inspection is to attempt to use it as a substitute for Operating process control. No form of inspection, and no use or plotting of inspection findings, can be a substitute for the actual controlling of processes by Operating and Engineering. Sampling inspection is a very useful technique but it should never be regarded as the principal element in a quality control program.

Another common mistake is attempting to modify the provisions of a statistical sampling plan without taking account of its statistical nature. In order to obtain the protection and other benefits promised by a statistical plan, all provisions having to do with the method of selecting samples, the sample size, the acceptance number and the sorting or other disposition of rejected product must be strictly and faithfully carried out.

C-4 QUALITY CONTROL MEETINGS TO MAKE QUALITY CONTROL WORK

Practically all the action required by quality control is joint action, involving at least Operating and Engineering. More often than not, especially in the early stages, it requires direct help from a quality control engineer also. The three people who are jointly responsible for putting quality control into the job and seeing that it works are:

(a) The product engineer.
(b) The Operating supervisor.
(c) The quality control engineer.

These three people are often spoken of as a "Quality Control Team."

The quality control team is a technique borrowed from the field known as "operations research." The product engineer supplies the technical know-how, information on costs and facilities, and the ability to change layouts, place orders, contact design engineers and suppliers, etc. The Operating supervisor contributes his practical shop knowledge and experience, his ability to make decisions about the job and his knowledge of dealing with people. The quality control engineer contributes statistical advice and experience which is helpful to the supervisor and the product engineer. Other specialists, such as design engineers, metallurgists, or inspectors, may be called in to assist the team as needed.

Any of these people, working alone, would find it a long hard pull to put quality control in and get it working. Together they can do wonders in a short space of time. The importance of teamwork on the part of these particular people is so great that everything possible should be done to encourage it.

C-4.1 The Quality Control Team: its structure and operation

Experience shows that if no formal provision for teamwork is made, the consultations between Operating and Engineering tend to become desultory or spasmodic, action is often limited to emergencies, and the quality control program does not develop rapidly and soundly into a permanent integral part of the plant's operations. On the other hand, where the teams meet regularly on a schedule and go over the control charts, there is no recorded case where they have failed to obtain effective results.

Consequently, for the most rapid development of the program, a Quality Control Team should be set up for each product or product line, or for each general area or type of operation. Figure 50 shows how the Team is organized and how it functions.

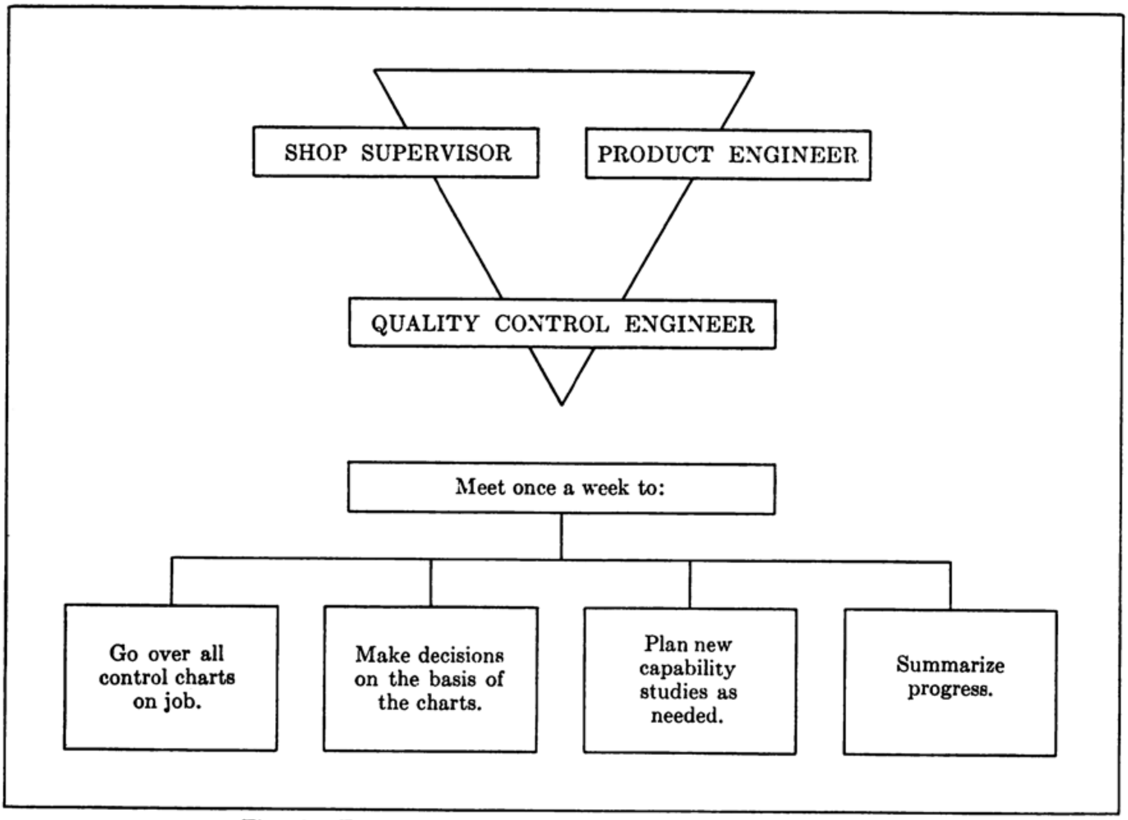

Fig. 50. Formation and functioning of a Quality Control Team.

The following are among the proper duties and responsibilities of a Quality Control Team:

(1) Planning and conducting process capability studies (or designed experiments) which cannot be conducted single-handed by the product engineer.

(2) Planning the process control charts in the shop and determining the proper type and number of charts.

(3) Installing the control charts, training the process checker and providing suitable forms and routines for the shop to use.

(4) Maintaining a continuous check on all the Operating process controls, to make sure that they are being used effectively and are resulting in maximum savings. This may include taking off charts that are not needed any longer, substituting one chart that will do the work of two, lengthening the checking intervals on charts as the processes are brought under control, or adding new charts as needed. It also includes regular and frequent audits of all control charts on the job to make sure that the charts are understood and that they are properly plotted, marked and used.

(5) Taking action as indicated by the charts to bring the job into a state of economical control.

(6) Measuring and reporting quality control progress.

The results obtained from a quality control program in the shop depend directly on the work of the Quality Control Team. Further information is given in Part D of the Shop Section (pages 223–229).

C-4.2 Management guidance

For the Quality Control Teams to function properly, they should be aware of the active interest and support of management at all levels. Management should assist in the formation of the Teams, drop in on their meetings occasionally, follow the reports on progress and recognize accomplishments.

It may also be necessary for management to make sure that the program moves smoothly from one phase to another, and at the proper time. For example, as soon as shop coverage (Phase II) is reasonably complete, management should see that the emphasis is shifted onto direct problems in Engineering.