THE
QUALITY ENGINEER
PRIMER

> A STATE OF STATISTICAL CONTROL IS NOT A NATURAL STATE FOR A MANUFACTURING PROCESS. IT IS INSTEAD AN ACHIEVEMENT, ARRIVED AT BY ELIMINATING ONE BY ONE, BY DETERMINED EFFORT, THE SPECIAL CAUSES OF EXCESSIVE VARIATION.
>
> W. EDWARDS DEMING

Statistical Applications

Statistical Applications are reviewed in two topic areas:

- **Statistical process control**
- **Process and performance capability**

Statistical Process Control (SPC)

Statistical Process Control (SPC) is presented in the following topic areas:

- **Objectives and benefits**
- **Common and special causes**
- **Selection of variable**
- **Rational subgrouping**
- **Control charts**
- **Control chart analysis**
- **Pre-control charts**
- **Short-run SPC**

Objectives and Benefits

Statistical process control (SPC) is a technique for applying statistical analysis to measure, monitor, and control processes. The major component of SPC is the use of control charting methods. The basic assumption made in SPC is that all processes are subject to variation. This variation may be classified as one of two types, chance cause variation and assignable cause variation. Benefits of statistical process control include the ability to monitor a stable process and determine if changes occur, due to factors other than random variation. When assignable cause variation does occur, the statistical analysis facilitates identification of the source so it can be eliminated.

Statistical process control also provides the ability to determine process capability, monitor processes, and identify whether the process is operating as expected, or whether the process has changed and corrective action is required.

Objectives and Benefits (Continued)

Control chart information can be used to determine the natural range of the process, and to compare it with the specified tolerance range. If the natural range is wider, then either the specification range should be expanded, or improvements will be necessary to narrow the natural range. Grant (1988)[6] identifies the following key information to be expected from the use of Shewhart control charts, which will become the basis for action:

- **Average level of the quality characteristic**
- **Basic variability of the quality characteristic**
- **Consistency of performance**

Benefits from control charting are derived from both attributes and variables charts. Once the control chart shows that a process is in control, and within specification limits, it is often possible to eliminate costs relating to inspection. (Grant, 1988)[6]

Control charts may be used as a predictive tool to indicate when changes are required in order to prevent the production of out of tolerance material. As an example, in a machining operation, tool wear can cause gradual increases or decreases in a part's dimension. Observation of a trend in the affected dimension allows the operator to replace the worn tool before defective parts are manufactured.

When the manufacturing method is lot production, followed by lot inspection, if inspection finds out of tolerance parts, very little can be done other than to scrap, rework or accept the defective parts. Using control charts, if the process changes, the process can be stopped and only the parts produced since the last check need to be inspected. By monitoring the process during production, if problems do arise, the amount of defective material created is significantly less than when using batch production and subsequent inspection methods.

An additional benefit of control charts is the ability to monitor continuous improvement efforts. When process changes are made which reduce variation, the control chart can be used to determine if the changes were effective.

The benefits of statistical process control are not without costs. Costs associated with SPC include the selection of the variable(s) or attribute(s) to monitor, setting up the control charts and data collection system, training personnel, and investigating and correcting the cause when data values fall outside control limits. As early as the 1940s, many companies found that the benefits of statistical process control far outweigh the related costs.

Common and Special Causes

An important consideration, on the road to process improvement, is the differentiation between special and common causes. Refer to Figure 10.1. When the circled special (bad) events occur, most of the available company resources converge on the process, fix the problem, and then go back to sleep.

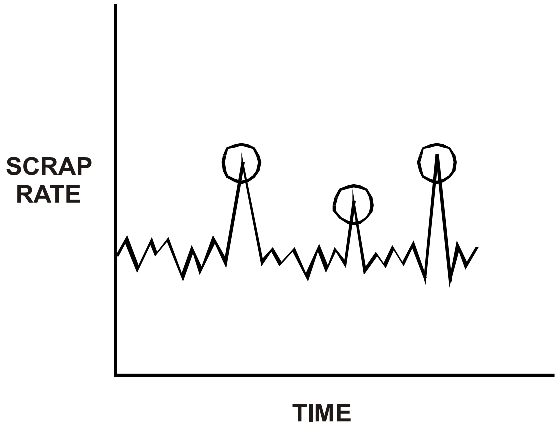


Figure 10.1 Special Cause Example

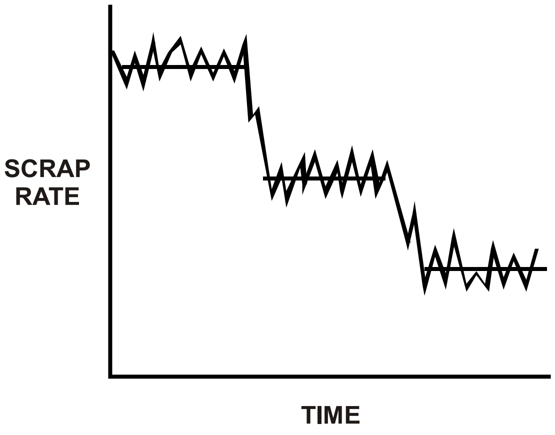


Figure 10.2 Common Cause Example

A process improvement team is required to investigate the reasons for the multitudes of chance causes, and to recommend an improved system. The resulting performance chart might look like Figure 10.2. It appears that the process has been improved, and it is both better and sustainable at the lower rate. But, what are the ingredients of this improvement?

The classical answer to the question posed above is "it depends." The solution may depend upon one, or a combination, of the input factors from a cause-and-effect diagram. The improvement may be accomplished by trial and error (simple case) or by a balanced design of experiments (complicated case). Referring back to Figure 10.2, is the improvement process complete? The answer should be obvious.

The high incidents of scrap in Figure 10.1 are easily detected because they are so obvious. Often, a control chart with upper and lower control limits is even more meaningful than a run chart. This could trigger appropriate reaction to the events. Quite often, when one knows precisely when something occurs, there is a good chance of determining what caused it.

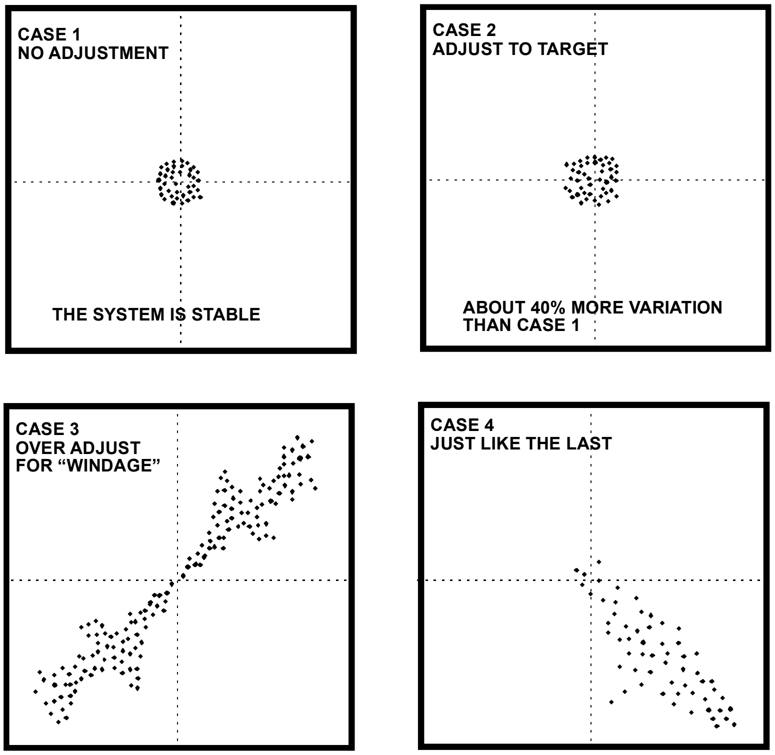
There might be a situation where something unusually good happens in a process. A control chart will help identify when to investigate unusually good performance, in order to do more of it.

Common and Special Causes (Continued)

Common causes occur in most processes and may produce a system that is stable and predictable in outcome. Deming felt that 94% of all problems are due to common cause variation. Usually, a decrease in common cause variation will require corrective management action. Fundamental changes in the process are necessary to reduce or remove the common causes. This means changing equipment, machinery, methods, materials, or other process factors.

Management often exhorts the workers to "do things right the first time" and attempts to motivate the work force to raise overall plant productivity through slogans. In this case, management is tampering with the system, and may cause unpredictable results. The subject of tampering was addressed by Walter Shewhart, and emphasized heavily by Dr. Deming, Dr. Nelson, and others. (Nelson, 1985)[9]

One of the best ways to illustrate what happens when a stable system is inappropriately adjusted is the Nelson funnel. A moveable funnel is placed over a grid and a ball is dropped through the funnel creating a "mark."



LIFE EXAMPLES (Case 2)

- WORKERS TWEAKING THE MACHINE
- MANAGERS TAMPERING WITH WORKER PERFORMANCE

LIFE EXAMPLES (Case 3)

- US TAX POLICY
- SOME CORPORATE "RIGHT SIZING"

LIFE EXAMPLES (Case 4)

- WORKER TRAINING WORKER
- USING PAINT MATCHES FROM PRIOR RUN
- SOME CORPORATE CULTURES

Figure 10.3 Nelson Funnel Illustrations

Common and Special Causes (Continued)

In Figure 10.3, cases 2, 3, and 4, represent the actions of management or workers when they treat a common cause of variation as a special cause. In case 2, any variation from target triggers an adjustment to target. Case 3, goes one step further, with an adjustment past target to allow for "windage." In case 4, the target is adjusted to the last reading. In all cases, variation is increased by the good intentions of workers, or management, or both.

Special causes affect the process in unpredictable ways and result in unstable outcomes. In a process, the special causes can be detected by simple statistical techniques and eliminated by improvement teams. Deming felt that 6% of all problems are attributed to special causes. Only a portion of these special causes are operator controllable.

Management often confuses both special and common causes of variation. However, the most frequent error is considering common causes to be special causes and tampering with the process.

Management must strive to reduce the variation in supplies, raw materials, delivery times, manufacturing changeovers, lab test measurements, business transactions, etc. By doing so, the process becomes more routine and efficient.

Selection of Variable

Given the benefits of control charting, one might be tempted to control chart every characteristic or process variable. The logic is if any characteristic changes, then the process can be stopped. This decision would also eliminate the need to determine if one characteristic is more important than another.

The risk of charting many parameters is that the operator will spend so much time and effort completing the charts, that the actual process becomes secondary. When a change does occur, it will most likely be overlooked. When more than a few charts are used for a process, the benefits may decrease, as quickly as the costs increase.

Some considerations for the selection of a control chart variable include:

- **Items that protect human safety**
- **Items that protect the environment or community**
- **Items that are running at a high defective rate**
- **Key process variables that impact the product**
- **Major sources of customer complaints**
- **Items that show adherence to applicable standards**
- **Items that are requested by key customers**
- **Variables that have caused processing difficulties**
- **Variables that can be measured by the person charting**
- **Items that can be counted by the person charting**
- **Items that contribute to high internal costs**
- **Variables that help control the process**

In an ideal case, one process variable is so critical that it is indicative of the process as a whole. Key process input variables (KPIVs) may be analyzed to determine the degree of their effect on a process. Key process output variables (KPOVs) are ideal for determining process capability and for process monitoring using control charts.

Design of experiments and analysis of variance may be used to identify the variables which are most significant to process control. Pareto analysis can be used to identify key internal and external losses.

Rational Subgrouping

> **...THE ULTIMATE OBJECTIVE IS NOT ONLY TO DETECT TROUBLE, BUT ALSO TO FIND IT. AND SUCH DISCOVERY NATURALLY INVOLVES CLASSIFICATION. THE ENGINEER WHO IS SUCCESSFUL IN DIVIDING HIS DATA INITIALLY INTO RATIONAL SUBGROUPS, BASED UPON RATIONAL HYPOTHESIS, IS THEREFORE INHERENTLY BETTER OFF IN THE LONG RUN THAN THE ONE WHO IS NOT THUS SUCCESSFUL.**
>
> **W.A. SHEWHART**

A control chart provides a statistical test to determine if the variation from sample-to-sample is consistent with the average variation within the sample. The key idea in the Shewhart control chart is the division of observations into what are called rational subgroups. The success of charting depends in large measure on the selection of these subgroups.

Generally, subgroups are selected in a way that makes each subgroup as homogeneous as possible, and that gives the maximum opportunity for variation from one subgroup to another. However, this selection depends upon a knowledge of the components of the total process variation.

In production control charting, it is very important to maintain the order of production. A charted process which shows out of control conditions (and resulting opportunities for correction) may be mixed to create new $\bar{X}$ - R charts which demonstrate remarkable control. By mixing, chance causes are substituted for the original assignable causes as a basis for the differences among subgroups.

Where order of production is used as a basis for subgrouping, two fundamentally different approaches are possible:

- The first subgroup consists of product produced as nearly as possible at one time. This method follows the rule for selection of rational subgroups by permitting a minimum chance for variation within a subgroup and a maximum chance for variation from subgroup to subgroup.

- Another subgroup option consists of product intended to be representative of all the production over a given period of time. Product may accumulate at the point of production, with a random sample chosen from all the product made since the last sample.

Rational Subgrouping (Continued)

If subgrouping is by the first method, and a change in process average takes place after one subgroup is taken and is corrected before the next subgroup, the change will not be reflected in the control chart. For this reason, the second method is sometimes preferred when one of the purposes of the control chart is to influence decisions on acceptance of product.

The choice of subgroup size should be influenced, in part, by the desirability of permitting a minimum chance for variation within a subgroup. In most cases, more useful information will be obtained from, say, five subgroups of 5 rather than from one subgroup of 25. In large subgroups, such as 25, there is likely to be too much opportunity for a process change within the subgroup.

Sources of Variability

Much of the discussion of process capability will concentrate on the analysis of sources of variability. It is therefore worthwhile to consider the possible sources of variation in a manufactured product.

The long-term variation in a product will, for convenience, be termed the product (or process) spread. There will be some difference between the process average and variation from lot-to-lot. One of the objectives of control charting is to markedly reduce the lot-to-lot variability.

The distribution of products flowing from different streams (machines, tanks, dies, etc.) may produce variabilities greater than those from individual streams. In order to eliminate this source of variability, it may be necessary to analyze each stream-to-stream entity separately. Another main objective of control charting is to reduce the time-to-time variation.

Physical inspection measurements may be taken at a number of different points on a given unit. Such differences are referred to as within-piece variability. Significant positional variation may necessitate changes in material or machinery.

Another source of variability is the piece-to-piece variability of a single production unit. Often, the inherent error of measurement is significant. This error consists of both human and equipment components. The remaining variability is referred to as the inherent process capability. It is the instant reproducibility of the machine and represents the ultimate capability of operating under virtual laboratory conditions.

One very important factor still missing from this discussion of variability is the interaction that takes place between man and machine. This includes the interaction not only between the operator and the machine, but also the inspector and the measurement device.

Breakdown of Variation

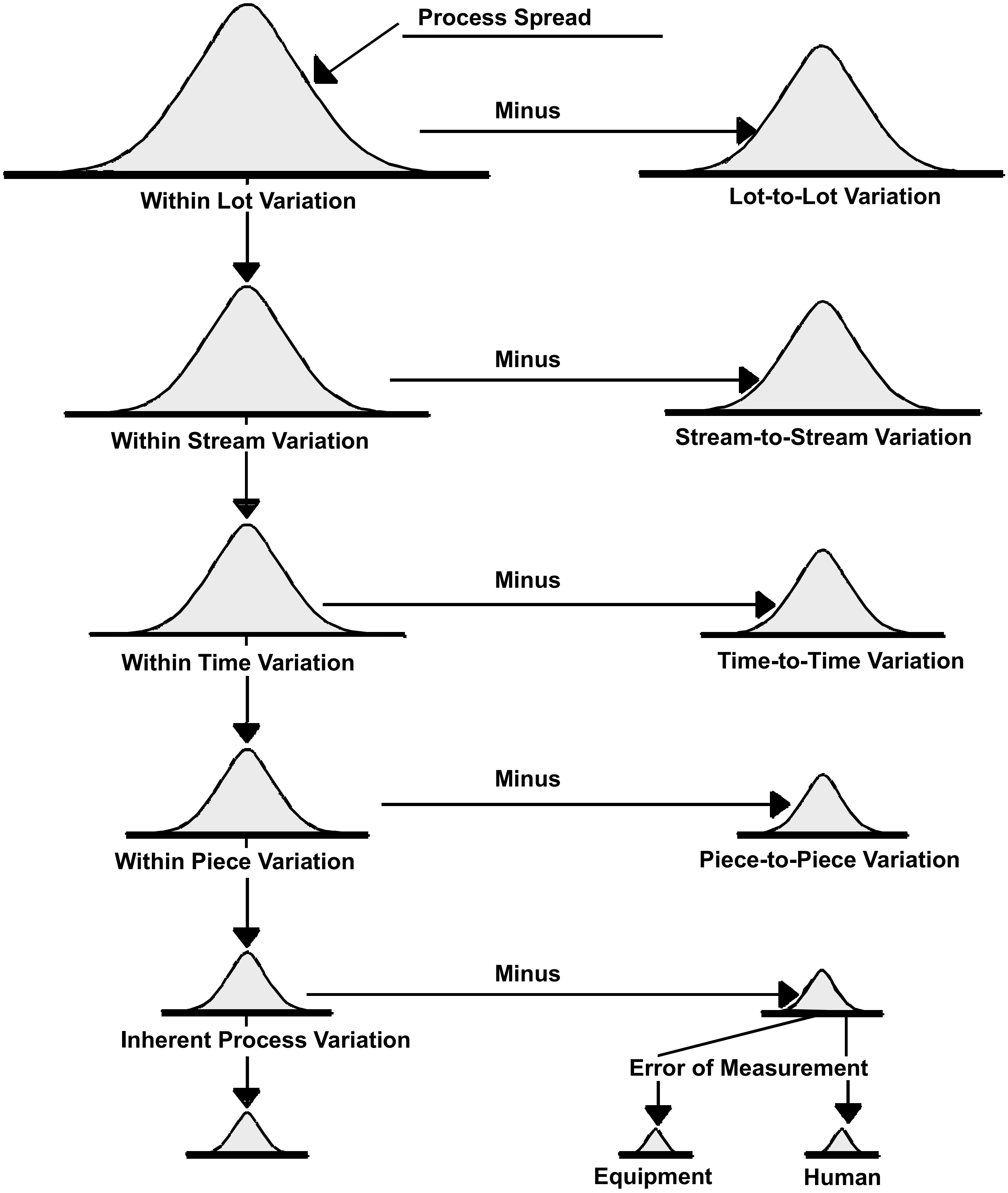


Figure 10.4 Schematic of Components of Variation

Control Charts *

Control charts are the most powerful tools to analyze variation in most processes - either manufacturing or administrative. Control charts were originated by Walter Shewhart (1931)[12]. A process which is in statistical control is characterized by plot points that do not exceed the upper or lower control limits. When a process is in control, it is predictable. There are many variations of possible control charts. The two primary types are:

Control Charts for Variables

Plots specific measurements of a process characteristic (temperature, size, weight, sales volume, shipments, etc.).

Types:
- $\bar{X}$ - R charts (when data is readily available)
- Run charts (limited single point data)
- M$\bar{X}$ - MR charts (limited data - moving average/moving range)
- X - MR charts (or I - MR charts) (limited data)
- $\bar{X}$ - s charts (when sigma is readily available)
- Median charts
- CuSum charts (cumulative sum)
- Moving average
- EWMA charts (exponentially weighted moving average)

Charts for variables are costly since each measured variable must have data gathered and analyzed. This is also the reason they are the most valuable and useful.

Control Charts for Attributes

Control charts for attributes plot a general measurement of the total process (the number of complaints per order, number of orders on time, absenteeism frequency, number of errors per letter, etc.).

Types:
- p charts (fraction defective)
- np charts (number of defectives)
- c charts (number of defects)
- u charts (number of defects per unit)

In some cases, the relatively larger sample sizes associated with attribute charts can prove to be expensive. There are short run varieties of these four types.

* Excellent control chart references include: Grant (1988)[6], Western Electric (1956)[13] and Besterfield (1993)[2]. See the references at the end of this Section.

$\bar{X}$ - R Chart Terms

n	**Sample size (subgroup size).**
X	**A reading (the data).**
$\bar{X}$	**Average of readings in a sample.**
$\bar{\bar{X}}$	**Average of all the $\bar{X}$s. It is the value of the center line on the $\bar{X}$ chart.**
R	**The range. The difference between the largest and smallest value in each sample.**
$\bar{R}$	**Average of all the Rs. It is the value of the center line on the R chart.**
UCL/LCL	**Upper and lower control limits. The control boundaries for 99.73% of the population. They are not specification limits.**

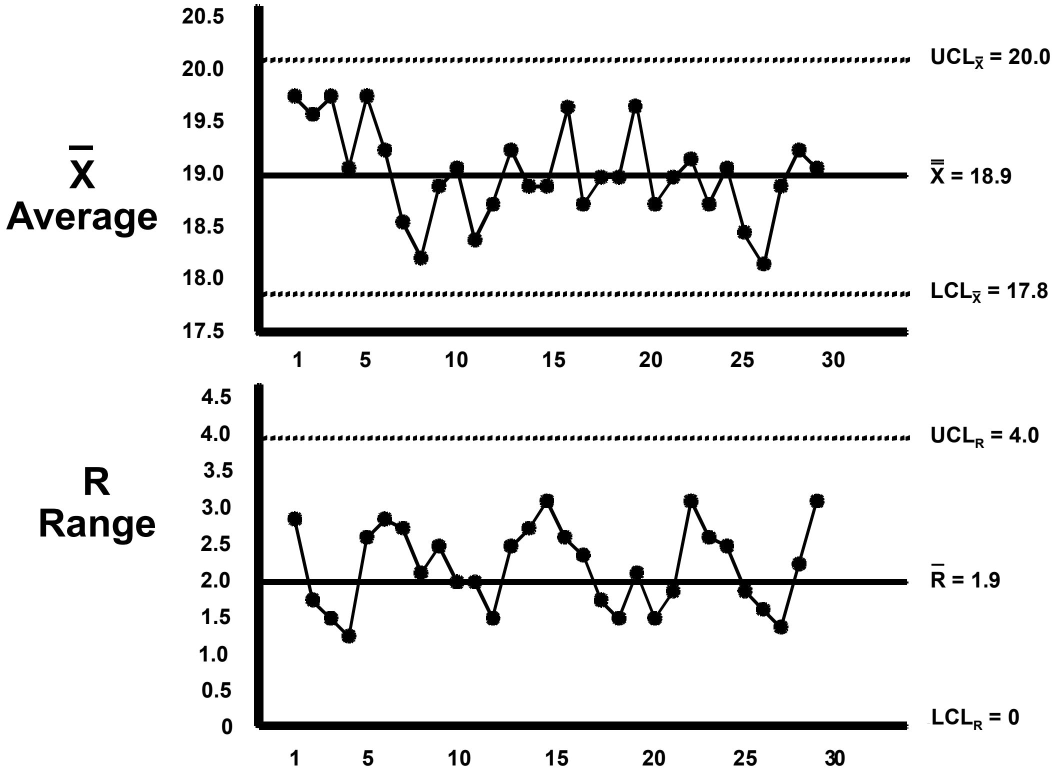


Figure 10.5 Typical $\bar{X}$ - R Control Chart