# Understanding Variation

To misunderstand the concepts of common and special causes of variation is to risk economic and psychological losses.

by Thomas W. Nolan and Lloyd P. Provost

THERE IS VARIATION IN ALL ASPECTS OF OUR lives. Household expenses, people's behavior, stress, weight, time required to travel to work, and the gas mileage of our cars all vary over time.

There is variation among people. The ability to perform a task, intelligence, methods of learning, and perceptions of quality all vary from person to person. Those things also vary over time for each individual.

There is variation among institutions. Profit margins vary from company to company in the same industry and from quarter to quarter for an individual company. Test scores for students in different schools vary. Crime rates in our communities change from month to month. Success rates for the same operation vary from hospital to hospital and from time period to time period for an individual hospital.

We constantly make decisions in our daily lives based partly on our interpretation of the variation we encounter. Is it time to have the car tuned up? Is my child's school improving? Is crime increasing in my community? The decision is often based on whether we think the variation we observe is indicative of a change or simply random variation that is no different from that which has occurred in the past.

## Critical knowledge for managers

One of the functions of managers is to make decisions. These decisions are often based on interpretation of patterns of variation in figures that are available to them. For three months in a row, sales are below forecast. Do the data indicate a trend? What action should be taken? There are differences in the performance of the people in the organization. Who among them needs special assistance and who deserves recognition? The number of accidents has been higher than last year's average for two months in a row. Is the company becoming a dangerous place to work? Should new safety procedures be instituted? Based on the patterns of variation in the processes, which of the proposals to spend capital are most likely to result in improvement?

Managers must also interpret the implications of variation in the external environment. Figures on the trade balance, interest rates, inflation, the gross national product, and the company's share of the market all vary over time.

It is vital that managers understand some of the basic statistical concepts needed to interpret variation. Managers must be able to determine whether the patterns of variation that are observed are indicative of a trend or of random variation that is similar to what has been observed in the past. This distinction between patterns of variation is necessary to minimize the losses resulting from the misinterpretation of the patterns. Typical losses resulting from misinterpretation are:

- Blaming people for problems beyond their control
- Spending money for new equipment that is not needed
- Wasting time looking for explanations of a perceived trend when nothing has changed
- Taking other actions when it would have been better to do nothing

The concepts of common and special causes of variation can be used to help minimize these and other losses resulting from misinterpretation of variation. The information here is directed toward managers, but the content is useful for anyone.

## Common and special causes of variation

As a starting point for understanding the concepts of common and special causes of variation, it is useful to review the notions of processes and systems.

A process can be defined[1] as a set of causes and conditions that repeatedly come together to transform inputs into outcomes. The inputs might include people, materials, or information. The outcomes include products, services, behavior, or people.

A system is an interdependent group of items, people, or processes with a common purpose.

Indicators of the performance of any process or system can be identified and measured. These indicators will be called quality characteristics.

For manufacturing processes, quality characteristics such as length, width, viscosity, color, temperature, line speed, number of accidents, and percentage of rejected material are examples. Number of billing errors, number of incorrect transactions in a bank, time of delivery, time to check out in a grocery store, frequency of program restarts in data processing, and the difference between a forecast of expenditures and the actual expenditures are examples of quality characteristics for administrative processes.

Quality characteristics for the organization can be defined by viewing the organization as a system. These quality characteristics will be related to the purpose of the organization. Some examples might be share of the market, profits, percent of sales due to new products, absenteeism, or employee turnover.

All of these quality characteristics will vary over time or location, and the analysis of this variation is often used as a basis for action on the process or the system. Sometimes this action is inappropriate or counterproductive because the concept of common and special causes of variation is not understood.

A fundamental concept for the study and improvement of processes or systems developed by Walter Shewhart[2] is that variation in a quality characteristic has two types of causes:[3]

1. Common causes: those causes that are inherently part of the process (or system) hour after hour, day after day, and affect everyone working in the process.

2. Special causes: those causes that are not part of the process (or system) all of the time or do not affect everyone, but arise because of specific circumstances.

For example, the attentiveness of 50 people at a presentation is affected by causes that are common to all of them, such as room temperature, lighting, the speaker's style, and the subject matter. There are also causes that affect attentiveness that are special to individuals, such as lack of sleep, family problems, and health. If lack of attentiveness is primarily due to common causes, then increased attentiveness at future presentations of the same type will require action by the speaker, by those setting up the room, or by those who arranged the presentation. If lack of attentiveness is due primarily to special causes, then increased attentiveness will require action by those in the audience.

From this example, one can begin to see the importance of knowing whether the variation in the process is dominated by common or special causes before a manager assigns responsibility for improvement. This example is used only to illustrate the concept. In practice, the distinction between common and special causes must be made with the aid of a control chart. (Control charts will be discussed later.)

A process (or a system) that has only common causes affecting the outcomes is called a stable process or said to be in a state of statistical control.

In a stable process, the cause system for variation remains essentially constant over time. This does not mean that there is no variation in the outcomes of the process, that the variation is small, or that the outcomes meet the requirements set by the customer. A stable process implies only that the variation in the outcomes is predictable within statistically established limits.

**• Figure 1. Two interpretations of variation.**

| | Variation that indicates good or bad performance | Variation that results from common or special causes |
|---|---|---|
| Focus | Outcomes of the process (product or service) | Causes of variation in the process |
| Aim | Classify outcomes as acceptable or not | Provide a basis for action on the process |
| Basis | What the customer wants or needs | What the process is actually delivering |
| Methods | Specifications, budgets, forecasts, numerical goals, other tools for judging performance | Control charts |

A process whose outcomes are affected by both common causes and special causes is called an unstable process. An unstable process does not necessarily have large variation. It's called unstable because the magnitude of the variation from one time period to the next is unpredictable.

The view of variation based on common and special causes is in contrast to the view of variation based on classification of performance of the process as good or bad. The latter view is most common.

The "good or bad" view of variation forms the basis for inspection of products or services. It is the basis of grading in schools. One shortcoming of this view of variation is that it does not provide any information on the causes of variation. Therefore, it does not provide useful information for improvement. The common and special cause view of variation and the good or bad view of variation are contrasted in Figure 1.

As special causes are identified and removed, the process becomes stable. Deming[4] gives several benefits of a stable process. Some of them are:

1. The process has an identity; its performance is predictable. Therefore, there is a rational basis for planning.

2. Costs and quality are predictable.

3. Productivity is at a maximum and costs at a minimum under the present system.

4. The effect of changes in the process can be measured with greater speed and reliability. In an unstable process it is difficult to separate changes to the process from special causes. Therefore, it is more difficult to know when a change results in improvement.

In addition to providing the basic concepts, Shewhart also provided a method to determine whether variation in a process is dominated by common or special causes. This method is the Shewhart control chart. The control chart is the means to operationally define the concept of a stable process. It consists of three lines and points plotted on a graph (Figure 2).

A control chart is constructed by obtaining measurements of some quality characteristic of the process such as delivery time,

**Figure 2. Illustration of the form of a control chart.**

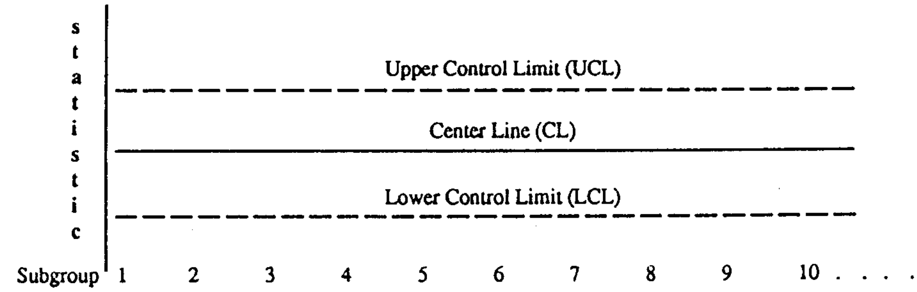
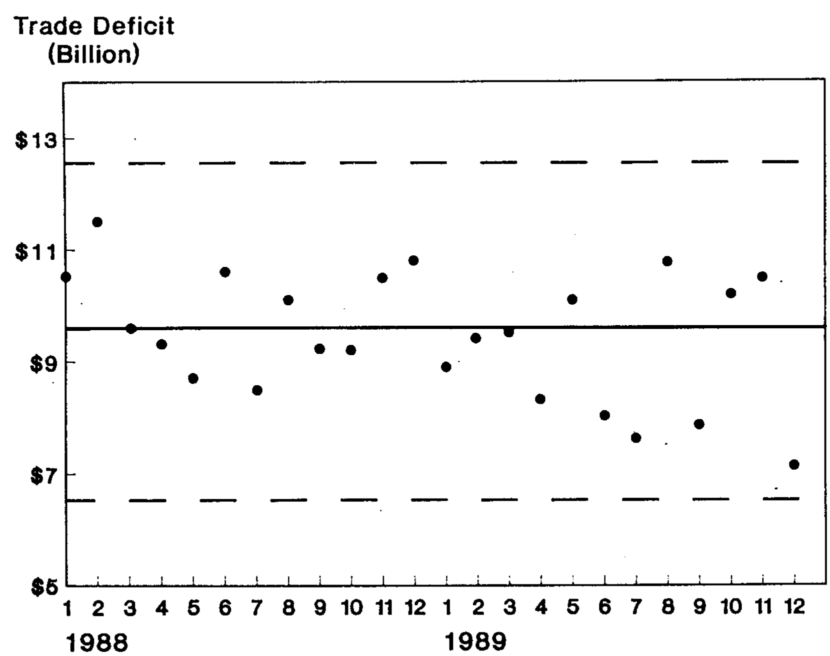



**Figure 3. Control chart for the U.S. trade deficit.**




viscosity, yield, temperature, cost, number of errors, volume of sales, forecast error, or percent absent. (These measurements need not be made only on outcomes of the process. For purposes of improvement, measurements at early stages in the process are desirable.) The data are then grouped by time, location, or other descriptive variables. These sets of data are called subgroups. Multiple subgroups, often obtained over time, are required to construct the control chart. The individual data or some descriptive statistic (the result of doing arithmetic on the data) such as average, range, or percent is plotted on the chart. The horizontal axis is the number or other identifier of the subgroup and the vertical axis is a scale for the statistic.

The centerline is the average of the data or the statistic that is plotted—for example, the average number of errors or the average monthly variance from the budget. The control limits bound the variation in the statistic due to common causes. Points outside the limits are indications of the existence of special causes. The control limits are not to be confused with specifications or other targets for the process. They are simply a prediction of the variation that will occur due to the system, that is, due to common causes. A process might be stable but turn out items of which a majority fail to meet the specifications.

There are numerous books on control charts including Wheeler and Chambers,[5] Grant and Leavenworth,[6] and Ishikawa.[7] The intention here is not to teach the control chart method, but rather to convey to managers the importance of the concepts of variation that underlie the method.

## Example: Trade balance

Each month the Department of Commerce releases figures on the amount of merchandise coming into and going out of the United States. The difference between imports and exports is called the trade balance. When imports exceed exports, there is a trade deficit.

Figure 3 is a control chart of the trade deficit from January 1988 to November 1989. The data from January 1988 to December 1989 were obtained from the Department of Commerce and were used to develop the control limits. The limits were extended and used to predict the deficit for the last six months. The data from the last six months were obtained from monthly press releases issued by the Department of Commerce.

The control chart indicates that the trade deficit was stable over that two-year period. This stability means that there was no change in the cause system that produces the trade deficit. The stability of the system does not mean that anyone is happy with the state of affairs, but only that the magnitude of the deficit will be predictable until a fundamental change is made.

Despite the fact that the deficit has been stable, the media report the monthly variations in the deficit as if they were indications of a change. The control chart indicates a pattern of random variation over this two-year period. An increase in the deficit over the previous month is reported as a sign of trouble, a sign of deterioration in the economy. Two months in a row of decreasing deficits is interpreted as an indication that good times are coming.

Financial analysts in the public and private sectors explain the causes of the ups and downs: a major strike, bad weather, and the like. Financial markets respond to the reports and the explanations.

This example illustrates two of the losses due to misinterpretation of variation. Time is wasted looking for explanations of a perceived trend when in fact nothing has changed. The financial markets respond to the variation in the monthly figures when in fact it would be better to ignore them. Their responses introduce needless variation into the economic system.

These losses occur because variation due to common causes is interpreted as if it were a result of a special cause. However, the trade deficit will not necessarily remain stable in the future. If the existence of a special cause relating to the trade deficit is indicated by a point outside the limits, then the public deserves an explanation of what has changed to make things better or worse. The public can then react to this change on a more informed basis.

## Application of the concept

Although Shewhart focused his initial work on manufacturing processes, the concepts of common and special causes of variation and of stable and unstable processes are just as important for processes of management, administration, and service. The application of these concepts has particular importance for:

- the operation of a process.
- the management of a system.
- supervision.

## Operation of a process

There are many examples of important applications of the concept of special and common causes to the operation of a process. Decisions are made to adjust equipment, to change speeds or flows, to calibrate a measurement device, to send a second letter of collection to a creditor, to adjust the forecast of sales, etc. All these decisions must consider the variation in the appropriate measurements or quality characteristics of the process.

In the operation of a process, there is usually a specified target for a quality characteristic. Without the aid of a control chart, operators often make the mistake of using the past results of inspection of the product to continually adjust the process. The aim of the adjustment is to bring the quality characteristic closer to the target in the future. For example, if a dimension of a machined part is inspected and is found to exceed the upper specification, an adjustment is made to the machine so that the average dimension of future parts is lowered. If a batch of a particular chemical is outside of specifications, an adjustment is made by changing the amount of catalyst added to the next batch.

Adjustments based on historical data can also be made to nonmanufacturing processes. Adjustments of next month's forecast of profits, sales, or costs are made based on how close this month's forecast is to the reported figures. Adjustments to the perpetual record of inventory are made based on physical counts or measurements (both subject to variation) of existing inventory. Phone calls from a manager who has reviewed figures that indicate unsatisfactory performance will result in adjustments by the workers to all sorts of processes.

In all of these cases, there are circumstances in which the adjustments will improve the performance of the process, and there are circumstances in which the adjustment will result in worse performance than if no adjustment is made. It is vital that both managers and operators be able to distinguish between these two sets of circumstances. Fortunately, an appropriate control chart provides a simple way to do this.

Continual adjustment of a stable process, that is, one whose output is dominated by common causes, will increase variation and usually make the performance of the process worse.[8] A stable process is most often improved through a fundamental change in the process that reduces or removes some of the common causes.

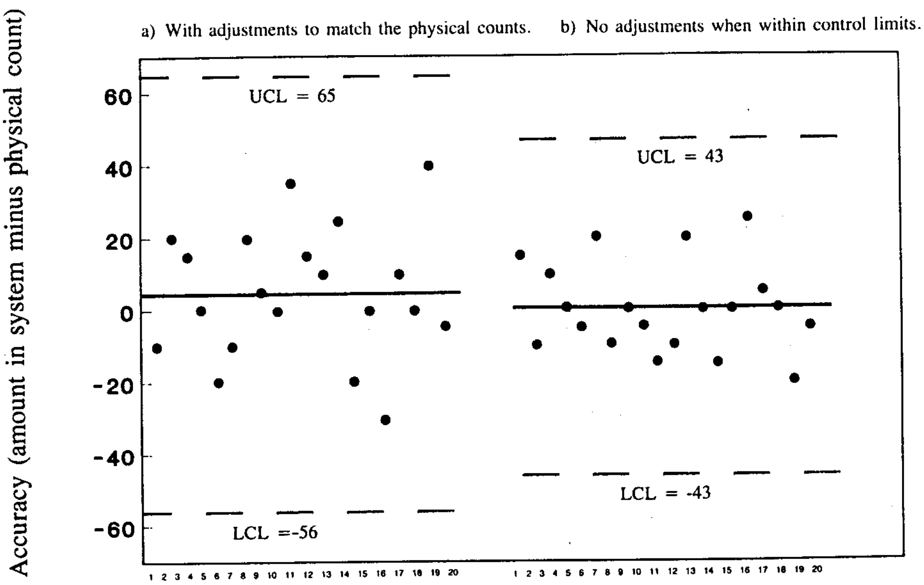
If a special cause is found that moves the quality characteristic away from the target, and the special cause will persist for some time, an adjustment of the process to counteract the special cause might be helpful in the short-term. Two examples of such a situation are a new lot of raw material in a manufacturing process or a stretch of bad weather causing late deliveries. The control chart is an important method to help the operator know when an adjustment to the process is needed.

## Example: evaluating inventory

The accurate determination of inventory was very important to a manufacturer of a product with many styles and colors. The many varieties of the product and the complication of semi-finished product in process made it difficult to physically count the inventory. A new computerized system had recently been installed to help keep track of inventory. Physical counts were still made after each run of a particular variety to determine yield. These physical counts were compared to the value in the computerized system. If there was a difference, the value in the computer was adjusted to equal the value from the physical count. Figure 4 shows control charts for the accuracy of the inventory.

Although the average difference was close to zero, the first control chart (a) in Figure 4 showed that the accuracy for an individual variety of product could be ±61 units. This level of accuracy was unacceptable for efficient operations. A decision was made to adjust the computer value only if the difference between the computer and physical count was greater than 61 units. The second control chart (b) shows the accuracy a month after this policy for adjustments was initiated. The accuracy for individual varieties improved by about 30%. Revised control limits were ±43 units, so these limits became the policy for adjusting based on physical counts.

● Figure 4. Control chart for accuracy of inventory.




In this example, a control chart for the accuracy has replaced the standard procedure for deciding on adjustments. Because the process was stable, making adjustments based on the last outcome of the process (the most recent physical count) only increased the variation of the inventory accuracy—the opposite of what was intended. The lack of acceptable accuracy was due only to common causes of variation. Only fundamental changes to the process for determining inventory would improve the accuracy. Now that the constant adjustments have been eliminated, the important common causes can be studied.

## Management of a system

Specifications, standards, forecasts, and budgets are useful for planning, pricing products, and other functions of management. They are used to communicate what the customer or manager expects, wants, or needs from the process. It is important to keep in mind that they do not communicate reality. That is, they do not communicate how the system is performing or what it is capable of producing.

A control chart of measures such as costs, material usage, volume of production, sales and profit, and an analysis of the capability of the system (if the system is stable) communicates a realistic view of the performance of the system.[9] Without the aid of a control chart and an understanding of the concepts of common and special causes of variation, the tools for planning are mistaken for reality or the capability of the system. Workers or other managers are asked to conform to that "reality." If the salesperson does not meet the forecast, his performance is unacceptable. When the production worker does not achieve the production standard, her performance is unacceptable.

When a manager compares a measure of performance of the system such as costs or sales to a planning tool such as a forecast or standard and uses this comparison as a basis for action, the manager's actions are analogous to the operator adjusting the machine when the specifications are not met. Sometimes the actions will be appropriate; other times they will not. Just as in the case of the operator, the use of a control chart will show which actions are appropriate.

If a system is stable with respect to a particular measure of performance such as costs, then a fundamental change in the system will be needed to reduce the cost. This change is the responsibility of management.

Exhortations to lower-level managers or workers in the system to meet the forecast or standard will make things worse. Deming has called this type of action tampering. Tampering results when action is taken on a process under the assumption that variation is a result of a special cause when, in fact, the variation is a result of common causes.

In the management of a system, it is vital that planning tools are kept in their proper place and that tools such as control charts and analysis of the capability of the system are used as a basis for action.

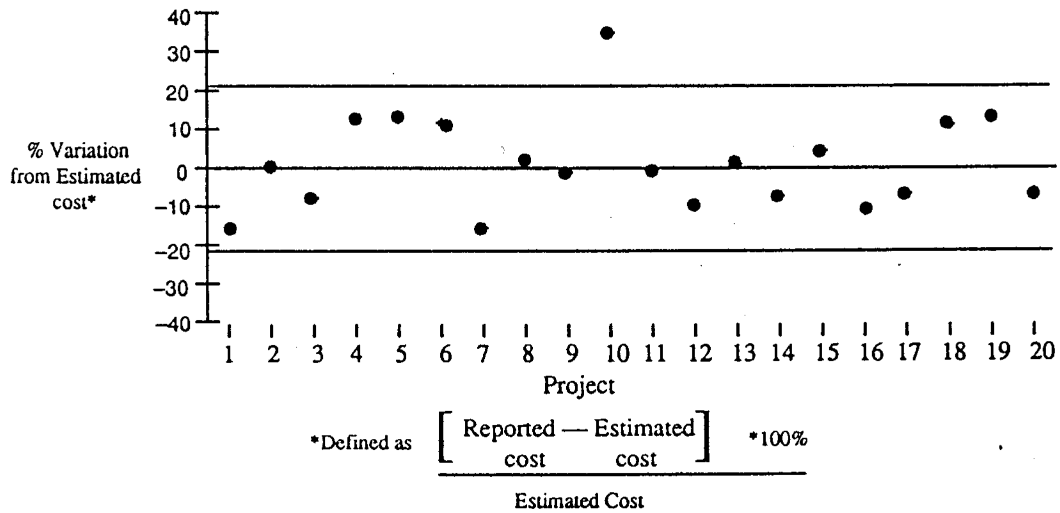
## Example: monitoring engineering costs

A manufacturing company gave a central engineering staff the responsibility for the construction of new manufacturing lines and the installation of new equipment. Before any project was begun, the engineer in charge estimated the cost of the project and submitted the estimate to the appropriate manager for approval. To control the costs of the projects, the company had a policy that, for any project with reported costs varying by more than 10% from the estimate, an analysis of the reasons for the cost overor underrun was to be made. The engineer in charge then submitted a report explaining what went wrong to the vice president of the division for which the work was performed.

In effect, the engineer was being asked to explain what was special about the project. The project was designated as special because it differed from the estimate by more than 10%. This is an example of mixing the two interpretations of variation. The 10% requirement communicates the accuracy of the estimate needed by managers for purposes of budgeting and planning. It is how a cost over- or underrun is defined. These are legitimate uses of the requirement.

The problem arises when the requirement is used to decide

**• Figure 5. Control chart for variance from estimated cost.**




that a particular project is special or that the causes of variation for projects outside of 10% are somehow different from those inside of 10%. This will likely lead to tampering. To decide that a particular project needs special analysis, it is necessary to use a control chart to know how much variation from the estimate would be produced by the common causes. (This has nothing to do with what the manager hopes the system will produce.) These common causes of variation are part of the processes of estimation, engineering, and construction that make up the system.

Figure 5 shows a control chart of the difference between the reported cost of the engineering project and the original estimated cost expressed as a percent of the original estimate. The occurrence of a point outside the control limits indicates the existence of a special cause. This project should be analyzed individually to determine the special cause. Most of the projects fall within the control limits, which are approximately ±20%. Based on the magnitude of the control limits, it is likely that, even after the special cause is eliminated, an engineering project can be expected at times to vary from the original estimate quite a bit more than 10%.

It should be noted that the interpretation of the control chart is not that any project that falls within the control limits has a satisfactory cost. A project could be within the control limits but still vary by more than 10% from the estimate. The control chart is used to provide a guide to the types of questions that a manager should ask and the type of action that is appropriate. For projects outside the limits, the engineer in charge of the project should be asked to determine the special cause. Since the variation in the system is larger than the requirements (as indicated by the control limits), the top managers of the engineering department should be asked what improvements to the system are being studied to eliminate or reduce the effect of common causes.

This example is but one of many that could illustrate the waste of resources that occurs when figures are reviewed and actions are taken without the guidance provided by a control chart. Moreover, the actions resulting from these costly exercises often lead to tampering.

## Supervision

More and more people are recognizing that the role of a supervisor must change from that of watchdog to that of leader. An understanding of the concepts of common and special causes and the simple statistical methods necessary to differentiate between them will help a supervisor perform the responsibilities of leadership.

Deming states: ". . . a leader must learn by calculation wherever meaningful figures are at hand, or by judgement otherwise, who if any of his people lie outside the system on one side or the other, and hence are in need either of individual help or deserve recognition in some form."[10]

Variation in the performance of people is a result of common causes (in the system) and special causes attributable to the individual or to special causes outside of the individual's control. Obviously, it is important that the supervisor differentiate between the different types of causes. Without this perspective, it is easy to attribute all the causes of variation in people's performances to the individuals themselves and ignore the effects of the system. The forced ranking of people in an organization from highest to lowest based on some measure of performance is an example of the failure to consider the impact of common causes on individual performance.

## Example: supervision of field salespeople

While developing an operating budget for the coming year, the marketing manager of a large division established a forecast of sales for each region. Each regional manager then used this forecast to establish goals for each of the salespeople under his supervision. A salesperson received a bonus equal to 1% of his or her salary for each percentage point that sales exceeded the goal.

Figure 6 shows a plot of the average of sales for the first two quarters for individual salespeople. The sales are expressed as a percent of their goals. All salespeople in region 1 exceeded their goals, and all received bonuses. In region 2, no one received a bonus, and in region 3, four of 10 received bonuses. The bonuses were distributed based on a comparison of the sales figure to

**● Figure 6. Sales figures vs. sales goal.**

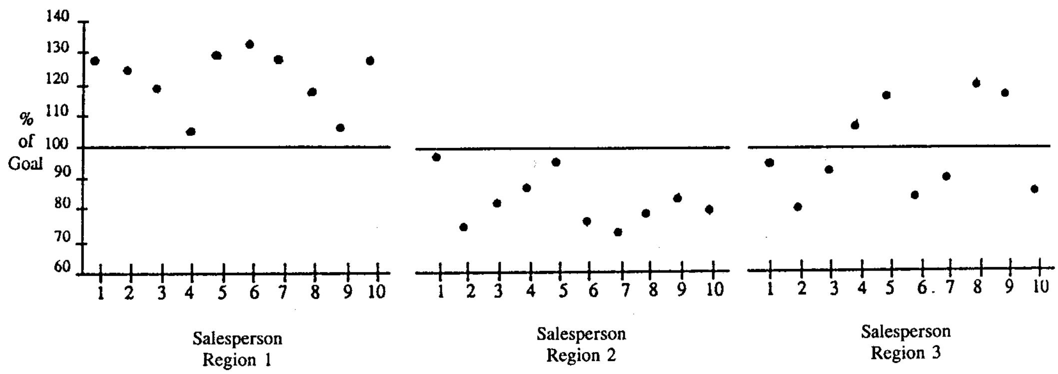
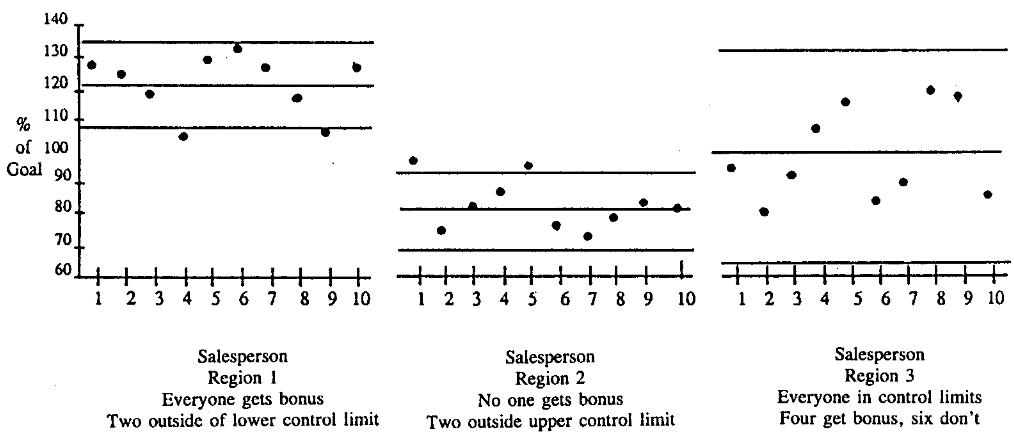
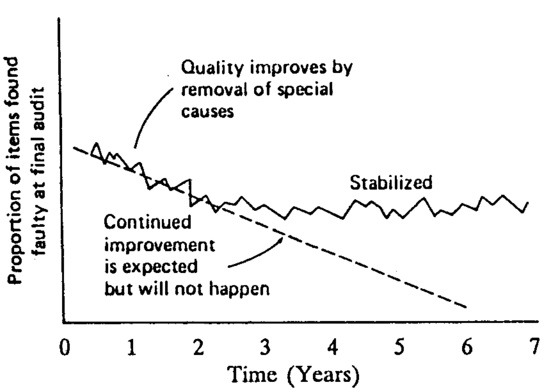



**Figure 7. Control charts for sales figures.**




**● Figure 8. Typical path of frustration.**

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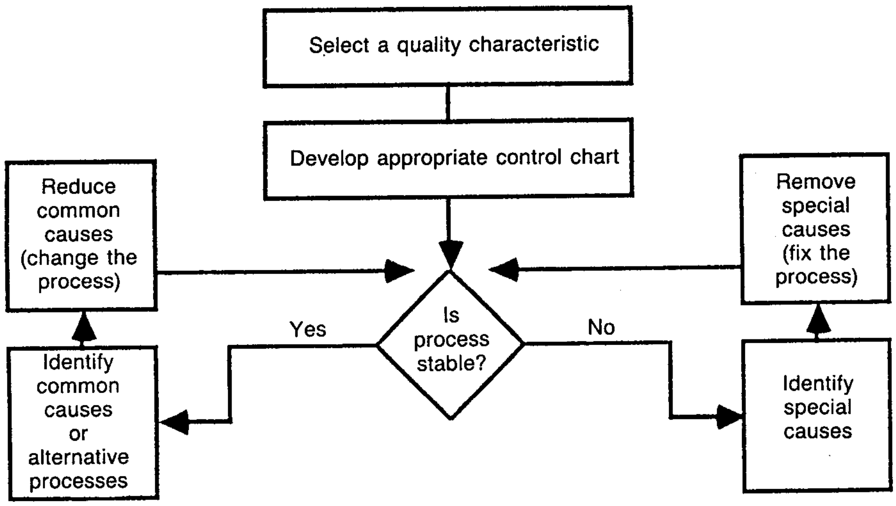
a planning tool, the goal derived from the sales forecast. This analysis did not take into account the variation between the salespeople that was attributable to the system.

Figure 7 shows control charts used to analyze the performance of the salespeople. (The width of the control limits depends on the quarter-to-quarter variation in sales for each person within a region.) In region 1, the sales for two of the salespeople were below the lower control limit. This indicates that their performance was worse than would have been expected from the system.

It is the responsibility of their supervisor, the regional manager, to determine what the special cause was and provide leadership to remove it. The special cause might or might not be within the control of the individual salesperson. Those below the lower control limit might need training, or they might not be suited for work in sales. If the latter is the case, another job in the organization should be found for them that would make better use of their talents.

Using a control chart to analyze the salespeople's performance allows the supervisor to determine which of the salespeople are performing in the system and which might need special attention. No such information is obtained when the sales data are

**● Figure 9. Methods and responsibilities for improvement.**




**Primary Statistical Methods**

| Stable Process | Unstable Process |
|---|---|
| 1. Planned experimentation | 1. Control charts |
| 2. Subgrouping/stratification | 2. Subgrouping/stratification |
| 3. Control charts | 3. Planned experimentation |

**Responsibility for Identification**

| Stable Process | Unstable Process |
|---|---|
| 1. Technical experts | 1. Workers in the process |
| 2. Supervisors | 2. Supervisors |
| 3. Workers in the process | 3. Technical experts |

**Responsibility for Improvement**

| Stable Process | Unstable Process |
|---|---|
| 1. Management | 1. Supervisors |
| 2. Technical experts | 2. Technical experts |
| 3. Supervisors | 3. Management |
| 4. Workers in the process | 4. Workers in the process |

(Note: Methods and responsibility are ordered by importance.)

compared to the goal.

In region 3, no one was outside of the control limits, indicating that the variation between the salespeople was attributable to common causes within the system, not to the individuals. It would be a mistake for the supervisor to try to use the sales figures to rank the performance of salespeople in the region. Ranking of people in this situation would be destructive to the individuals and to the organization.

This example provides a contrast between the two views of variation. In Figure 6, the figures are compared to what the manager hoped or forecasted the sales process would produce in order to evaluate the performance of the sales force. The forecast was needed for planning. In Figure 7 the planning tools are set aside and the control chart is used to evaluate who is better or worse than the system. The supervisor can then use this information to provide leadership to improve the performance of those under his or her supervision.

## Implications for the improvement of quality

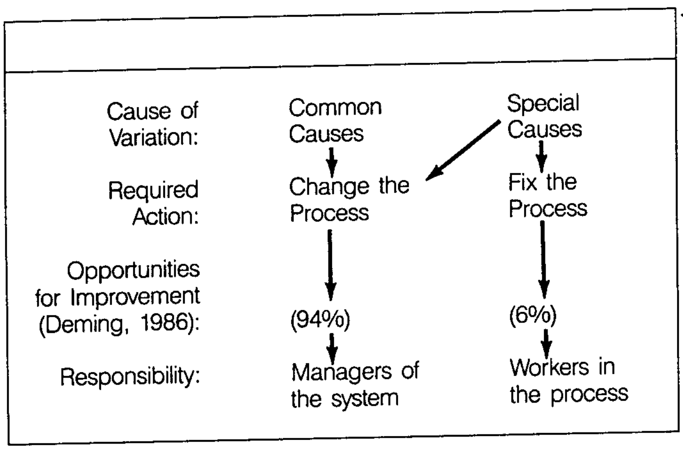
Many companies have begun some organized activities to improve quality. Too often, these activities start with much fanfare and commitment by top management to provide resources and training for people at the middle and lower levels to work on problems. As Deming points out,[11] these efforts usually produce some reduction of unacceptable product or customer complaints during the first two years and then level off (Figure 8). There is then a sense of frustration on the part of management when progress slows or ceases altogether.

What usually has happened is that initially some special causes have been found and eliminated by common sense and the direction of resources. The processes are then dominated by common causes and frustration sets in at all levels. Continued progress will require leadership from management to direct activities and make the fundamental changes that will be necessary.

Without some understanding of the concepts of variation, it will be difficult for managers to provide effective leadership for the improvement of quality. Activities to improve quality include the assignment of various people in the organization to work on common causes and special causes. The appropriate people to identify special causes are different from those needed to identify common causes. The same is true of those needed to remove the causes.

Figure 9 shows that workers in the process should be the primary identifiers of special causes, followed by supervisors and technical experts. The order is reversed for the identification of common causes because identifying common causes usually requires more sophisticated methods and a higher level of understanding of the process than identifying special causes does.

Many leaders in the field of quality have emphasized that most improvements in quality will require action by management. Some special causes can by removed by operators or supervisors. Others will require action by management in another process, possibly one of management or administration. For example, a special cause of variation in a production process might result when there is a change from one supplier's material to another. To prevent the special cause from occurring in the particular production process or other production processes, a change in the way the organization chooses and works with suppliers is needed. Figure 10 summarizes these concepts.




From the theories of variation discussed here, the following can be said about activities to improve quality:

1. Leadership by top management will be needed to ensure that everyone in the organization is given the appropriate responsibility for improvement. Inappropriate allocation of responsibility leads to waste of human resources.

2. Approaches to the improvement of quality that start with people at lower levels of the organization, or place the emphasis on them, are doomed to failure. To improve quality, the primary role of workers in the process is to identify special causes and remove those that they can control.

3. If workers are not trained in the use of basic statistical methods and are not given time to identify special causes, technical experts will have to perform this role. This is a waste of the abilities and expertise of both groups.

4. The use of numerical goals as a way to motivate groups or individuals to improve quality is inappropriate if the person setting the goals does not take into account whether the variation of the process is dominated by common or special causes. To achieve the goal might or might not require a fundamental change in the process. Management should provide leadership and emphasize methods of improvement. The amount of improvement will depend on how good the methods are.

5. The allocation of capital for new equipment and tools to improve quality is an important function of management. New equipment is a fundamental change to a process that is most appropriate when the process is dominated by common causes related to the equipment. If capital is allocated to improve quality without regard to whether the process is stable, management might not be getting the best return on investment. When approving a request for new equipment, management should require evidence in the form of a control chart indicating that special causes have been eliminated and therefore a fundamental change is really needed.

## Understand variation and minimize losses

There is variation in all aspects of our life: in our personal lives, in the performance of people, in the economy, and in our organizations. We make decisions daily based in part on an interpretation of the meaning of the patterns of variation that we observe. Does the pattern of variation indicate a change, or is it a random pattern similar to what has been observed in the past? Misinterpretation of the pattern of variation leads to an incorrect answer to that question and results in economic and psychological losses.

These losses can be minimized by understanding that variation can be caused by either common or special causes, by knowing how to determine whether a system is stable or not, and by basing action on this analysis. It is vital that the leaders of our organizations acquire this understanding.

### Acknowledgments

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2. Walter A. Shewhart, *The Economic Control of Quality of Manufactured Product* (New York: D. Van Nostrand Company, 1931, reprinted by ASQC Quality Press, Milwaukee, WI, 1980).
3. Shewhart used the terms "assignable cause" and "chance cause" to distinguish between the two types of causes. For further understanding of the specific meaning that Shewhart attached to these terms, see Reference 2. W. Edwards Deming popularized the terms common and special causes.
4. W. Edwards Deming, *Out of the Crisis* (Cambridge, MA: MIT Center for Advanced Engineering Study, 1986).
5. D.J. Wheeler and D.S. Chambers, *Understanding Statistical Process Control* (Knoxville, TN: Statistical Process Controls, Inc., 1986).
6. Eugene L. Grant and Richard S. Leavenworth, *Statistical Quality Control* (New York: McGraw-Hill, 1980).
7. Kaoru Ishikawa, *Guide to Quality Control* (Tokyo: Asian Productivity Organization, 1976).
8. Students of time series analysis will recognize that when the measurements are auto-correlated, adjustments to a stable process using an appropriate feedback controller can reduce variation. However, discussion of this case is beyond the scope of this article.
9. See Deming, *Out of the Crisis*, p. 339, for a discussion of the concept of capability.
10. Deming, *Out of the Crisis*, p. 248.
11. Deming, *Out of the Crisis*, p. 323.

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