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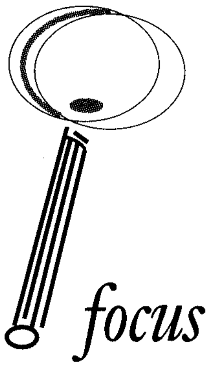
Introduction to Statistical Process Control



Learning Objectives

By the end of this chapter, you should be able to:

- Describe the concept of statistical process control.
- Define the concept of variation and how it can be described statistically.
- Construct a histogram of a set of data.
- Explain the Deming Cycle and Juran's approach to quality improvement.

TOTAL QUALITY MANAGEMENT AND STATISTICAL PROCESS CONTROL

Total Quality Management (TQM) has become a mainstay of organizations throughout the world in their efforts to achieve competitive success. Within the last 15 years, TQM has permeated the industries of manufacturing, service, government, and education throughout the United States. Few today still consider it a fad; TQM is a basic business operating strategy.

No universal definition of TQM exists. However, most experts agree that TQM embodies several key elements. The U.S. Department of Defense defines Total Quality Management as "both a philosophy and a set of guiding principles that represent the foundation of a continuously improving organization. TQM is the application of both quantitative methods and human resources to improve the material and services supplied to an organization, and the degree to which the needs of the customer are met, now and in the future. TQM integrates fundamental management techniques, existing improvement efforts, and technical tools under a disciplined approach focused on continuous improvement" (U.S. Department of Defense, 1989).

An important aspect of this definition is that TQM is a disciplined approach using quantitative methods as a basis for continuous improvement. Meeting the quality and performance goals of an organization requires that decisions be based on reliable facts, data, and analysis that support a variety of purposes, such as planning, reviewing company performance, improving operations, and comparing quality performance with that of competitors. The objective analysis of factual data using quantitative methods is the basis for problem solving and continuous improvement. Other guiding principles of TQM emphasize a focus on the customer, strategic planning and leadership throughout the organization, and teamwork and participation.

Statistical Process Control

Statistical process control, or SPC, is a fundamental approach to quality control and improvement that is based on objective data and analysis. The origin of SPC dates back to the 1920s and 1930s at the Western Electric Company and Bell Telephone Laboratories. Walter Shewhart (1891-1967) recognized that variation in a production process can be understood and controlled through the use of statistical methods. He pioneered the use of statistical methods as a tool to manage and control production. Over the next several decades, these tools were taught to engineers and production personnel throughout American industry. The need for higher-quality production to support the defense industry during World War II gave a boost to the use of SPC.

One of Shewhart's disciples, W. Edwards Deming (1900-1993), was a strong advocate of SPC and trained many engineers in the concept during the war years. However, he was never able to convince upper management in the U.S. of SPC's benefits and importance. When Deming was invited to train Japanese engineers in statistical methods after the war, he realized that quality improvement efforts could never be sustained without top management support. It was not difficult for him to gain the attention of every level of worker-from maintenance to CEO, since Japan was rebuilding from complete devastation. The Japanese were eager to learn and apply new tools that would help them rebuild their economy. And the rest, as they say, is history. Statistical methods, combined with strong programs in human resources and a focus on continuous improvement to better respond to customer needs, enabled Japanese companies to emerge as powerful global competitors within only a few decades.

When Deming's contributions to Japan became recognized in America around 1980, the modern quality movement began. Many major corporations began to experiment with quality improvement techniques, such as statistical process control. Ford Motor Company and other U.S. automobile manufacturers began to require their suppliers to show statistical evidence of the quality of their products as part of their Q 101 Quality System Standard. Ford insisted that statistical process control be used as an integral part of suppliers' processes to assure quality and provide accurate information for continuous quality and productivity improvement (Chaudhry and Higbie, 1990). As these requirements spread throughout the logistics chain, the use of SPC became widespread throughout American industry.

SPC consists of three words: statistical, process, and control. Understanding each of these is crucial to using SPC effectively. Let's start with process.

A Focus on Processes

A major difference between the old-style approach to management and TQM is a focus on processes. In the past, quality control was product driven. Inspectors would measure critical dimensions carefully, and either scrap or rework the parts that did not conform. Although this practice resulted in good quality of the final product, it was wasteful and did not lead to improvements in quality, cost, or productivity.

The quality of production output is determined by the process that produces the output. A process is a way of doing things. A process takes inputs (materials) from a supplier, transforms them, and delivers outputs (products) to a customer. The transformation is accomplished by the particular combination of equipment, labor, work methods, and materials used to create the product or service. By focusing on how work gets done and what process factors affect product output, quality can be improved and the number of mistakes can be reduced. SPC is a method of gathering and analyzing data about processes to better understand them and, ultimately, to improve them.

Improvement of processes leads to better quality products and services and to less waste and rework. Better quality leads to higher customer satisfaction, higher sales and higher revenues; less waste and rework reduces costs. The net result is higher corporate profitability and improved competitiveness.

Variation and Statistics

We see variation all around us-in the weather, in sports, and in our own performance and behavior. When a baseball player has a .300 batting average, it does not mean that he will always get 3 hits out of every 10 at bats. He may get 5 hits in a row, or he could go 10 at bats without a hit. We cannot predict what he will do at any one time that he steps up to the plate, but we can predict, with reasonable accuracy, what he will do over a long period of time provided everything remains the same-no injuries or scandals!

The same holds true for manufacturing and service processes. When measuring the diameter of a drilling operation or the length of time it takes to process an invoice, there is some variation. Process variation results from many different factors in the system that interact, such as machine vibration, temperature, humidity, materials, human emotions, and the workload. We cannot fully understand or predict the variation in each of these individual factors, but we can describe them in aggregate. Once we understand the variation in a system, we can draw conclusions about it and make decisions based on it. Statistics helps us to understand variation. The term statistical simply means organizing, describing, and drawing conclusions from data. (It does not require the use of a lot of complicated mathematics.)

It is everyone's responsibility-workers and managers alike-to understand work processes and to improve them. Quantitative methods and statistical tools provide workers and managers with the tools needed to quantify variation, identify causes, find solutions to reduce or remove unwanted variation, and monitor progress objectively. Statistical process control can help to achieve these goals when it is part of a total problem-solving effort. Simply going through the motions and providing data because the boss or customer wants it will not help to improve operations or better satisfy customers. Teamwork and participation play an important organizational role.

Control

Shewhart recognized that there are two major causes of variation in a process: *common causes* and *special causes.* Common causes of variation result from natural factors in the process and occur at random. Variation due to common causes cannot be changed except through fundamental change in the process itself. Changes might include replacing a machine with newer technology, providing training in improved work methods to the operators, or switching to a supplier of better quality materials. All these actions are the responsibility of management.

Special causes are unusual, sporadic events that cause unwanted variation, but are not inherent in the process itself. Some examples of special causes are a machine setting that shifts out of adjustment, materials that become damaged in transit, or an operator who works while ill or fatigued. These problems can be fixed by short-term corrective action, often by the workers themselves.

A process is *in control* if it is affected only by common causes of variation. A process that is in control is stable, and its performance can be predicted, at least within limits of variation. On the other hand, if special causes occur frequently and without our knowledge, we do not know how the process will perform. This is illustrated in Exhibit 1-1. We need to be able to control a process to maintain its stability. Control is the process of evaluating performance, comparing that performance to a goal or standard, and then taking corrective action when necessary.

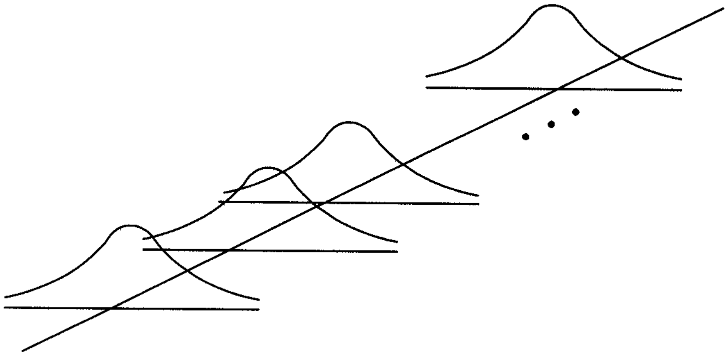
Control is not a substitute for continuous improvement; it is a means of maintaining improvements. The data collected through systematic measurement can be used productively to identify further areas for improvement. Measures give managers the information needed to reach their goals and lead to actions for improvement.

Some quality problems are management-controllable while others are operator-controllable. Joseph Juran, who also made substantial contributions to the Japanese quality education effort after World War II, defines operator-controllability in the following way: To be operator-controllable, three conditions must be met: (1) the operators must have the means of knowing what is expected of them through clear instructions and specifications, (2) they must have the means of determining their actual performance, typically through inspection and measurement, and (3) they must have a means of making corrections if they discover a variance between what is expected of them and their actual performance. If any one of these criteria is not met, then the

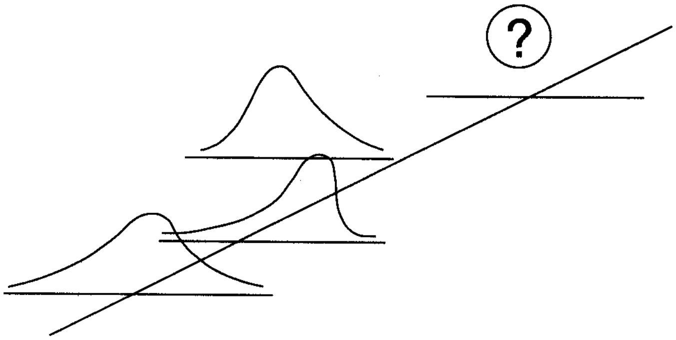
Exhibit 1–1

Illustration of Control Variation

Common cause variation allows predictability:



Performance cannot be predicted when special causes are present:



quality problem must be management-controllable, not operator-controllable. W. Edwards Deming also made this important distinction.

One of the major problems that has confronted American industry is the inability to distinguish between these two types of controllability. If operators are held accountable for or expected to act on problems that are beyond their control, the result is only frustration and eventual game-playing with management. Juran and Deming state that the vast majority of quality problems are management controllable; they are the result of common cause variation. For the smaller proportion of operator-controllable problems resulting from special causes, operators must be given the tools they need to identify the causes, and the authority to take action. It is this philosophy that has shifted the burden of quality from inspection departments and quality control personnel to the workers on the line. SPC can help operators identify quality problems that result from special causes and can also help management identify quality problems resulting from common causes.

QUANTIFYING VARIATION

Statistical methods help us to quantify variation. As we stated, complicated mathematics are unnecessary. In fact, many statistical tools are graphic in nature, allowing easy visualization and interpretation of data.

To help you understand many of the statistical concepts that we present in this course, we use "hands-on" exercises using an ordinary deck of playing cards. So dig them out and let's get started.

Variation Exercise

Remove one of each card, ace through 10, from the deck (the suit does not matter). These 10 cards represent the material you receive each day from your supplier. Your "production process" is to deal three cards and record the average; this is your "product." You may use the worksheet in Exhibit 1-2 to assist you with these calculations. Shuffle the cards, deal three cards, and compute the average. Then replace the cards in the ten-card deck, reshuffle (this is important!) and repeat until you have done this 25 times and completed the worksheet.

The averages you compute will lie between 2 and 9. Next, count the number of hands for which the average was at least 2 but less than 3, 3 but less than 4, and so on, and record this in the table below. (Your total should add to 25.) Finally, compute the percentage in each interval category and record this in the last column in the table.

Interval	Average	Number	Percentage
A	2 but less than 3		
B	3 but less than 4		
C	4 but less than 5		
D	5 but less than 6		
E	6 but less than 7		
F	7 but less than 8		
G	8 or more		
		Total 25	100%

What conclusions can you reach about the variation in your product? In what interval does the average fall most often? How likely is it that you will get an average of less than 3, or 8 or more in the next three cards you deal? Even though you cannot predict what the next average will be, you now

Exhibit 1-2

Worksheet for Variation Exercise

Trial	Card 1	Card 2	Card 3	Total	Average
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					
13.					
14.					
15.					
16.					
17.					
18.					
19.					
20.					
21.					
22.					
23.					
24.					
25.					

have a much better idea of the relative occurrence of averages in each of the categories.

It is not very difficult to compute the percentage you would expect to find in each category if this exercise were repeated a very large number of times. This is given in the table on the following page.

Interval	Average	Percentage (rounded)
A	2 but less than 3	3.33
B	3 but less than 4	10.00
C	4 but less than 5	20.00
D	5 but less than 6	25.00
E	6 but less than 7	22.50
F	7 but less than 8	13.33
G	8 or more	5.83
		100.00%

Exhibit 1-3 shows a bar chart, or histogram, of these percentages. You might want to think of this as a picture of the common causes of variation in this process. This picture tells us that the highest percentage of averages falls in interval D, and, in fact, about two-thirds fall in intervals C, D, and E together. We would not expect to find many values in intervals A and G. If we think of the averages as the outputs from a production process, we could tell our customers what to expect with reasonable certainty-as long as the process doesn't change. Changing the process might include changing the material, (for example, the constitution of the deck) or the manufacturing method (averaging 7 cards instead of 3).

We cannot reduce the variation except by "management action," such as getting more consistent-quality material from our suppliers. Suppose we replace the ace and 2 with a 4 and 5, and replace the 9 and 10 with a 6 and 7. (Since all the cards are now between 3 and 8, the averages tend to cluster closer to the center.) If we do this, we would then get the distribution shown in Exhibit 1--4. You can see that the variation is smaller and we can predict

Exhibit 1-3

Histogram for Variation Exercise

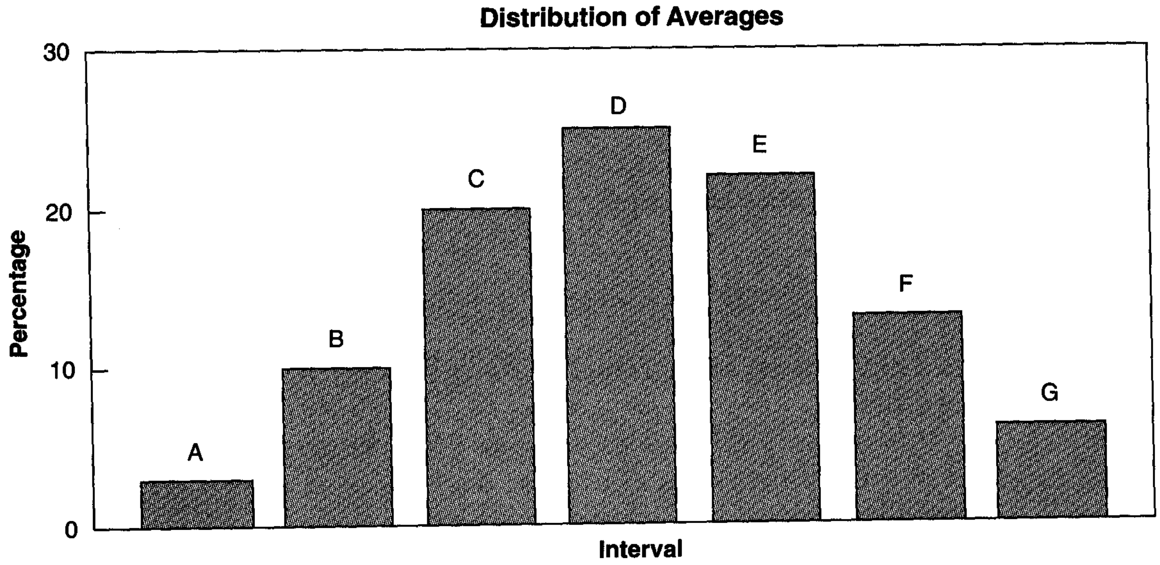
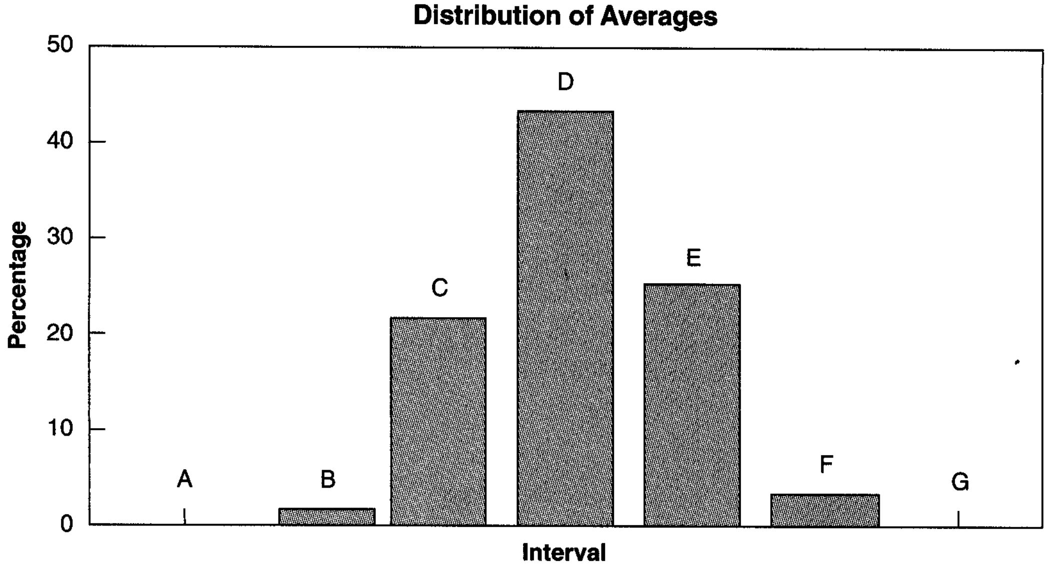


Exhibit 1–4

Histogram with Reduced Variation



the outcomes more precisely. Nearly all the values fall in intervals C, D, and E and only a few in intervals B and E Presumably, our customers will be happier.

Now, suppose that the ace, 2, and 3 are replaced with 8, 9, and 10 (a bad batch of material). Exhibit 1-5 shows a histogram of percentages in each interval for this situation. Looks quite different, doesn't it? This is a statistical signal that the process has changed and that we need to take some action to bring it back in control!

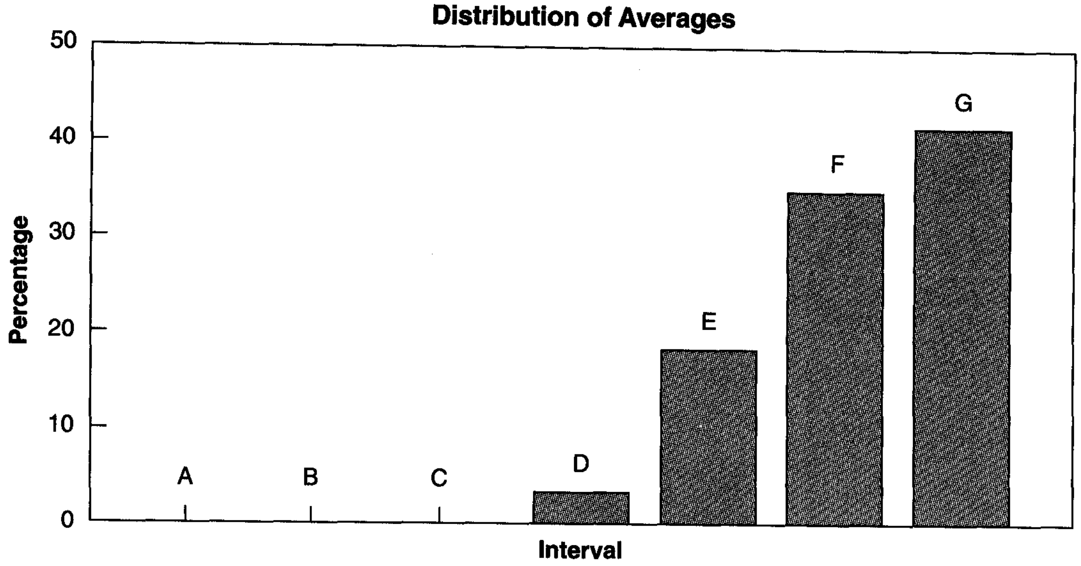
This is the kind of information that SPC provides-statistical signals that a process remains stable or that the system of variation has changed-no more, no less. Of course, there are quite a few other details and procedures to learn, but in a nutshell, that's it. To use SPC effectively, you need to go further than just learning how much variation your process has or how it might have changed. You need to identify reasons for the variation and approaches to improve the process. To do this, you need a systematic problem-solving and improvement procedure.

APPROACHES TO CONTINUOUS IMPROVEMENT

SPC is but a small part of the total quality improvement effort. The knowledge accumulated from studies of statistical data can help both front-line workers and management to address quality problems and improve quality.

Exhibit 1-5

Histogram for Special Cause Variation



Leaders in the quality revolution such as W. Edwards Deming and Joseph Juran advocate specific approaches for quality improvement. We will discuss the Deming Cycle and Juran's Improvement Program. Both rely extensively on the objective use of data and statistical methods.

The Deming Cycle

The *Deming cycle* is a methodology for improvement. It was originally called the Shewhart cycle after its creator, Walter Shewhart, but was renamed the Deming Cycle by the Japanese in 1950. The Deming cycle is composed of four stages: *plan, do, study* (formerly called *check*), and *act* (see Exhibit 1-6). Sometimes this is called the PDSA cycle.

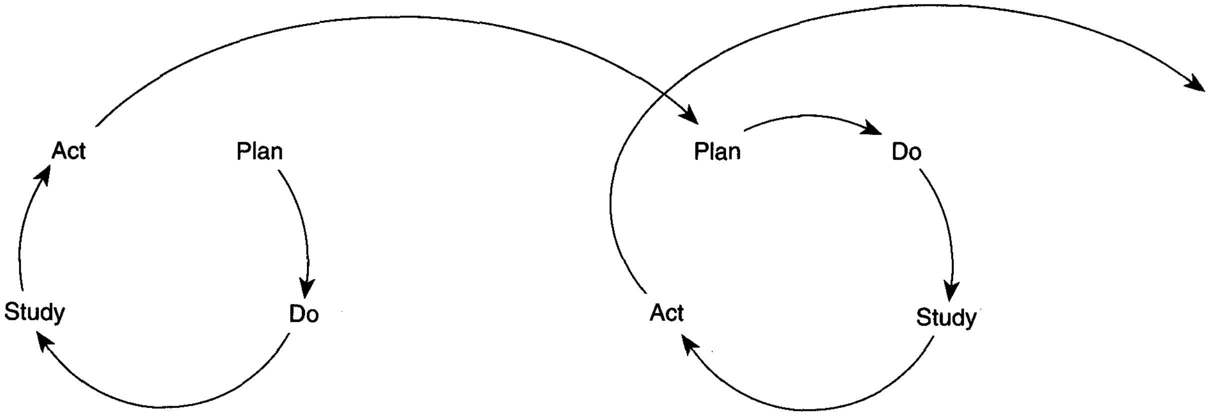
The Deming Cycle is based on the scientific method and focuses on acquiring knowledge through the testing of ideas and theories. As such, the emphasis is on objectivity. This process may take more time, but it eliminates making decisions based on intuition or opinions, which are often wrong.

The *plan* stage consists of several steps. First, we investigate the process in order to identify how things are currently being done. We need to focus on objectives: what do the customers of this process want? We need to develop a research plan. This includes identifying good measurements for collecting data or asking questions, as well as strategies for conducting experiments. We need to collect data, analyze the results, and suggest specific improvements.

In the *do* stage, the plan is implemented, preferably on a small-scale, trial basis. This might be in a laboratory, as a short-term experiment on the

Exhibit 1–6

The Deming Cycle



production floor, or with a small group of customers. The focus is to understand whether the trial solution indeed results in an improvement. We must define process measures, plan data collection, and gather data to study the effects of the change.

The study stage is designed to determine if the trial plan works correctly and if any further problems or opportunities are found. Data gathered in the do stage are analyzed, and we try to learn from the experiment. The greatest challenge is to remain objective, particularly if the data contradict intuition or prior experience.

The last stage, act, focuses on what to do next. We might implement the change and institute controls to ensure that the improvements will be standardized and practiced continuously. An implementation strategy nor mally outlines training requirements, equipment requirements, changes to current procedures, a schedule for making the transition, and cost/benefit implications. Or, we might conclude that the change will not result in a sustained improvement and continue with another experiment. In either case, we return to the plan stage for further diagnosis and improvement.

As Exhibit 1-6 suggests, this cycle is never ending; that is, it focuses on continuous improvement. The improved standards are only a springboard for further improvements. This is what distinguishes it from more traditional problem-solving approaches. It is one of the essential elements of the Deming philosophy.

The Deming Cycle is used routinely by many companies. Florida Power and Light, AT&T, and Zytec Corporation, all winners of either Japan's Deming Prize or America's Malcolm Baldrige National Quality Award, use the Deming Cycle as a fundamental part of their quality-improvement training and implementation programs.

Juran's Improvement Program

Joseph Juran emphasizes the importance of developing a habit of making annual improvements in quality and annual reductions in quality-related costs. Juran defines breakthrough as any improvement that takes an organization to unprecedented levels of performance. Breakthrough focuses on attacking chronic losses or, in Deming's terminology, common causes of variation. All breakthroughs follow a common sequence of discovery, organization, diagnosis, corrective action, and control. This "breakthrough sequence" is described below.

1. *Proof of the need* Managers, especially top managers, need to be convinced that quality improvements are simply good economics. Through quality cost analysis or supplemental data-collection efforts, information on poor quality, low productivity, or poor service can be translated into the language of money to justify a request for resources in order to implement a quality improvement program.
2. *Project identification* All breakthroughs are achieved project by project, and in no other way. By taking a project approach, management provides a forum for converting an atmosphere of defensiveness or blame into one of constructive action. Identification of the most beneficial projects is often done through data collection and prioritization efforts or by consensus-voting approaches.
3. *Organization for breakthrough* Organization for improvement requires identifying clear responsibility for guiding the project. The responsibility for the project may be assigned to as broad a group as an entire division with formal committee structures or as narrow a group as a small team of workers at one production operation. These groups must define and agree to the specific aims of the project, the authority to conduct experiments, and implementation strategies.
4. *The diagnostic journey* This focuses on finding causes of symptoms. Diagnosticians skilled in data collection, statistics, and other problem-solving tools are needed at this stage. Some projects require full-time, specialized experts, while others can be performed by the workforce themselves.
5. *The remedial journey* The remedial journey-moving from cause to remedy-consists of several phases: choosing an alternative that optimizes total cost, implementing remedial action, and dealing with resistance to change.
6. *Holding the Gains* This final step involves establishing the new standards and procedures, training the workforce, and instituting controls to make sure that the breakthrough does not die over time.

Many companies have followed Juran's program religiously. A Xerox plant in Mitcheldean, England, for example, cut quality losses by up to 40 percent and won a national prize in Britain in 1984 for quality improvement using the Juran system (Main, 1986). Many other companies have integrated this approach in their problem-solving efforts.

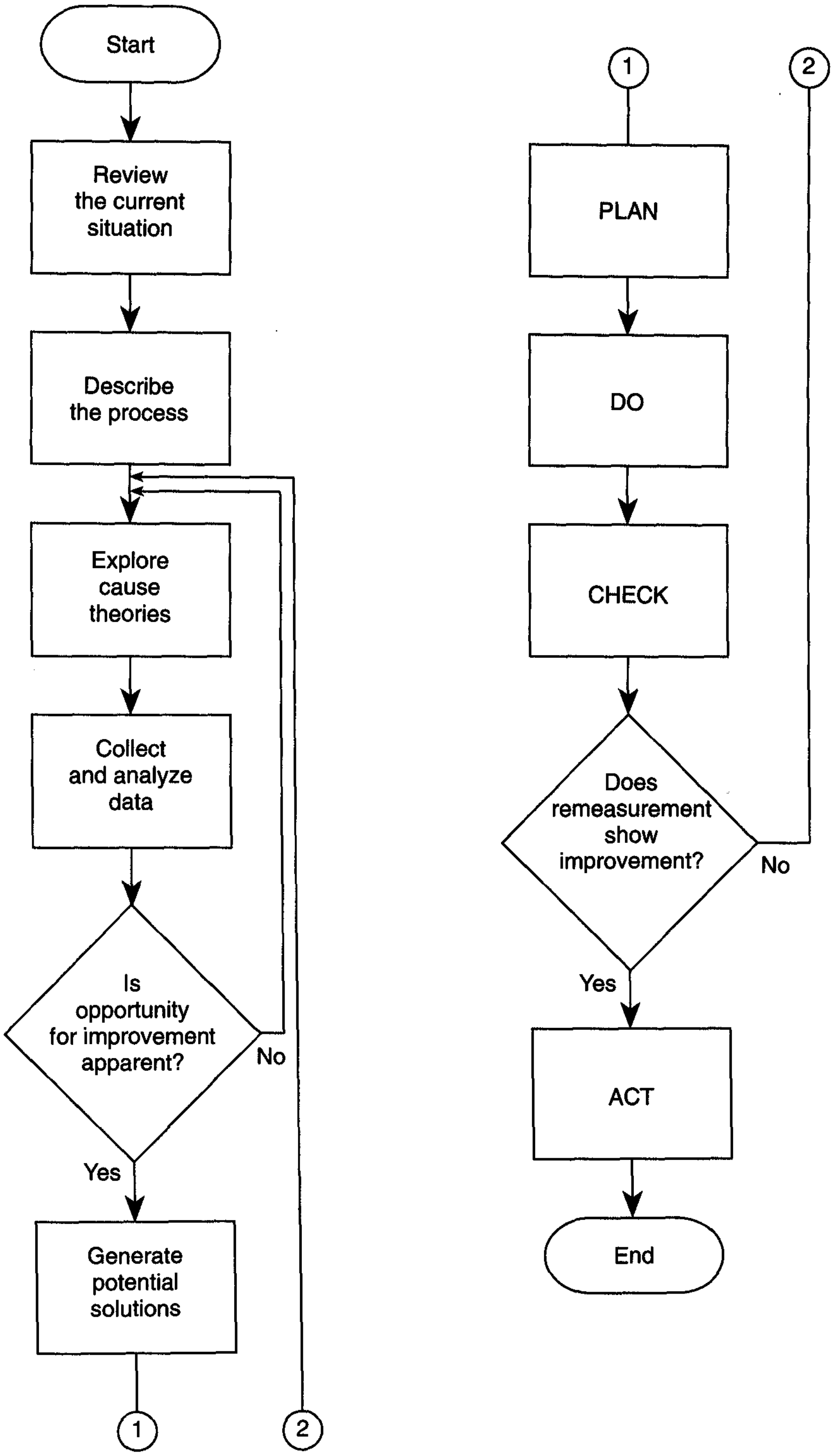
Juran's approach focuses on overall organizational planning and the solution of quality problems through careful diagnosis of causes and remedial action. The Deming Cycle has its principal focus on solution verification and implementation; hence, the Deming Cycle is most relevant in the last two steps of Juran's approach. Bethesda Hospital of Cincinnati, Ohio, one of the early adopters of TQM among healthcare organizations, has embedded the Deming Cycle in a general process-improvement model that captures the essence of Juran's ideas, as shown in Exhibit 1-7.

SUMMARY

Statistical process control (SPC) is an approach for understanding variation in production systems and for using the knowledge gained to eliminate special causes and reduce common causes of variation. Variation can be quantified statistically and described using frequency distributions and histograms. SPC does not provide answers; at best, it raises important questions. Thus, SPC should be integrated into an overall problem-solving approach, such as the Deming Cycle, Juran's Improvement Program, or some combination of these.

Exhibit 1–7

Bethesda Hospital's Process Improvement Model



Source: Reprinted with permission from Bethesda Hospital, Inc., Cincinnati, Ohio, 1994.

Review Questions

1. Which of the following is not a fundamental principle of total quality management? 1. (c)
   (a) Customer orientation
   (b) Quantitative analysis of data
   (c) Individual goal setting
   (d) Strategic planning and leadership

2. The primary reason that statistical process control received widespread attention in America is: 2. (a)
   (a) the success that SPC had in Japan.
   (b) the training that engineers received from Deming and others during World War II.
   (c) the publicity it received after being used at Western Electric.
   (d) the U.S. government's requirement that it be used in government contracts.

3. The key elements of a process are: 3. (a)
   (a) equipment, labor, materials, and work methods.
   (b) customer and supplier.
   (c) machines and inspectors.
   (d) statistical data and control mechanisms.

4. Common causes: 4. (d)
   (a) can be recognized by the workers who run a process.
   (b) are unusual, sporadic events.
   (c) can be eliminated by short-term, corrective action.
   (d) are the responsibility of management.

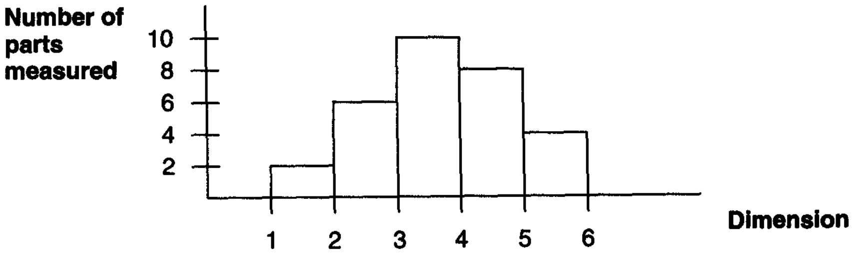
5. A process is in control if 5. (c)
   (a) operators monitor the process carefully.
   (b) the process always produces according to specification.
   (c) only common causes are present.
   (d) management has provided well-maintained equipment.

6. A graphic representation of the variation in a process is called a: 6. (b)
   (a) distribution.
   (b) histogram.
   (c) statistical signal.
   (d) breakthrough chart.

7. The phase of the Deming Cycle in which one determines whether or not an improvement is effective is: 7. (c)
   (a) plan.
   (b) do.
   (c) study.
   (d) act.

8. The Deming Cycle is most similar to which step in Juran's improvement program? 8. (d)
   (a) Project identification
   (b) Organization for breakthrough
   (c) The diagnostic journey
   (d) The remedial journey

Refer to the following histogram for dimensions of a machined part to answer questions 9 and 10.



9. What percentage of the data has a dimension between 2 and 4? 9. (a)
   (a) About 53
   (b) 16%
   (c) About 27%
   (d) It is impossible to tell.

10. If the specifications on this product required this dimension to be between 3 and 8, then out of every 100 parts, approximately how many would be scrapped or reworked?
    - (a) Half
    - (b) One-quarter
    - (c) Three-quarters
    - (d) All of them

10. (b)