OVERVIEW OF TOTAL QUALITY TOOLS

The significant problems we face cannot be solved at the same level of thinking we were at when we created them. **—Albert Einstein**

MAJOR TOPICS

- **Total Quality Tools Defined**
- **Pareto Charts**
- **Cause-and-Effect Diagrams**
- **Check Sheets**
- **Histograms**
- **Scatter Diagrams**
- **Run Charts and Control Charts**
- **Stratification**
- **Some Other Important Tools Introduced**
- **Management's Role in Tool Deployment**
- **Selecting the Right Tool for the Job**

One of the basic tenets of total quality is *management by facts*. This is not in harmony with the capability so revered in North America and the West in general: the ability to make snap decisions and come up with quick solutions to problems in the absence of input beyond intuition, gut feel, and experience. Management by facts requires that each decision, each solution to a problem, is based on relevant data and appropriate analysis. Once we get beyond the very small business (in which the data are always resident in the few heads involved, anyway), most decision points and problems will have many impacting factors, and the problem's root cause or the best-course decision will remain obscure until valid data are studied and analyzed. Collecting and analyzing data can be difficult. The total quality tools presented in this chapter make that task easy enough for anyone. Their use will ensure better decision making, better solutions to problems, and even improvement of productivity and products and services.

Writing about the use of statistical methods in Japan, Dr. Kaoru Ishikawa said:

> The above are the so-called seven indispensable tools . . . that are being used by everyone: company presidents, company directors, middle management, foremen, and line workers. These tools are also used in a variety of [departments], not only in the manufacturing [department], but also in the [departments] of planning, design, marketing, purchasing, and technology.[1]

No matter where you fit into your organization today, you can use some or all of these tools to advantage, and they will serve you well for your future prospects.

This chapter explains the most widely used total quality tools and their applications, provides some insights on the involvement of management and the cross-functional nature of the tools, and issues some cautions.

TOTAL QUALITY TOOLS DEFINED

Carpenters use a kit of tools designed for very specific functions. Their hammers, for example, are used for the driving of nails and their saws for the cutting of wood. These and others enable a carpenter to build houses. They are *physical* tools. Total quality tools also enable today's employees, whether engineers, technologists, production workers, managers, or office staff, to do their jobs. Virtually no one can function in an organization that has embraced total quality without some or all of these tools. Unlike those in the carpenter's kit, these are *intellectual* tools. They are not wood and steel to be used with muscle; they are tools for collecting and displaying information in ways to help the human brain grasp thoughts and ideas. When thoughts and ideas are applied to physical processes, the processes yield better results. When they are applied to problem solving or decision making, better solutions and decisions are developed.

The seven tools discussed in the following seven sections of this chapter represent those generally accepted as the basic total quality tools. Some authors would include others, and we discuss some of the others briefly later in this chapter. A case can be made that *just-in-time (JIT), statistical process control*, and *quality function deployment* are total quality tools. But these are more than tools: They are complete systems under the total quality umbrella.

A tool, like a hammer, exists to help do a job. If the job includes *continual improvement*, problem solving, or decision making, then these seven tools fit the definition. Each of these tools is some form of chart for the collection and display of specific kinds of data. Through the collection and display facility, the data become useful information—information that can be used to solve problems, enhance decision making, keep track of work being done, and even predict future performance and problems. The beauty of the charts is that they organize data so that we can immediately comprehend the message. This would be all but impossible without the charts, given the mountains of data flooding today's workplace.

PARETO CHARTS

The *Pareto* (pah-ray-toe) *chart* (see Figure 1) is a very useful tool wherever one needs to separate the important from the trivial. The chart, first promoted by Dr. Joseph Juran, is named after Italian economist and sociologist Vilfredo Pareto (1848–1923). He had the insight to recognize that in the real world a minority of causes lead to the majority of problems. This is known as the Pareto Principle. Pick a category, and the Pareto Principle will usually hold. For example, in a factory you will find that of all the kinds of problems you can name, only about 20% of them will produce 80% of the product defects: Eighty percent of the cost associated with the defects will be assignable to only about 20% of the total number of defect types occurring.[2] Examining the elements of this cost will reveal that once again 80% of the total defect cost will spring from only about 20% of the cost elements.

Charts have shown that approximately 20% of the professionals on the tennis tour reap 80% of the prize money and that 80% of the money supporting churches in the United States comes from 20% of the church membership.

All of us have limited resources. That point applies to you and to me, and to all enterprises—even to giant corporations and to the government. This means that our resources (time, energy, and money) need to be applied where they will do the most good. The purpose of the Pareto chart is to show you where to apply your resources by distinguishing the significant few from the trivial many. It helps us establish priorities.

The Pareto chart in Figure 1 labels a company's customers A, B, C, D, E, and all others. The bars represent the percentages of the company's sales going to the respective customers. Seventy-five percent of this company's sales are the result of just two customers. If one adds customer C, 90% of its sales are accounted for. All the other customers together account for only 10% of the company's sales. Bear in mind that "all others" may include a very large number of small customers. Which customers are the ones who should be kept happy? Obviously, A, B, and perhaps C are the most critical. This would suggest that customers A, B, and C are the company's core market and all the other customers represent a marginal business. Decisions on where to allocate resources should be made accordingly.

The Pareto chart in Figure 2 shows bars representing the sales of a particular model of automobile by age group of the buyers. The curve represents the cumulative percentage of sales and is keyed to the *y*-axis scale on the right. The manufacturer has limited resources in its advertising budget, and the chart reveals which age groups are the most logical choice to target. Concentrating on the 26 to 45 age bracket will result in the best return on investment because 76% of the Swift V-12 buyers come from the combination of the 36 to 45 and 26 to 35 age groups. The significant few referred to in the Pareto Principle are in the 26 to 45 age group. The insignificant many are all those under 26 and over 45.

Cascading Pareto Charts

You can cascade Pareto charts by determining the most significant category in the first chart, making a second chart related only to that category, and then repeating this as far as possible, to three, four, or even five or more charts. If the cascading is done properly, root causes of problems may be determined rather easily.

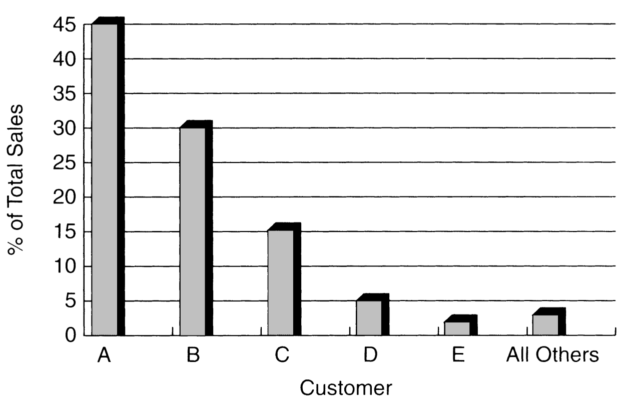


FIGURE 1 Pareto Chart: Percentage of Total Sales by Customer

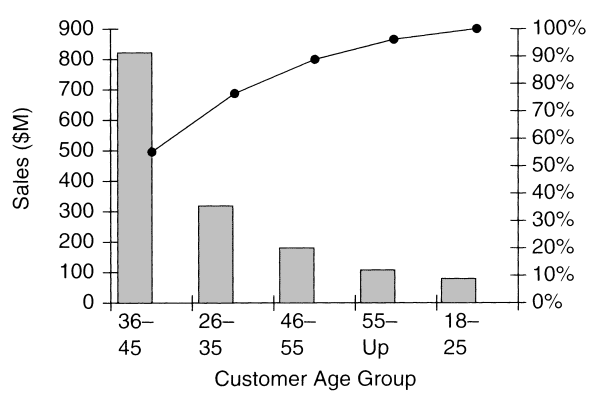


FIGURE 2 Swift V-12 Sales by Age Group

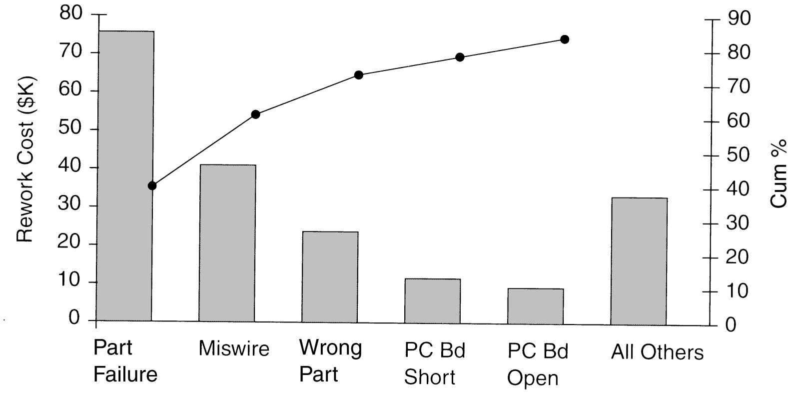


FIGURE 3 Top Five Defects by Rework Cost

Consider the following example. A company produces complex electronic assemblies, and the test department is concerned about the cost of rework resulting from test failures. It is costing more than $190,000 per year, and that amount is coming directly out of profit. The department formed a special project team to find the cause of the problem and reduce the cost of rework. The Pareto chart in Figure 3 showed them that about 80% of the cost was related to just five defect causes. All the others, and there were about 30 more, were insignificant—*at least at that time.*

The longest bar alone accounted for nearly 40% of the cost. If the problem it represents could be solved, the result would be an immediate reduction of almost $75,000 in rework cost. The team sorted the data again to develop a level 2 Pareto chart, Figure 4, to focus on any part types that might be a major contributor to the failures.

Figure 4 clearly showed that one type of relay accounted for about 60% of the failures. No other part failures came close. In this case and at this time, the relay was the significant one, and all the other parts were the insignificant many. At this point, another team was formed to analyze the failure modes of the relay in order to determine a course of action for eliminating the relay problem. It was determined that there were a number of failure modes in the relay. They were plotted on the Pareto chart shown in Figure 5, which immediately revealed that 66% of all the failures were associated with one failure mode. The second longest bar in Figure 5 represented another manifestation of the same root cause. The relay contacts were not switching on *at all* (longest bar) or were not switching on *completely* (next longest bar). With this information known, the relay contacts were carefully examined, and it was determined that the relays were being damaged at incoming inspection where they were tested with a voltage that was high enough to damage the gold plating on the contacts. Changing the incoming test procedure and working with the relay vendor to improve its plating process eliminated the problem.

Earlier in this chapter, we implied that although a particular problem might be insignificant at one point in time, it might not stay that way. Consider what happens to the bars on the cascaded charts when the relay contact problem is solved. The second longest bar on the chart in Figure 3 clearly becomes the longest (assuming it was not being solved simultaneously with the relay problem). At this point, more than $100,000 a year is still being spent from profit to rework product rather than making it properly in the first place. The cycle must continue to be repeated until perfection is approached.

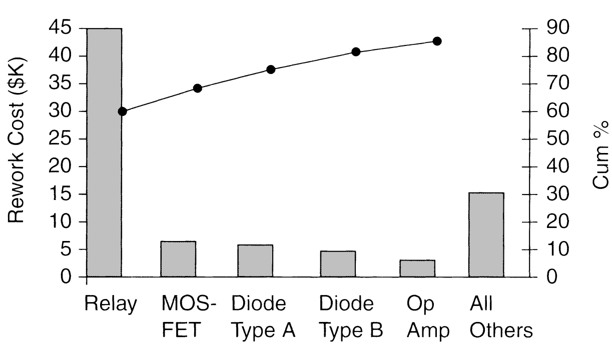


FIGURE 4 Rework Cost by Top Five Part Failure Categories

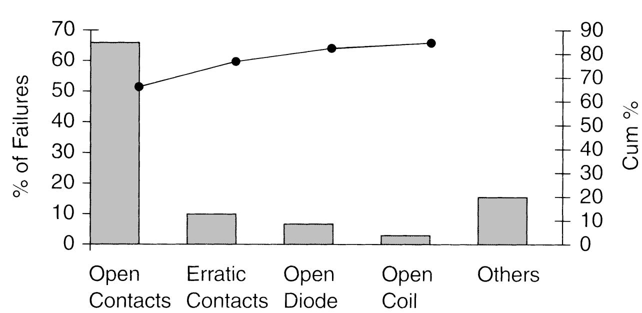


FIGURE 5 Relay Failure Categories

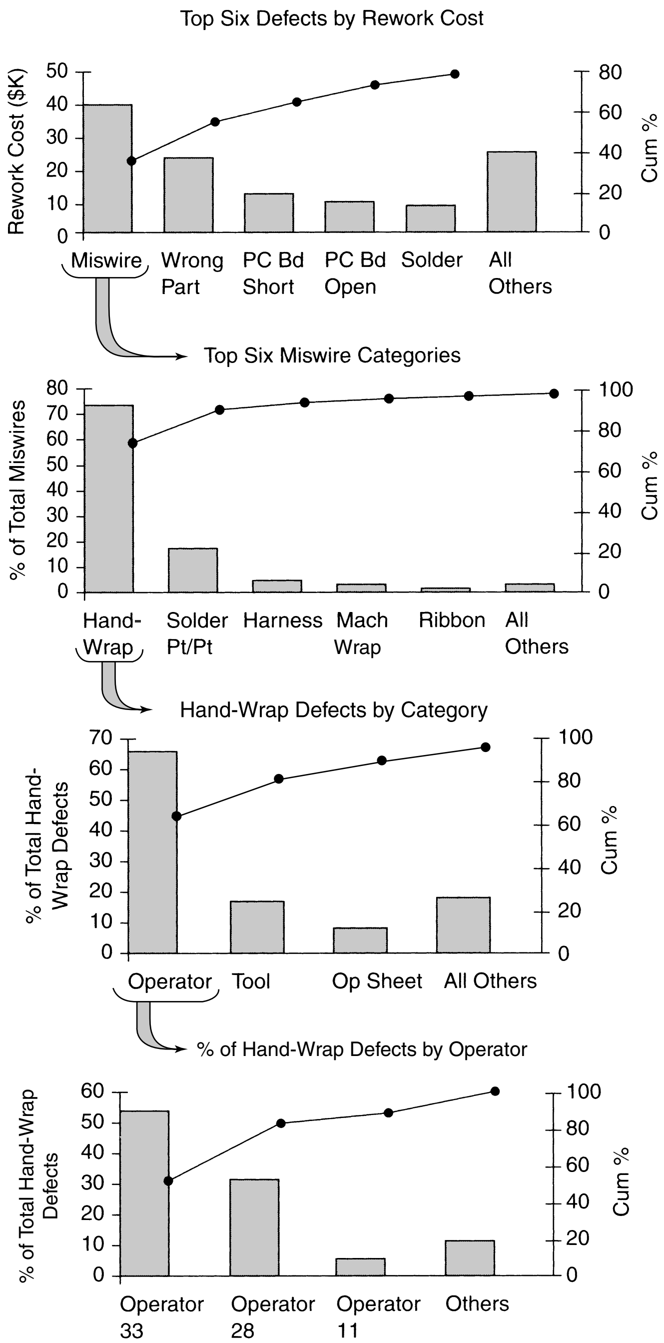


FIGURE 6 Second Cascading of Pareto Charts

Note: The tallest bar becomes the subject of the next Pareto chart.

The next cycle of Pareto charts might look like those in Figure 6. Starting at the top, we see the following points:

1. Miswires (wires connected to the wrong point or not properly attached to the right point) account for 40% of the remaining rework cost.
2. Wires connected with hand-wrapping tools represent more than 70% of all miswires.
3. Of the hand-wrap defects, more than 65% are caused by operator error.
4. Of all the operators doing hand-wrap work, operators 33 and 28 contribute more than 80% of the defects.

Attention must be given to those operators in the form of training or, perhaps, reassignment.

The third Pareto chart cascading would break down the Wrong Part problem. For example, perhaps Part abc is mistakenly substituted for Part xyz on a printed circuit board. The cycle may be repeated over and over, each time dealing with the significant few, while ignoring the trivial many. Eventually, perfection is approached. A few companies are getting close with some of their products, but most have ample opportunity for significant improvement. One need not worry about running out of improvement possibilities.

CAUSE-AND-EFFECT DIAGRAMS

A team typically uses a *cause-and-effect diagram* (see Figure 8) to identify and isolate causes of a problem. The technique was developed by the late Dr. Ishikawa, a noted Japanese quality expert, so sometimes the diagram is called an *Ishikawa diagram*. It is also often called a fishbone diagram because that is what it looks like.

In his book *Guide to Quality Control*, Ishikawa explains the benefits of using cause-and-effect diagrams as follows:[3]

> Creating the diagram itself is an enlightening, instructive process.
>
> Such diagrams focus a group, thereby reducing irrelevant discussion.
>
> Such diagrams separate causes from symptoms and force the issue of data collection.
>
> Such diagrams can be used with any problem.

The cause-and-effect diagram is the only tool of the seven tools that is not based on statistics. This chart is simply a means of visualizing how the various factors associated with a process affect the process's output. The same data could be tabulated in a list, but the human mind would have a much more difficult time trying to associate the factors with each other and with the total outcome of the process under investigation. The cause-and-effect diagram provides a graphic view of the entire process that is easily interpreted by the brain.

Suppose an electronics plant is experiencing soldering rejects on printed circuit (PC) boards. People at the plant decide to analyze the process to see what can be done; they begin by calling together a group of people to get their thoughts. The group is made up of engineers, solder machine operators, inspectors, buyers of materials, production control specialists, and others. All the groups in the plant who have anything at all to do with PC boards are represented, which is necessary to get the broadest possible view of the factors that might affect the process output.

The group is told that the issue to be discussed is the solder defect rate and that the objective is to list all the factors in the process that could possibly have an impact on the defect rate. The group uses brainstorming to generate the list of possible *causes*. The list might look like Figure 7.

The group developed a fairly comprehensive list of factors in the PC board manufacturing process—factors that

machine	solderability	operator
solder	conveyer speed	temperature
preheat	materials	parts
operator attitude	operator attention	flux
conveyer angle	wave height	cleanliness
age of parts	age of boards	part preparation
parts vendors	board vendors	type of flux
specific gravity	machine maintenance	training
skill	vibration	storage
instruments	lighting	calibration
handling	wait-time	contamination
air quality	humidity	

FIGURE 7 Brainstormed List of Possible Causes for Solder Defects

could *cause* the *effect* of solder defects. Unfortunately, the list does nothing in terms of suggesting which of the 35 factors might be major causes, which might be minor causes, and how they might relate to each other. This is where the cause-and-effect diagram comes into play. Ishikawa's genius was to develop a means by which these random ideas might be organized to show relationships and to help people make intelligent choices.

Figure 8 is a basic cause-and-effect diagram. The spine points to the *effect*. The effect is the "problem" we are interested in—in this case, machine soldering defects. Each of the ribs represents a cause leading to the effect. The ribs are normally assigned to the causes considered to be *major factors*. The lower level factors affecting the major factors branch off the ribs. Examine Figure 7 to see whether the major causes can be identified. These causes are assigned to the ribs.

Six major groupings of causes are discernible listed as follows:

1. The solder machine itself is a major factor in the process.
2. The operators who prepare the boards and run the solder machine are also major factors.
3. The list includes many items such as parts, solder, flux, boards, and so on, and these can be collected under the word *materials*, which also appears on the list. Materials is a major factor.
4. Temperature within the machine, conveyor speed and angle, solder wave height, and so on are really the *methods* (usually published procedures and instructions) used in the process. Methods is a major factor.
5. Many of these same items are subject to the plant's methods (how-to-do-it) and measurement (accuracy of control), so measurement is a major factor, even though it did not appear on the list.
6. The cleanliness, lighting, temperature and humidity, and quality of the air we breathe can significantly affect our performance and thus the quality of output of processes with which we work. We will call this major factor *environment*.

The designated six major factors, or causes, are those that the group thinks might have an impact on the quality of output of the machine soldering process: machine, operator, materials, methods, measurement, and environment. The cause-and-effect fishbone diagram developed from this information has six ribs, as shown in Figure 9.

Having assigned the major causes, the next step is to assign all the other causes to the ribs they affect. For example, *machine maintenance* should be assigned to the Machine rib because machine performance is obviously affected by how well or how poorly the machine is maintained. *Training* will be attached to the Operator rib because the degree to which operators have been trained certainly affects their expertise in running the machine. In some cases, a possible cause noted on the list may appropriately branch not from the rib (major cause) but from one of the branches (contributing cause). For example, *solderability* (the relative ease—or difficulty—with which materials

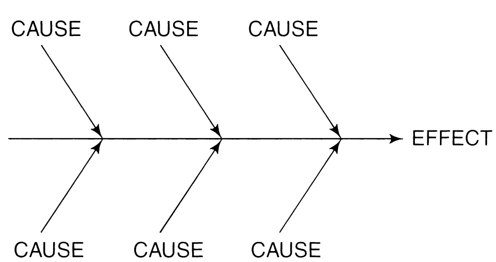


FIGURE 8 Basic Cause-and-Effect or Fishbone Diagram

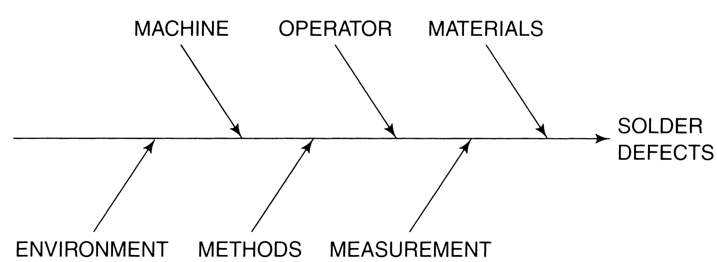


FIGURE 9 Cause-and-Effect Diagram with Major Causes and Effect Assigned

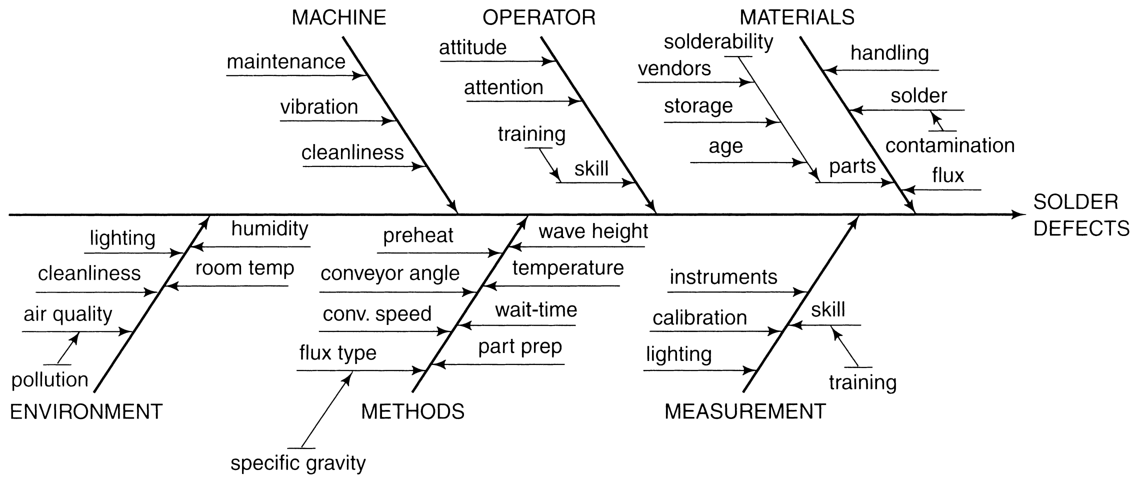


FIGURE 10 Completed Cause-and-Effect Diagram

can be soldered) will branch from the Materials rib because it is a contributor to the materials' cause of solder defects. An important cause of poor solderability is age of parts. So *age of parts* will branch not from Materials but from solderability. Study Figure 10 to get a graphic sense of the relationships described in this paragraph.

Figure 10 is the completed fishbone diagram. It presents a picture of the major factors that can cause solder defects and, in turn, the smaller factors that affect the major factors. Examination of the Materials rib shows that there are four factors directly affecting materials in regard to solder defects: the parts themselves, the handling of the materials, and the solder and flux used in the process. The chart points out that contamination can affect the solder's performance and also that the big issue affecting the parts is solderability. In this case, the branches go to three levels from the rib, noting that solderability can be affected by the vendor supplying the parts, storage of the parts before use, and age of the parts.

Now you may say, "The diagram didn't configure itself in this way. Someone had to know the relationships before the diagram was drawn, so why is the diagram needed?" First, picture these relationships in your mind—no diagram, just a mental image. If you are not familiar with the process used in the example, pick any process involving more than two or three people and some equipment, such as the process of an athletic event. If you try this, you will probably find it virtually impossible to be conscious of all the factors coming into play, to say nothing of how they relate and interact. Certainly, the necessary knowledge and information already existed before the 35 factors were arranged in the cause-and-effect diagram. The key to the diagram's usefulness is that it is very possible that no *one* individual had all that knowledge and information. That is why cause-and-effect diagrams are normally created by teams of people widely divergent in their expertise.

The initial effort by the team is developing the list of possible factors. This is usually done using brainstorming techniques. Such a list can be made in a surprisingly short time—usually no more than an hour. It is not necessary that the list be complete or even that all the factors listed be truly germane. Missing elements will usually be obvious as the diagram is developed, and superfluous elements will be recognized and discarded. After the list has been compiled, all the team members contribute from their personal knowledge and expertise to assemble the cause-and-effect diagram.

The completed diagram reveals factors or relationships that had previously not been obvious. The causes most likely responsible for the problem (solder defects) will normally be isolated. Further, the diagram may suggest possibilities for action. It is conceivable in the example that the team, because it is familiar with the plant's operation, could say with some assurance that solderability was suspected because the parts were stored for long periods of time. They might recommend that, by switching to a JIT system, both storage and aging could be eliminated as factors affecting solderability.

The cause-and-effect diagram serves as an excellent reminder that the items noted on it are the things the company needs to pay attention to if the process is to continually improve. Even in processes that are working well, continual improvement is the most important job any employee or team can have. In today's competitive global marketplace, it is truly the key to survival.

CHECK SHEETS

The *check sheet* (see Figure 12) is introduced here as the third of the seven tools. The fuel that powers the total quality tools is data. In many companies, elaborate systems of people, machines, and procedures exist for the sole purpose of collecting data. At times, this quest for data has become zealous to the point of obscuring the reason for data collection in the first place. Many organizations are literally drowning in their own data, while at the same time not knowing what is actually going on; they are "data rich and information poor." With the advent of powerful desktop computers, information collection has become an end unto itself in many instances.

Having access to data is essential. However, problems arise when trivial data cannot be winnowed from the important and when there is so much of it that it cannot be easily translated into useful information. Check sheets help deal with this problem.

The check sheet can be a valuable tool in a wide variety of applications. Its utility is restricted only by the imagination of the person seeking information. The check sheet can take any form. The only rules are that data collection must be the equivalent of entering a check mark and that the displayed data must be easily translated into useful information. For example, it may take the form of a drawing of a product with the check marks entered at appropriate places on the drawing to illustrate the location and type of defect. An accounts receivable department might set up a check sheet to record the types and numbers of mistakes on invoices prepared. Check sheets apply to any work environment—not just to the factory floor.

The purpose of the check sheet is to make it easy to collect data for specific purposes and to present it in a way that facilitates conversion from data to useful information. For example, suppose we are manufacturing parts that have a specified dimensional tolerance of 1.120 to 1.130 inches (in.). During the week, each part is measured and the data are recorded. Figure 11 is a summary of the week's results.

This figure contains all the data on shaft length for the week of July 11. Without a lot of additional work, it will be difficult to glean much useful information from this list of data. Imagine how much more difficult it would be if, instead of a table, you were presented with a stack of computer runs several inches thick. That is frequently the case in the information age. (The information age should be called the *data age*, in our opinion, reflecting the abundance of raw, often meaningless data and the real paucity of *useful* information.)

The computer could be programmed to do something with the data to make them more useful, and in some situations, that would be appropriate. After all, computers are good at digesting raw data and formatting the result for human consumption. But before the computer can do that, some human must tell it exactly what it must do, how to format the information, what to discard, what to use, and so on. If we can't first figure out what to do with the data, no amount of computer power will help. On the supposition that we do know what to do with the data, it is possible that we could *preformat* the data so that it will be instantly useful *as it is being collected*. This is one of the powerful capabilities of the check sheet.

The importance of the data in Figure 11 rests in reporting how the shafts being produced relate to the shaft length specification. The machine has been set up to produce shafts in the center of the range so that normal variation would not spill outside the specified limits of 1.120 and 1.130 in. and thereby create waste. If the raw data could give us a feel for this as it is being collected, that would be very helpful. We would also like to know when the limits are exceeded. The check sheet in Figure 12 has been designed to facilitate both data collection and conversion to information.

The check sheet of Figure 12 is set up to accept the data very easily and at the same time display useful information. The check sheet actually produces a histogram as the data are entered. (See the following section for information

Shaft length: Week of 7/11 (Spec: 1.120–1.130")

Date	Length	Date	Length	Date	Length	Rem
11	1.124	11	1.128	11	1.123	
11	1.126	11	1.128	11	1.125	
11	1.119	11	1.123	11	1.122	
11	1.120	11	1.122	11	1.123	
12	1.124	12	1.126	12	1.125	
12	1.125	12	1.127	12	1.125	
12	1.121	12	1.124	12	1.125	
12	1.126	12	1.124	12	1.127	
13	1.123	13	1.125	13	1.121	
13	1.120	13	1.122	13	1.118	
13	1.124	13	1.123	13	1.125	
13	1.126	13	1.123	13	1.124	
14	1.125	14	1.127	14	1.124	
14	1.126	14	1.129	14	1.125	
14	1.126	14	1.123	14	1.124	
14	1.122	14	1.124	14	1.122	
15	1.124	15	1.121	15	1.123	
15	1.124	15	1.127	15	1.123	
15	1.124	15	1.122	15	1.122	
15	1.123	15	1.122	15	1.121	

FIGURE 11 Weekly Summary of Shaft Dimensional Tolerance Results

Note: This is *not* a check sheet.

Check Sheet

Shaft length: Week of 7/11 (Spec: 1.120–1.130")

1.118**	13	
1.119**	11	**** Out of Limits**
1.120	11 13	
1.121	12 13 15 15	
1.122	11 11 13 14 14 15 15 15	
1.123	11 11 11 13 13 13 14 15 15 15	
1.124	11 12 12 12 13 13 14 14 14 15 15 15	
1.125	11 12 12 12 12 13 13 14 14	
1.126	11 12 12 13 14 14	
1.127	12 12 14 15	
1.128	11 11	
1.129	14	**Enter day of month for data point.**
1.130		
1.131**		
1.132**		

FIGURE 12 Check Sheet of Shaft Dimensional Tolerance Results

QUALITY TIP ▼

Give the Operator Some Responsibility

The taking of measurements and the logging of data on the check sheet should ideally be done by the operator who runs the machine, not a quality control inspector. In a total quality system, the operators are responsible for the quality of their output—for checking it, taking data, responding to the data, and so on. The quality control department is there to audit the processes to make sure that they are under control and that procedures are followed.

Source: Stanley B. Davis and David L. Goetsch.

about histograms.) Data are taken by measuring the shafts, just as was done for Figure 11. But rather than logging the measured data by date, as in Figure 11, the check sheet in Figure 12 only requires noting the date (day of month) opposite the appropriate shaft dimension. The day-of-month notation serves as a check mark, while at the same time keeping track of the day the reading was taken.

This check sheet should be set up on an easel on the shop floor, with entries handwritten. That will make the performance of the machine continually visible to all—operators, supervisors, engineers, or anyone else in the work area.

The data in Figure 11 are the same as the data in Figure 12. Figure 11 shows columns of sterile data that, before meaning can be extracted, must be subjected to hard work at someone's desk. Assuming it does get translated into meaningful information, it will probably still remain invisible to the people who could make the best use of it—the operators. That can, of course, be overcome by more hard work, but in most cases, the data will languish. On the other hand, Figure 12 provides a simple check sheet into which the data are entered more easily and, once entered, provide a graphic presentation of performance. If the check sheet reveals that the machine is creeping away from the center of the range or if the histogram shape distorts, the operator can react immediately. No additional work is required to translate the data to useful information, and no additional work is required to broadcast the information to all who can use it.

To set up a check sheet, you must think about your objective. In this example, we were making shafts to a specification. We wanted data indicating how well the machine was performing, a graphic warning whenever the machine started to deviate, and information about defects. Setting up the check sheet as a histogram provided all the information needed. This is called a *Process Distribution Check Sheet* because it is concerned with the variability of a process. Other commonly used check sheets include Defective Item Check Sheets (detailing the variety of defects), Defect Location Check Sheets (showing where on the subject product defects occur), and Defect Factor Check Sheets (illustrating the factors—time, temperature, machine, operator—possibly influencing defect generation).

If we wanted to better understand what factors might be contributing to excessive defects on the shop floor, we could set up a Defect Factors Check Sheet. As an example, go back to the section on Pareto charts and look at Figure 6. The top chart there revealed that miswires were the most significant defect in terms of cost. To collect some data about the factors that might be contributing to the miswire defects, a reasonable approach would be to set up a Defect Factors Check Sheet and collect data for a week. We are primarily concerned with the operators themselves and the factors that may influence their performance. The check sheet will list each operator's number and bench location within the factory. To determine whether the day of the week or the time of day has anything to do with performance, the data will be recorded by day and by morning or afternoon. We could have included tool numbers as well, but using a tool that produces faulty connections is something the operator must guard against. In other words, we will not consider a tool to be at fault—only the operator if he or she continues to use a defective tool.

In the check sheet shown in Figure 13, five types of miswire defects, covering all types experienced, are coded by symbols, and these symbols are the only raw data entered on the chart. Sums of all defect categories are shown at the bottom of each column, and the weekly total for each operator is shown at the end of each row. A quick glance at the check sheet points to operators 28 and 33 as the sources of the problem. We don't know the *cause* at this point, but we know where to start looking.

In past times, these two people might very well have been summarily fired. In a total quality setting, that decision would be considered the last resort. Most employees want to do a good job and will if they are provided with the necessary resources and training. In a case like this, it is not unusual to find that the fault lies with management. The employees were not adequately trained for the job, or some environmental factor (noise, temperature, lighting, or something else) is at fault, or the operators may simply not be equipped for the task (because of vision impairment, impaired motor skills, or some other problem). In any of those scenarios, management is at fault and, therefore, should do the morally right thing to correct the problem.

Check sheets can be valuable tools for converting data into useful and easy-to-use information. The key is teaching operators how to employ them and empowering them to do so.

QUALITY TIP ▼

Statistics Expertise Not Required

We recognize that although much of the following discussion of histograms and control charts is related to statistics, many readers will not be expert statisticians. Unfortunately, the scope of this text does not allow for a treatise on statistics, so we have attempted to present the material and mathematical processes in a way that can be followed by the uninitiated who are willing to stay with us. In doing this, we have sacrificed nothing in the accuracy of the information presented or the techniques applied. Our objective is that both the statistics novice and the expert will be rewarded with a good understanding of these tools, their applications, and the methodology and significance of the math. For those interested in delving deeper into the tools or statistics, many books are dedicated to each of them.

Operator No.	Bench No.	11/2		11/3		11/4		11/5		11/6		Week Totals
		AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	
8	A3					●				○ □		○ - 1 ● - 1 3 □ - 1
10	A2			● ●			□					● - 2 □ - 1 3
11	B1	○						○				○ - 2 2
13	A1		○				△				□ □	○ - 1 △ - 1 4 □ - 2
28	C2	○ ● ○	○ △	○ ○ ○	△ ○ ○	○	○ ○	○ △	□ ○	○ ○	○ ● ○	○ - 17 ● - 2 △ - 3 23 □ - 1
33	C3	○ ○ ○ △ ○	● ○ ○ ○	○ △ ○ ○	○ ○ □	○ ●	□ ○ ○	△ ○ ○	○ ○	○ ○ ○ ○ △ ○	○ ○ ○ ○	○ - 28 ● - 2 △ - 4 36 □ - 2
40	B2	+							○ ●			○ - 1 ● - 1 3 + - 1
	Half-day totals	10	7	9	6	4	7	6	6	10	9	39 35
	Full-day totals	17		15		11		12		19		74

LEGEND: ○ = Hand wrap
● = Solder point to point
△ = Harness
+ = Ribbon
□ = Other

FIGURE 13 Check Sheet: Defect Factors—Miswires

HISTOGRAMS

Histograms are used to chart frequency of occurrence. How often does something happen? Any discussion of histograms must begin with an understanding of the two kinds of data commonly associated with processes: *attributes* and *variables* data. Although they were not introduced as such, both kinds of data have been used in the illustrations of this chapter. An *attribute* is something that the output product of the process either has or does not have. From one of the examples (Figure 6), either an electronic assembly had wiring errors or it did not. Another example (Figure 30) shows that either an assembly had broken screws or it did not. These are attributes. The example of making shafts of a specified length (Figures 11 and 12) was concerned with *measured data*. That example used shaft length measured in thousandths of an inch, but any scale of measurement can be used, as appropriate for the process under scrutiny. A process used in making electrical resistors would use the scale of electrical resistance in ohms, another process might use a weight scale, and so on. *Variables data* are something that results from measurement.

Using the shaft example again, an all-too-common scenario in manufacturing plants would have been to place a Go–No Go screen at the end of the process, accepting all shafts between the specification limits of 1.120 and 1.130 in. and discarding the rest. Data might have been recorded to keep track of the number of shafts that had to be scrapped. Such a record might have looked like Figure 14, based on the original data.

Shaft Acceptance: Week of 7/11 (Spec: 1.120–1.130")

Date	Accepted	Rejected
11.	11	1
12.	12	0
13.	11	1
14.	12	0
15.	12	0
Totals:	58	2

FIGURE 14 Summary Data: Weekly Shaft Acceptance

An Important Distinction to Remember

Attributes Data

- Has or has not
- Good or bad
- Pass or fail
- Accept or reject
- Conforming or nonconforming

Variables Data

- Measured values (dimension, weight, voltage, surface, etc.)

Figure 14 would tell us what we wanted to know if we were interested only in the number of shafts accepted versus the number rejected. Looking at the shaft process in this way, we are using *attributes data*: either they passed or they failed the screening. This reveals only that we are scrapping between 3 and 4% of all the shafts made. It does not tell us anything about the process adjustment that may be contributing to the scrap rate. Nor does it tell us anything about how robust the process is—might some slight change push the process over the edge? For that kind of insight, we need *variables data*.

One can gain much more information about a process when variables data are available. The check sheet of Figure 12 shows that both of the rejects (out-of-limits shafts) were on the low side of the specified tolerance. The peak of the histogram seems to occur between 1.123 and 1.124 in. If the machine were adjusted to bring the peak up to 1.125 in., some of the low-end rejects might be eliminated without causing any new rejects at the top end. The frequency distribution also suggests that the process as it stands now will always have occasional rejects—probably in the 2 to 3% range at best.

Potential Trap with Histograms

Be aware of a potential trap when using histograms. The histogram is nothing more than a measurement scale across one axis (usually the x-axis) and frequency of like measurements on the other. (Histograms are also called *frequency distribution diagrams*.) The trap occurs when measurements are taken over a long period of time. Too many things can affect processes over time: wear, maintenance, adjustment, material differences, operator influence, and environmental influence. The histogram makes no allowance for any of these factors. It may be helpful to consider a histogram to be the equivalent of a snapshot of the process performance. If the subject of a photograph is moving, the photographer must use a fast shutter speed to prevent a blurred image. If the histogram data are not collected over a suitably short period of time, the result will be blurred, just as if the camera's shutter is too slow for the action taking place, because it is possible that the process's performance changes over time. Blurred photographs and blurred histograms are both useless. A good histogram will show a crisp snapshot of process performance as it was at the time the data were taken, not before and not after. This leads some people to claim that histograms should be used only on processes that are known to be *in control*. (See the section on control charts later in this chapter.)

That limitation is not necessary as long as you understand that histograms have this inherent flaw. Be careful that any interpretation you make has accounted for time and its effect on the process you are studying. For example, we do not know enough about the results of the shaft-making process from Figure 12 to predict with any certainty that it will do as well next week. We don't know that a machine operator didn't tweak the machine two or three times during the week, trying to find the center of the range. What happens if that operator is on vacation next week? Would we dare predict that performance will be the same? We can make these predictions only if we know the process is statistically in control; thus, the warnings. Taking this into consideration, the histogram in Figure 12 provides valuable information.

Histograms and Statistics

Understanding a few basic facts is fundamental to the use of statistical techniques for quality and process applications. We have said that all processes are subject to variability, or variation. There are many examples of this. One of the oldest and most graphically convincing is the Red Bead experiment.[4] This involves a container with a large number of beads. The beads are identical except for the color. Suppose there are 900 white beads and 100 red beads, making a total of 1,000. The beads are mixed thoroughly (Step 1). Then 50 beads are drawn at random as a sample (Step 2). The red beads in the sample are counted. A check mark is entered in a histogram column for that number. All the beads are put back into the container, and they are mixed again (Step 3). When you repeat these steps a second time, the odds are that a different number of red beads will be drawn. When a third sample is taken, it will probably contain yet another number of red beads. The process (steps 1, 2, and 3) has not changed, yet the output of the process does change. This is *process variation* or *variability*. If these steps are repeated over and over until a valid statistical sampling has been taken, the resulting histogram will invariably take on the characteristic bell shape common to process variability (see Figure 15).

It is possible to calculate the process variability from the data. The histogram in Figure 15 was created from 100 samples of 50 beads each. The data were as shown in Figure 16.

The flatter and wider the frequency distribution curve, the greater the process variability. The taller and narrower the curve, the lesser the process variability.

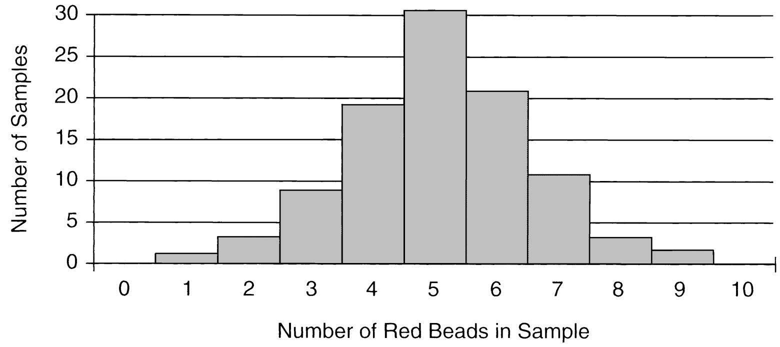


FIGURE 15 Frequency Distribution of Red Beads in Samples

Even though the variability may change from process to process, it would be helpful to have a common means of measuring, discussing, or understanding variability. Fortunately, we do. To express the process's variability, we need to know only two things, both of which can be derived from the process's own distribution data: *standard deviation* and *mean*. Standard deviation is represented by the lowercase Greek letter sigma (σ) and indicates a deviation from the average, or *mean*, value of the samples in the data set. The mean is represented by the Greek letter mu (μ). In a normal histogram, μ is seen as a vertical line from the peak of the bell curve to the base, and it is the line from which deviation is measured, minus to the left of μ and plus to the right. Standard deviation (σ) is normally plotted at -3σ, -2σ, and -1σ (left of μ) and $+1\sigma$, $+2\sigma$, and $+3\sigma$ (right of μ); refer to Figure 18. Because mean and standard deviation are always derived from data from the process in question, standard deviation has a constant meaning from process to process. From this, we can tell what the process can do in terms of its statistical variability (assuming that it remains stable and no changes are introduced):

- 68.26% of all sample values will be found between $+1\sigma$ and -1σ.
- 95.46% of all sample values will be found between $+2\sigma$ and -2σ.
- 99.73% of all sample values will be found between $+3\sigma$ and -3σ.
- 99.9999998% of all sample values will be found between $+6\sigma$ and -6σ.

Note: Six Sigma practitioners use 99.99966% rather than the actual statistical value.

This information has a profound practical value, as we shall see as we develop the discussion.

In order to calculate the process mean value (μ) and standard deviation (μ), we must first use the raw process data from Figure 16 to develop the information required for those calculations. As we develop the information, we will post it in the appropriate columns of Figures 17a, b, and c.

Columns 1 and 2 of Figures 17a, b, and c contain the measured raw data from the colored bead process from Figure 16. Column 1 lists the number of red beads possible to be counted (from 0 to 10) in the various samples. Column 2 lists the number of samples that contained the corresponding number of red beads. The number of samples in column 2 is totaled, yielding $n = 100$.

Samples with 0 red beads	0
Samples with 1 red bead	1
Samples with 2 red beads	3
Samples with 3 red beads	9
Samples with 4 red beads	19
Samples with 5 red beads	31
Samples with 6 red beads	21
Samples with 7 red beads	11
Samples with 8 red beads	3
Samples with 9 red beads	2
Samples with 10 red beads	0
Total samples taken	100

FIGURE 16 Data on Red Beads in Samples

Calculating the Mean

For a histogram representing a truly normal distribution between $\pm$ infinity, the mean value would be a vertical line to the peak of the bell curve. Our curve is slightly off normal because we are using a relatively small sample, so the mean (μ) must be calculated. The equation for μ is

$$\mu = \sum \chi \div n$$

where χ is the product of the number of red beads in a sample times the number of samples containing that number of red beads, or for Figure 17a, the product of columns 1 and 2. We calculate column 3 of Figure 17b.

1	2	3	4	5	6
Measured data from Figure 15–16					
# of Red Beads	# of Samples				
0	0				
1	1				
2	3				
3	9				
4	19				
5	31				
6	21				
7	11				
8	3				
9	2				
10	0				
	$n = 100$				

FIGURE 17a Raw Data from the Colored Bead Experiment (see Figure 16)

1	2	3	4	5	6
Measured data from Figure 15–16		Multiply Col 1 by Col 2			
# of Red Beads	# of Samples	*X* Value			
0	0	0			
1	1	1			
2	3	6			
3	9	27			
4	19	76			
5	31	155			
6	21	126			
7	11	77			
8	3	24			
9	2	18			
10	0	0			
	$n = 100$	$\Sigma X = 510$			

FIGURE 17b Calculating Values of X and ΣX

Now that we have the X values, we simply add them up to give us the sum of the X values (ΣX). The figure tells us that $n = 100$ and $\Sigma X = 510$. Using the equation for μ,

$$\mu = \sum X \div n$$

$$\mu = 510 \div 100$$

$$\mu = 5.1$$

The mean (μ) is placed at 5.1 on the histogram's x-axis, and all deviations are measured relative to that. (See Figure 18.)

Calculating Standard Deviation (σ)

To understand the process's variability, we must know its standard deviation. The formula for standard deviation is

$$\sigma = \sqrt{\sum d^2/(n - 1)}$$

where

d = the deviation of any unit from the mean
n = the number of units sampled

1	2	3	4	5	6
Measured data from Figure 15–16		Multiply Col 1 by Col 2	Deviation from μ (Col 1 $-$ μ)	Deviation squared (Col 4)^2	Sum of deviations squared (Col 2 $\times$ Col 5)
# of Red Beads	**# of Samples**	***X* Value**	***d***	***d*^{2}**	
0	0	0	−5.1	26.01	0
1	1	1	−4.1	16.81	16.81
2	3	6	−3.1	9.61	28.83
3	9	27	−2.1	4.41	39.69
4	19	76	−1.1	1.21	22.99
5	31	155	−0.1	0.01	0.31
6	21	126	0.9	0.81	17.01
7	11	77	1.9	3.61	39.71
8	3	24	2.9	8.41	25.23
9	2	18	3.9	15.21	30.42
10	0	0	4.9	24.01	0
	n = 100	ΣX = 510			Σd^2 = 221

FIGURE 17c Completed Deviation Data Table

We already have the value of n (100), but we have not calculated the values of d, d^2, or Σd^2. We will perform these calculations and post the information in the remaining three columns of Figure 17c. The values of the deviations (d) are determined by subtracting μ (5.1) from each of the red bead values (0 through 10) of column 1. The first entry in column 4 (deviation from μ) is determined by subtracting μ from the value in column 1, that is, $0 - 5.1 = -5.1$. Similarly, the second entry in column 4 is the value of column 1 at the 1-bead row minus μ, or $1 - 5.1 = -4.1$. Repeating this process through the 10-bead row completes the deviation column.

Column 5 of Figure 17c is simply a list of the column 4 deviation values squared. For example, in the 0-bead row, column 4 shows $d = -5.1$. Column 5 lists the square of -5.1, or 26.01. The 1-bead row has $d = -4.1$. Column 5 lists its square, 16.81. This process is continued through the 10-bead row to complete column 5 of the figure.

Column 6 of Figure 17c lists the results of the squared deviations (column 5) multiplied by the number of samples at the corresponding deviation value (column 2). For the column 6 entry at the 0-bead row, we multiply 0 (from column 2) by 26.01 (from column 5); since, $0 \times 26.01 = 0$, 0 is entered in column 6. For the 1-bead row, we multiply 1 by 16.81; 16.81 is the second entry in column 6. At the 2-bead row, we multiply 3 by 9.61 and enter 28.83 in column 6. This process is repeated through the remaining rows of the figure.

Next we add column 6's entries to obtain the sum of the squared deviations, $\Sigma d^2 \cdot \Sigma d^2$ for our bead process experiment is 221.

Now we have all the information we need to calculate the standard deviation (σ) for our process.

$$\sigma = \sqrt{\sum d^2/(n-1)}$$
$$\sigma = \sqrt{221 \div 99}$$
$$\sigma = \sqrt{2.23} \text{ (2.23 is called the \textit{mean squared deviation}.)}$$
$$\sigma = 1.49 \text{ (1.49 is called the \textit{root mean squared deviation}.)}$$

Note: Calculations are to two decimal places.

Next calculate the positions of, $\mu \pm 1\sigma$, 2σ, and 3σ.

$$\sigma = 1.49 \quad 2\sigma = 2.99 \quad 3\sigma = 4.47$$

These values are entered in Figure 15 to create Figure 18:

$$\mu - 1\sigma = 5.1 - 1.49 = 3.61$$
$$\mu + 1\sigma = 5.1 + 1.49 = 6.59$$
$$\mu - 2\sigma = 5.1 - 2.99 = 2.11$$
$$\mu + 2\sigma = 5.1 + 2.99 = 8.09$$
$$\mu - 3\sigma = 5.1 - 4.47 = 0.63$$
$$\mu + 3\sigma = 5.1 + 4.47 = 9.57$$

Suppose we have a process that is operating like the curve in Figure 18. We have specifications for the product output that require us to reject any part below 3.6 and above 6.6. It turns out that these limits are approximately $\pm 1\sigma$. We know immediately that about one-third of the process output will be rejected. If this is not acceptable, which is highly probable, we will have to improve the process or change to a completely

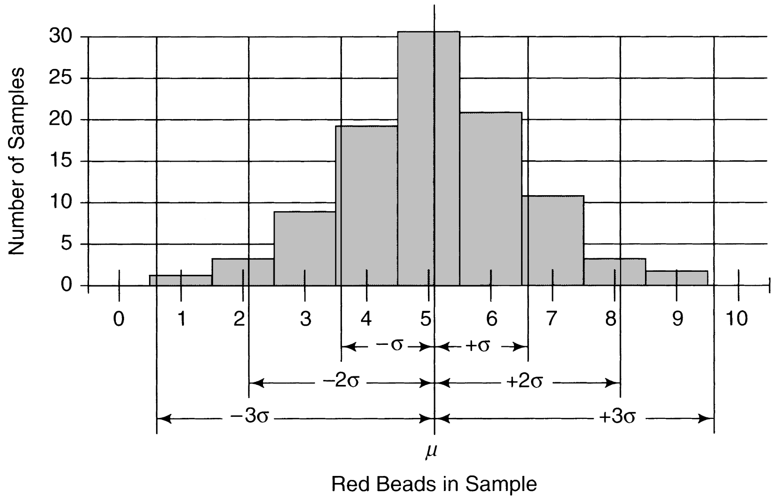


FIGURE 18 Application of Standard Deviation Calculations to Red Bead Histogram

different process. Even if more variation could be tolerated in the product and we took the specification limits out to 2 and 8, about 5 of every 100 pieces flowing out of the process would still be rejected. In a competitive world, this is poor performance indeed. Many companies no longer consider 2,700 parts per million defective ($\pm 3\sigma$) to be good enough. A growing number of organizations are seeking the Motorola version of Six Sigma quality performance. These companies target a defect rate of 3.4 nonconformances per million opportunities (NPMO) for nonconformance. Technically speaking, 3.4 NPMO is not very close to the statistically pure 6-sigma rate of 0.002 per million opportunities, or 1 nonconformance in 500 million. Although the popular Six Sigma does not match the true 6-sigma, 3.4 NPMO is a remarkable achievement. Whatever the situation, with this statistical sampling tool properly applied, there is no question about what can be achieved with any process because you will be able to predict the results.

Shapes of Histograms

Consider the shape of some histograms and their position relative to specification limits. Figure 19 is a collection of histograms. Histogram A represents a normal distribution. So does B, except it is shallower. The difference between the process characteristics of these two histograms is that process A is much tighter, whereas the looser process B will have greater variances. Process A is usually preferred. Processes C and D are skewed left and right, respectively. Although the curves are normal, product will be lost because the processes are not centered. Process E is bimodal. This can result from two batches of input material, for example. One batch produces the left bell curve, and the second batch the curve on the right. The two curves may be separated for a better view of what is going on by stratifying the data by batch. (See the "Stratification" section later in this chapter.)

Histogram F suggests that someone is discarding the samples below and above a set of limits. This typically happens when there is a 100% inspection and only data that are within limits are recorded. The strange Histogram G might have used data from incoming inspection. The message here is that the vendor is screening the parts and someone else is getting the best ones. A typical case might be electrical resistors that are graded as 1%, 5%, and 10% tolerance. The resistors that met 1% and 5% criteria were screened out and sold at a higher price. You got what was left.

Histogram H shows a normal distribution properly centered between a set of upper and lower control limits. Histograms I and J illustrate what happens when the same normal curve is allowed to shift left or right, respectively. There will be a significant loss of product as a control limit intercepts the curve higher up its slope.

Histograms K through P show a normal, centered curve that went out of control and drifted. Remember that histograms do not account for time and you must, therefore, be careful about making judgments. If all the data that produced Histograms K through P were averaged, or even if all the data were combined to make a single histogram, you could be misled. You would not know that the process was drifting. Plotting a series of histograms over time, such as K through P, clearly illustrates any drift right or left, shallowing of the bell, and the like.

The number of samples or data points has a bearing on the accuracy of the histogram, just as with other tools. But with the histogram, there is another consideration: How does one determine the proper number of intervals for the chart? (The intervals are, in effect, the data columns of the histogram.) For example, Figure 15 is set up for 11 intervals: 0, 1, 2, and so on. The two outside intervals are not

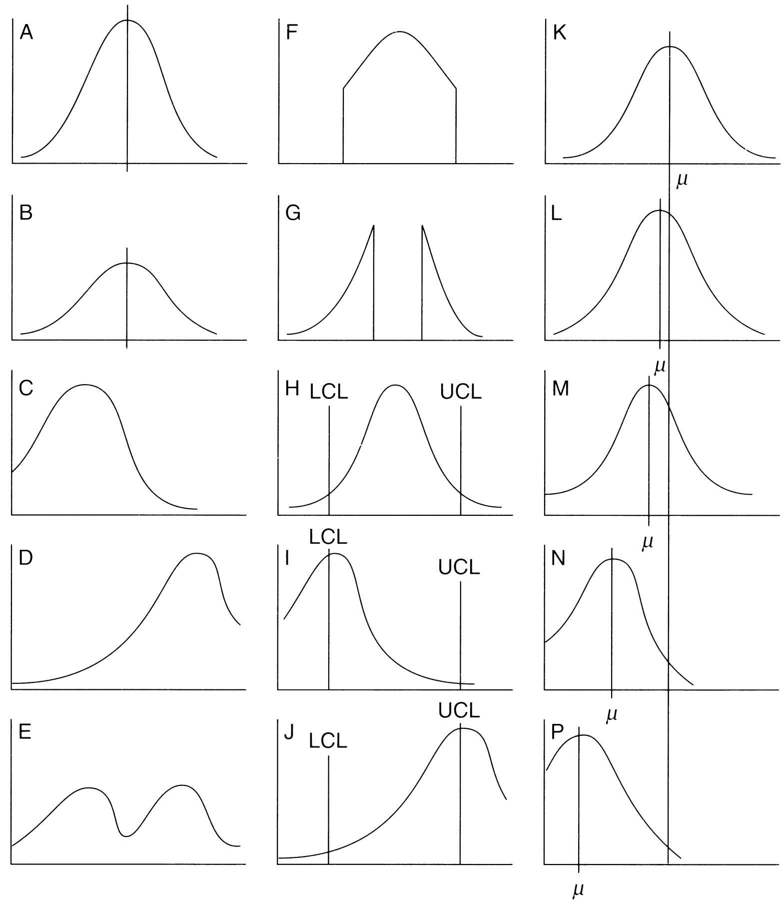


FIGURE 19 Histograms of Varying Shapes

used, however, so the histogram plots data in nine intervals. The rule of thumb is as follows:

Number of Observations (*N*)	**Number of Intervals (*k*)**
<75	5–7
75–300	6–10
>300	10–20

Or, you may use the formula

$$k = \sqrt{N}$$

It is not necessary to be very precise with this. These methods are used to get close and adjust one way or the other for a fit with your data.

Suppose we are using steel balls in one of our products and the weight of the ball is critical. The specification is 5 ± 0.2 grams. The balls are purchased from a vendor, and because our tolerance is tighter than the vendor's, we weigh the balls and use only those that meet our specification. The vendor is trying to tighten its tolerance and has asked for assistance in the form of data. Today 60 balls were received and weighed. The data were plotted on a histogram. To give the vendor the complete information, a histogram with intervals every 0.02 gram is established.

Figure 20 does not look much like a bell curve because we have tried to stretch a limited amount of data (60 observations) too far. There are 23 active or skipped

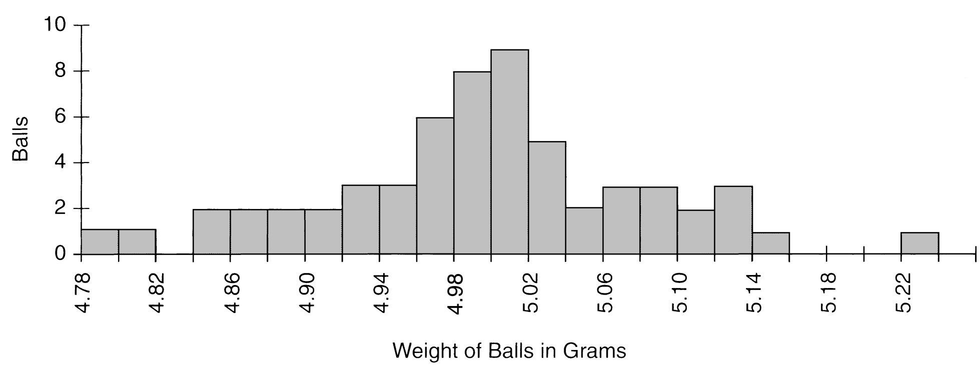


FIGURE 20 Histogram with Limited Amount of Data Stretched

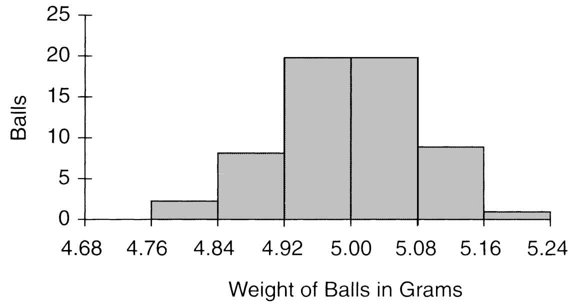


FIGURE 21 Histogram with Appropriate Intervals for the Amount of Data

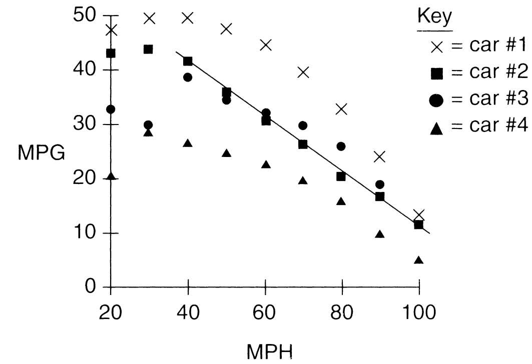


FIGURE 22 Scatter Diagram: Speed Versus Fuel Consumption for Four Automobiles

intervals. Our rule of thumb suggests 5 to 7 intervals for less than 75 observations. If the same data were plotted into a histogram of 6 intervals (excluding the blank), it would look like Figure 21. At least in this version, it looks like a histogram. With more data—say, 100 or more observations—one could narrow the intervals and get more granularity. Don't try to stretch data too thin because the conversion to real information can become difficult and risky.

SCATTER DIAGRAMS

The fifth of the seven tools is the *scatter diagram*. It is the simplest of the seven and one of the most useful. The scatter diagram is used to determine the correlation (relationship) between two characteristics (variables). Suppose you have an idea that there is a relationship between automobile fuel consumption and the rate of speed at which people drive. To prove, or disprove, such an assumption, you could record data on a scatter diagram that has miles per gallon (mpg) on the y-axis and miles per hour (mph) on the x-axis; mpg and mph are the two characteristics.

Examination of the scatter diagram of Figure 22 shows that the aggregate of data points contains a slope down and to the right. This is correlation, and it supports the thesis that the faster cars travel, the more fuel they use. Had the slope been upward to the right, as it actually appears to be (for three of the four cars) between 20 and 30 mph, the correlation would have suggested that the faster you travel, the better the fuel mileage. Suppose, however, that the data points did not form any recognizable linear or elliptical pattern but were simply in a disorganized configuration. This would suggest that there is no correlation between speed and fuel consumption.

Figure 23 is a collection of scatter diagrams illustrating strong *positive correlation* (Diagram A), weak *negative correlation* (Diagram B), and *no correlation* (Diagram C). To be classified as a strong correlation, the data points must be tightly grouped in a linear pattern. The more loosely grouped, the less correlation, and, therefore, the term *weak correlation*. When a pattern has no discernible linear component, it is said to show no correlation.

Scatter diagrams are useful in testing the correlation between process factors and characteristics of product flowing out of the process. Suppose you want to know whether conveyor speed has an effect on solder quality in a machine soldering process. You could set up a scatter diagram with conveyor speed on the x-axis and solder rejects or nonconformities on the y-axis. By plotting sample data as the conveyor speed is adjusted, you can construct a scatter diagram to tell whether a correlation exists.

In this case, Figure 24 suggests that the correlation is a curve, with rejects dropping off as speed is initially raised but then increasing again as the conveyor speed continues to increase. This is not atypical of process factors that have optimum operating points. In the case of the conveyor, moving too slowly allows excess heat to build up, causing defects. So increasing speed naturally produces better results, until the speed increases to the point where insufficient preheat-

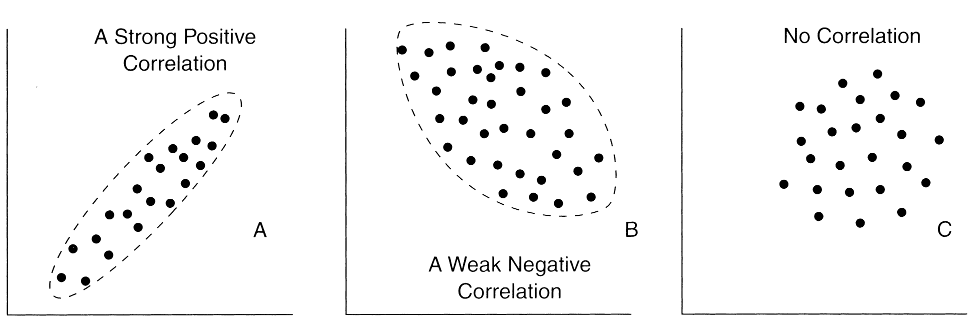
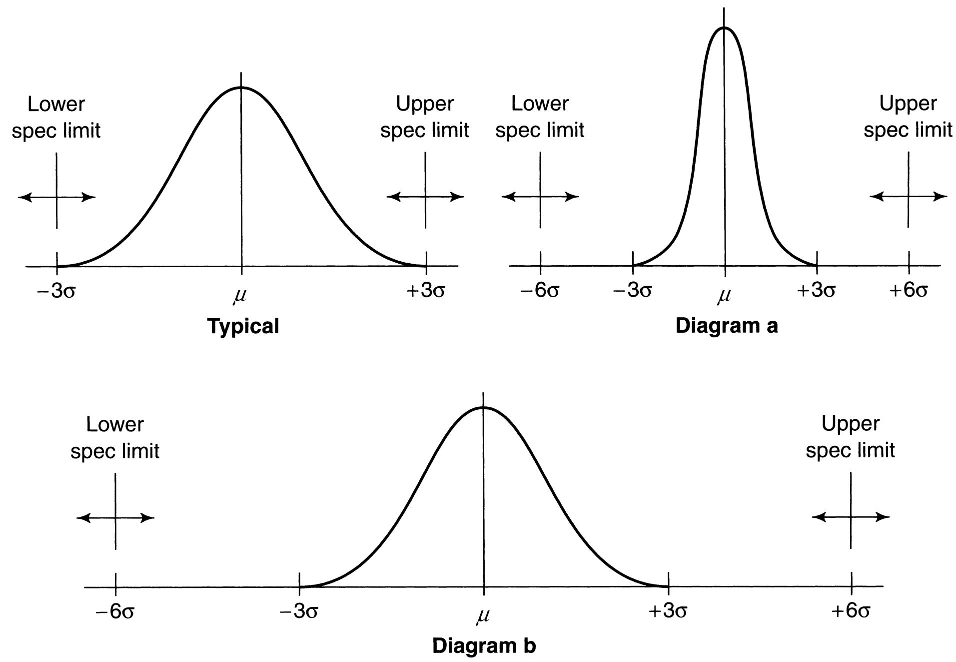


FIGURE 23 Scatter Diagrams of Various Correlations

QUALITY TIP ▼

Six Sigma Process Capability



- When specification limits (defining acceptable products) are set to correspond to the $\pm 3\sigma$ capability of the process, NPMO will be 2,700. This may mean that out of every 1 million parts produced, 2,700 are unacceptable; that out of 1 million operations, 2,700 mistakes will be made; and so on.
- When specification limits correspond to the $\pm 6\sigma$ process capability, a vanishingly small 0.002 NPMO will be achieved. See Diagrams a and b. (Note that at $\pm 6\sigma$ the Motorola Six Sigma method will yield a still small 3.4 NPMO.)
- One method used in striving for statistical 6σ (or Motorola's Six Sigma) performance involves narrowing the bell curve through the development of superior processes. Compare the Typical 3σ diagram above with Diagram a. Note that the specification limits have remained constant, but the process variation has been reduced, moving the process's $\pm 6\sigma$ points inward to the specification limits.
- Another method for working toward Six Sigma performance involves designing products that can tolerate wider physical or functional variation in their component parts, while still performing to product specifications. Compare the Typical 3σ diagram above with Diagram b. This technique is usually referred to as *robust design*.

ing increases the number of defects. Figure 24, then, not only reveals a correlation, but also suggests that there is an optimum conveyor speed, operation above or below which will result in increased product defects.

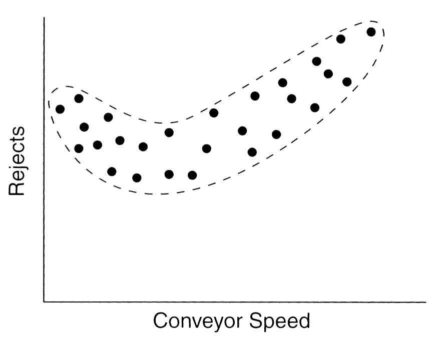


FIGURE 24 Scatter Diagram: Conveyor Speed versus Rejects

It is also possible to determine a correlation between two process factors. If your manufacturing process includes the washing of parts in a cleaning agent and you are interested in reducing the time the parts are in the cleaning tank, you might want to know whether the temperature of the solution is correlated with the time it takes to get the parts thoroughly clean. The scatter diagram could have temperature of the cleaning agent on one axis and time to clean on the other. By adjusting the temperature of the solution and plotting the cleaning time, a scatter diagram will reveal any existing correlation.

Assume that the scatter diagram shows a discernible slope downward to the right, as in Figure 25. This shows that over the temperature range tested, there *is* a correlation between cleaning solution temperature and cleaning time. With this information, you might be able to reduce the cycle time of the product. *Cycle time* in manufacturing is basically elapsed time from the start of your build process until the

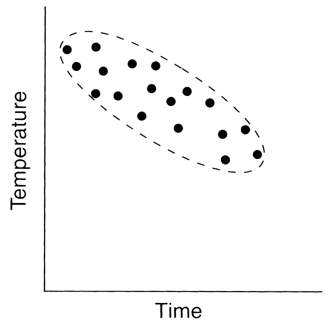


FIGURE 25 Scatter Diagram: Cleaning Solution Temperature versus Cleaning Time

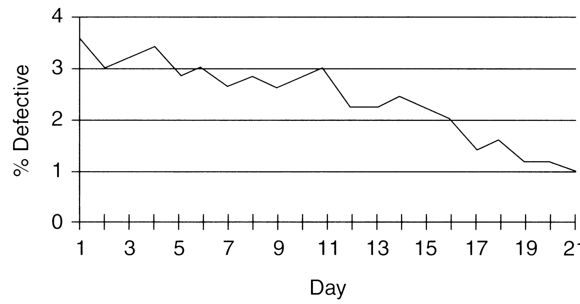


FIGURE 26 Run Chart: Pen Defect Rate for 21 Working Days

product is finished. Cycle time is becoming more important as manufacturers adopt world-class techniques to compete in the global marketplace. If you can find a safe, cost-effective way to raise the cleaning agent temperature to some more efficient level, and in the process shorten the cycle (or perhaps maintain the cycle and do a better job of cleaning), doing so might provide a competitive advantage.

Not all scatter diagrams require that special tests be run to acquire raw data. The data are frequently readily available in a computer. Few companies would have to record new data to determine whether a correlation exists between the day of the week and employee performance. Such data are often available from the day-to-day inspection reports. In fact, where people are involved, it is advisable to use existing data rather than collecting new data to be sure that the data were not influenced by the test itself. Imagine people being told they were to be part of a test to determine whether their performance was as good on Friday or Monday as the rest of the week. This knowledge would undoubtedly affect their performance.

RUN CHARTS AND CONTROL CHARTS

The run chart is straightforward, and the control chart is a much more sophisticated outgrowth of it. Therefore, the two are usually thought of together as a single tool. Both can be very powerful and effective for the tracking and control of processes, and they are fundamental to the improvement of processes.

Run Charts

The *run chart* records the output results of a process over time. The concept is strikingly simple, and, indeed, it has been used throughout modern times to track performance of everything from AAA membership to zwieback production. Because one axis (usually the x-axis) represents time, the run chart can provide an easily understood picture of what is happening in a process as time goes by. That is, it will cause trends to "jump" out at you. For this reason, the run chart is also referred to as a *trend chart*.

Consider as an example a run chart set up to track the percentage of product that is defective for a process that makes ballpoint pens. These are inexpensive pens, so production costs must be held to a minimum. On the other hand, many competitors would like to capture our share of the market, so we must deliver pens that meet the expectations of our customers—as a minimum. A sampling system is set up that requires a percentage of the process output to be inspected. From each lot of 1,000 pens, 50 will be inspected. If more than one pen from each sample of 50 is found defective, the whole lot of 1,000 will be inspected. In addition to scrapping the defective pens, we will attempt to discover why the defects were there in the first place and to eliminate the cause. Data from the sample will be plotted on a run chart. Because we anticipate improvements to the process as a result of this effort, the run chart will be ideal to show whether we are succeeding.

The run chart of Figure 26 is the result of sample data for 21 working days. The graph clearly shows that significant improvement in pen quality was made during the 21 working days of the month. The trend across the month was toward better quality (fewer defects). The most significant improvements came at the 12th day and the 17th day as causes for defects were found and corrected.

The chart can be continued indefinitely to keep us aware of performance. Is it improving, staying the same, or losing ground? Scales may have to change for clarity. For example, if we consistently found all samples with defects below 2%, it would make sense to change the y-axis scale to 0 to 2%. Longer term charts would require changing from daily to weekly or even monthly plots.

Performance was improved during the first month of the pen manufacturing process. The chart shows positive results. What cannot be determined from the run chart, however, is what *should* be achieved. Assuming we can hold at two defective pens out of 100, we still have 20,000 defective pens out of a million. Because we are sampling only 5% of the pens produced, we can assume that 19,000 of these find their way into the hands of customers—the very customers our competition wants to take away from us. So it is important to improve further. The run chart will help, but a more powerful tool is needed.

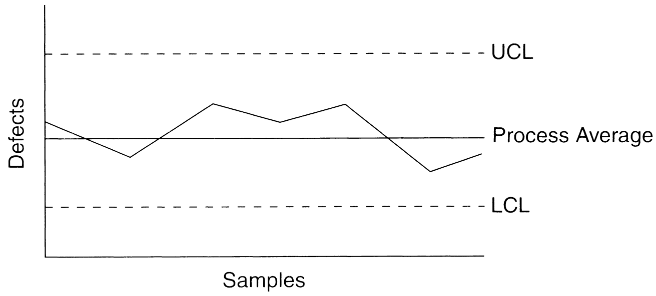


FIGURE 27 Basic Control Chart

Control Charts

The problem with the run chart and, in fact, many of the other tools is that it does not help us understand whether the variation is the result of *special causes*—things such as changes in the materials used, machine problems, lack of employee training—or *common causes* that are purely random. Not until Dr. Walter Shewhart made that distinction in the 1920s was there a real chance of improving processes through the use of statistical techniques. Shewhart, then an employee of Bell Laboratories, developed the control chart to separate the special causes from the common causes.[5]

In evaluating problems and finding solutions for them, it is important to distinguish between special causes and common causes. Figure 27 shows a typical control chart. Data are plotted over time, just as with a run chart; the difference is that the data stay between the upper control limit (UCL) and the lower control limit (LCL) while varying about the centerline or average *only so long as the variation is the result of common causes (i.e., statistical variation)*. Whenever a special cause (nonstatistical cause) impacts the process, one of two things will happen: Either a plot point will penetrate UCL or LCL, or there will be a "run" of several points in a row above or below the average line. When a penetration or a lengthy run appears, this is the control chart's signal that something is wrong that requires immediate attention.

As long as the plots stay between the limits and don't congregate on one side or the other of the process average line, the process is in statistical control. If either of these conditions is not met, then we can say that the process is not in statistical control or simply is "out of control"—hence the name of the chart.

If you understand that it is the UCL, LCL, and process average lines added to the run chart that make the difference, you may wonder how those lines are set. The positioning of the lines cannot be arbitrary. Nor can they merely reflect what you want out of the process, for example, based on a specification. Such an approach won't help separate common causes from special causes, and it will only complicate attempts at process improvement. UCL, LCL, and process average must be determined by valid statistical means.

All processes have built-in variability. A process that is in statistical control will still be affected by its natural random variability. Such a process will exhibit the normal distribution of the bell curve. The more finely tuned the process, the less deviation from the process average and the narrower the bell curve. (Refer to Figure 19, Histogram A and Histogram B.) This is at the heart of the control chart and is what makes it possible to define the limits and process average.

Control charts are the appropriate tool to monitor processes. The properly used control chart will immediately alert the operator to any change in the process. The appropriate response to that alert is to stop the process at once, preventing the production of defective product. Only after the special cause of the problem has been identified and corrected should the process be restarted. Having eliminated a problem's root cause, that problem should never recur. (Anything less, however, and it is sure to return eventually.) Control charts also enable continual improvement of processes. When a change is introduced to a process that is operated under statistical process control charts, the effect of the change will be immediately seen. You know when you have made an improvement. You also know when the change is ineffective or even detrimental. This validates effective improvements, which you will retain. This is enormously difficult when the process is not in statistical control because the process instability masks the results, good or bad, of any changes deliberately made.

STRATIFICATION

Stratification is a simple tool in spite of its name. It involves investigating the cause of a problem by grouping data into categories. This grouping is called *stratification*. The groups might include data relative to the environment, the people involved, the machine(s) used in the process, materials, and so on. Grouping data by common element or characteristic makes it easier to understand the data and to pull insights from them.

Consider an example from a factory floor. One of the factory's products requires five assemblers, all doing the same thing at the same rate. Their output flows together for inspection. Inspection has found an unacceptably high rate of defects in the products. Management forms a team to investigate the problem with the objective of finding the cause and correcting it. They plot the data taken over the last month (see Figure 28).

The chart in Figure 28 plots all operator-induced defects for the month. The team believes that for this product, zero defects can be approached. If you were going to react to this chart alone, how would you deal with the problem? You have five assemblers. Do they all contribute defects equally? This is hardly ever the case. The data can be stratified by the operator to determine each individual's defect performance. The charts in Figure 29 do this.

FIGURE 28 Chart of Operator Defects for November

The five stratified charts in Figure 29 indicate that one operator, Assembler B, is responsible for more defects than the other four combined. Assembler A also makes more than twice as many errors as Assembler C or Assembler D and eight times as many as Assembler E, the best performer of the group.

The performance of Assembler A and Assembler B must be brought up to the level of the others. Possible causes of the operator-induced defects could be inherent skill, training, vision, attitude, attentiveness, and environmental factors, such as noise, lighting, and temperature in the operator's workstation area. The charts provide an indication of the place to start making changes.

The Pareto charts of Figure 6 also represent stratification. Figure 6 started with a series of defect types that were the most costly (the first chart). Then it took the worst case, Miswires, and divided it into the *kinds* of miswires (the second chart). Then the worst kind, Hand Wrap, was split into several categories (the third chart). The dominant Hand-Wrap defect category was operator induced. Finally, the Operator category was stratified by individual operator (the fourth chart).

The power of stratification lies in the fact that if you stratify far enough, you will arrive at a *root cause* of the problem. Only when root causes are corrected will the problem be solved. Any other kind of solution is a *work-around* fix. Work-arounds are often used in the real world, but when they are, the underlying problem remains and will eventually cause disruption again.

In the present example, we probably did not go all the way to the root cause, unless Assembler B has serious mental, vision, or motor problems that could not be corrected. The most likely root cause is that Assembler B has not been adequately trained for the job; something readily ascertained when the focus is on that individual. One or two more charts looking at the time of day when the mistakes are being made might yield some information, but once the problem is isolated to a person, discussion will usually take you quickly to the root cause. If, on the other hand, Assembler B is a robot and not a human (which is entirely possible in today's automated environment), the stratification should go to at least one more level. We would have to determine the kinds of defects that Assembler B (the robot) is making. That may lead to adjustment or repair of the machine.

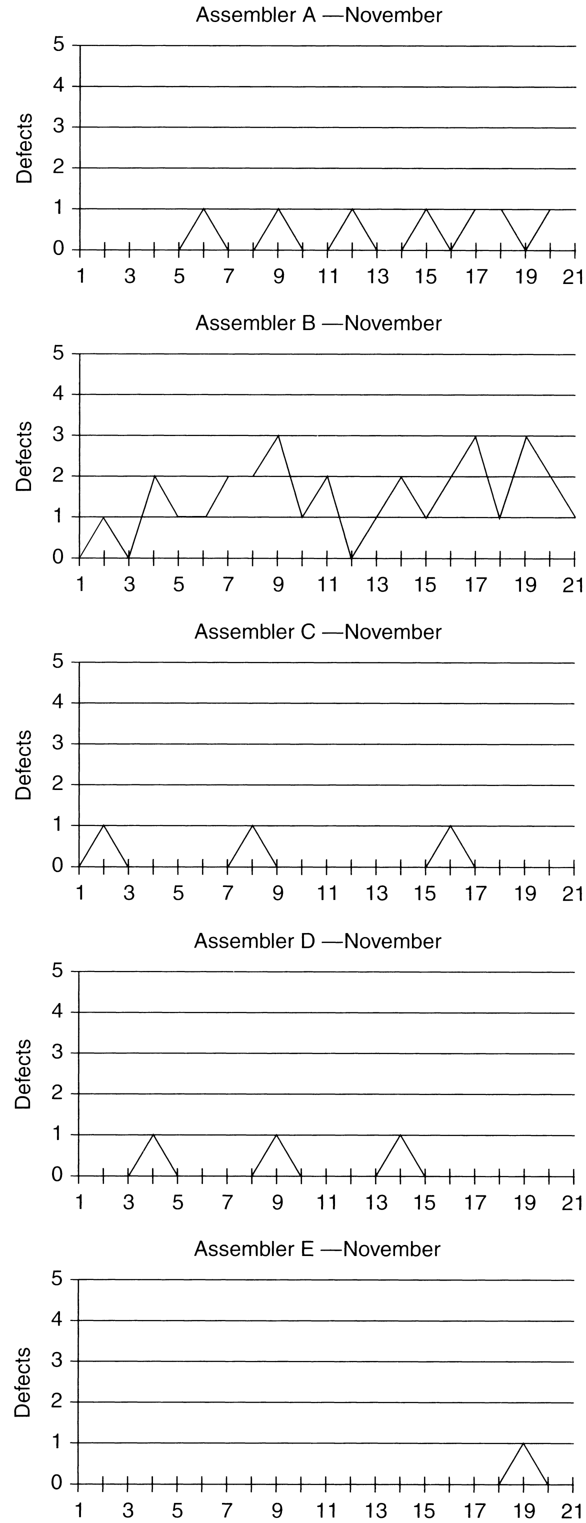


FIGURE 29 Stratified Charts for Each Operator

Figure 30 shows that the defects induced by this machine are almost all concerned with screws. The robot is either damaging the screws or breaking them off. Show this chart to the robot maintenance technician, and that person will immediately recognize that the robot needs an adjustment or replacement of its torque controller. The root cause

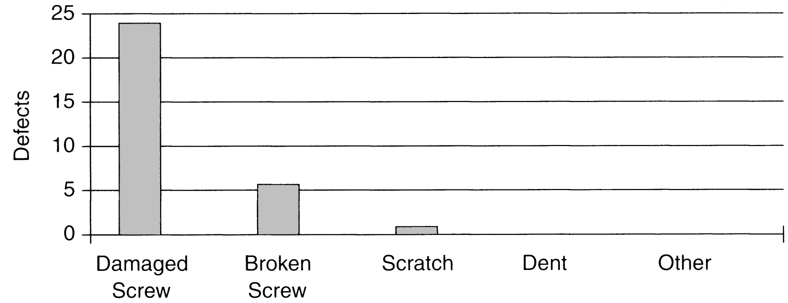


FIGURE 30 Robot B Defect Category for November

of the problem is either misadjustment or a defective controller. The technician can confirm the diagnosis by running tests on the robot before certifying it for return to service.

Data collected for Pareto charts and run charts (Figure 28) can be stratified. Virtually any data can be subjected to stratification. This includes the data collected for control charts, check sheets, histograms, and scatter diagrams. Consider an example of a stratified scatter diagram.

Scatter diagrams, which show the relationship between the *x*- and *y*-axes, lend themselves well to stratification. In this example, parts are being finished on two identical machines. A scatter diagram is plotted to correlate surface flatness and machine speed.

Figure 31 suggests that there is a correlation between machine speed (revolutions per minute, or rpm) and surface flatness between 500 and 1,000 rpm but no correlation at higher revolutions per minute. When the same data are stratified in the charts of Figure 32, the picture becomes clearer.

In Figure 32, the charts reveal that the two machines react similarly to speed increase, but Machine 1 is better than Machine 2 by about 0.00010 in its ability to produce a flat surface. The Machine 1 chart also suggests that increases beyond 1,000 rpm do not produce much improvement. A finish of 0.000950 is about as good as the machine will produce. On the other hand, the Machine 2 chart does show some improvement (two data points) past 1,300 rpm. Given the difference between the two machines, one message coming from the charts is that Machine 2 should be examined to determine the cause of its poorer performance. (More than likely it will be found that bearing wear is the factor in question, and that can be corrected easily.) After the machine has been repaired, new data should be taken to verify that 1,000 to 1,100 rpm is the best practical machine speed.

The charts in Figure 32 indicate another message. Both machines had data points better than normal at 550 and 1,100 rpm. It appears that the machines have a natural resonance that affects performance. The clue here is that both machines show it at 550 rpm and at double that speed

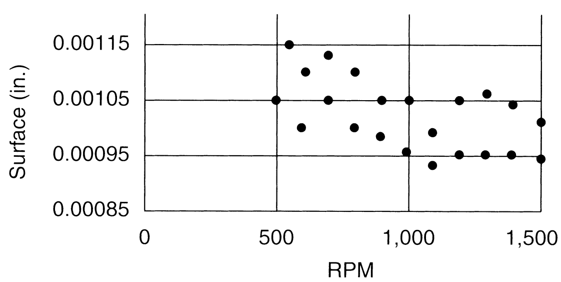


FIGURE 31 Scatter Diagram: Surface Flatness versus Revolutions per Minute

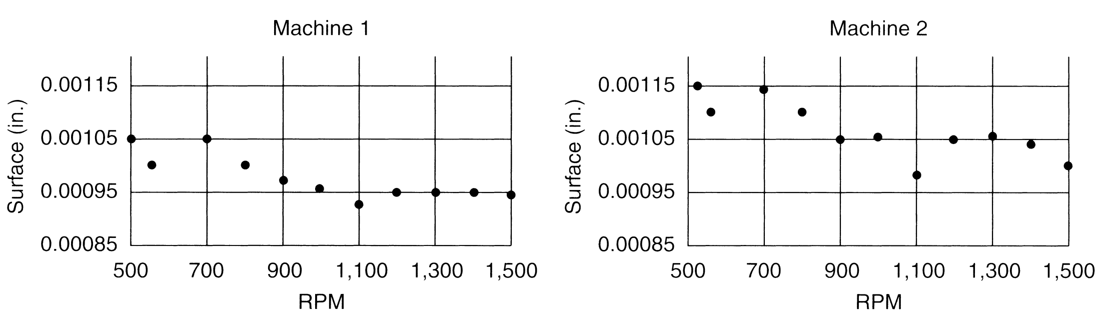


FIGURE 32 Stratified Scatter Diagrams: Surface Flatness versus Revolutions per Minute

QUALITY CASE ▼

Delphi Packard Chihuahua and Lean Manufacturing

The Delphi Packard plant in Chihuahua, Mexico, produces power and signal distribution systems (wire harnesses) for the automotive industry. Competition in the production of wire harnesses is intense and global. Consequently, Delphi Packard must produce world-class quality and its personnel must commit to continual improvement. One of the most effective continual-improvement strategies for the company has been lean manufacturing.

By effectively deploying the concept of lean manufacturing, Delphi Packard has been able to achieve the following results:

- Inventory reduction of 34% over a 12-month period
- Improvement in uptime to a level of 93.5% of a 12 month period
- Savings of $750,000 in one year from continual-improvement projects undertaken by salaried personnel
- Made the manufacturing system sufficiently flexible to serve 86 different customers and produce 1,100 different parts or products

In recognition of its effective application of the principles of total quality, Delphi Packard-Chihuahua was awarded the prestigious Shingo Prize for excellence in manufacturing.

Source: www.reliableplant.com/Articles/Print/4697

(1,100 rpm). This should be checked out because it could be adversely affecting performance across the range. If vibration and resonance could be "quieted" across the operating range as it apparently is at 550 and 1,100 rpm, the performance might be significantly improved in both machines. The data that gave us this signal are in the scatter diagram of Figure 31, but they don't jump out at you the way they do in the stratified charts of Figure 32.

In these examples, we have stratified assembly defects by operator, machine-induced defects by type of defect, and machine performance by machine. It was also pointed out that the earlier Pareto chart discussion involved stratification in which defects were stratified to types of defects, the worst of which was, in turn, stratified to the processes producing those defects. The process (Hand Wrap) producing the most defects was stratified to process factors, and, finally, the factor revealed as the most significant (Operator) was stratified to individual operators.

There is virtually no limit on the directions stratification can take. For example, the operators could have been stratified by age, training, gender, marital status, teams, experience, or other factors. The machines could have been stratified by age, date of maintenance, tools, and location (and in the case of similar but not identical machines, by make and model number). In similar fashion, operating procedures, environment, inspection, time, materials, and so on, can be introduced.

SOME OTHER IMPORTANT TOOLS INTRODUCED

The preceding sections have discussed the statistical tools that have come to be known as "the seven tools." One should not conclude, however, that these seven are the only tools needed for pursuing world-class performance. These seven are the ones that have been found most useful for the broadest spectrum of users. Ishikawa referred to them as the "seven indispensable tools for quality control."[6] He went on to say that they are useful to everyone from company presidents to line workers and across all kinds of work—not just manufacturing. These seven probably represent the seven basic methods most useful to all the people in the workplace. We recommend five more as necessary to complete the tool kit of any business enterprise, if not each of the players within the business:

Five-S
Flowcharts
Surveys
Failure mode and effects analysis (FMEA)
Design of experiments (DOE)

Five-S

Five-S is considered as essential to continual improvement. Its most significant proponent is Hiroyuki Hirano, author of *5 Pillars of the Visual Workplace*, who claims that an organization that cannot implement five-S successfully will be unable to integrate any large-scale change. Hirano holds that Total Quality Management (TQM), Just-in-time/Lean (JIT/Lean), and Kaizen are supported by the five pillars represented by the five S's and are probably unattainable without five-S. The authors heretofore have considered these five S's to be an integral part of TQM and JIT/Lean, but we have come to believe that they should be recognized as a tool that is separable from TQM but that may serve as an entry point for TQM in many organizations.

The five S's were originally conceived in Japanese, as represented by five words beginning with the letter *s*. Translated to English, the words did not, as you might expect, begin with *s*, so five-S required some "adjustment" in order to make sense in English. The table below shows the evolution from Japanese to English.

Japanese Word	Translation	Action Implied	English Word for Five-S
Seiri	Organization	Sort useful from useless	Sort
Seiton	Neatness	Everything in its place	Store
Seiso	Cleaning	Workplace and equipment clean	Shine
Seiketsu	Standardization	Select the best practice	Standardize
Shitsuke	Discipline	Make sure rules are followed	Sustain

Five-S is a way of doing things that eliminates waste and reduces errors, defects, and injuries. A recurring comment from executives returning from visits to Japanese industrial plants in the seventies and eighties was that the Japanese plants were spotlessly clean and orderly and seemed far less chaotic than corresponding plants in the West. Much of that was the result of Hiroyuki Hirano's five-S philosophy. Five things must happen under five-S, which are as follows:

1. ***Sort:*** First, one has to *sort* through items in the workplace to determine which are useful and which are not. Those that are not are discarded. That might include tools, equipment, inventory of stock, spare parts, documentation—everything in the area. If it is not useful, dispose of it, or at least get it out of the work area. The objectives are the elimination of unnecessary items from the workplace and the elimination of time wasted in continually having to search through or work around clutter in order to do the job.
2. ***Store:*** The things remaining, the useful items, must be *stored* in such a manner that they are visible and immediately available to the workforce. An example is a shadow board with the silhouettes of the tools assigned to a workstation. The silhouette shows where the tool is to be stored when not in use. There has to be an assigned place for everything, and everything should always be kept in its place. The objective is elimination of time wasted looking for tools, parts, and so on by having it easily at hand and visible every time it is needed.
3. ***Shine:*** The work area and everything in it must *shine*; that is, it must be kept clean at all times. An important consideration here is that this cleaning is not left to a "cleaning crew" but is the responsibility of the employees assigned to the work area. Once cleaned, it is kept that way at all times, not just after the workday. While cleanliness is a good thing in its own right, the act of keeping everything clean becomes a form of inspection of machines, tools, and environmental conditions. The objective is reduced errors and defects that result from defective tools and equipment and from contamination.
4. ***Standardize:*** Next we must develop the rules and procedures for the work area, *standardizing* on the best practices (the best known way of doing something). When a best practice for accomplishing a task is adopted, everyone doing that task must do it the same way—until a better way is found through continual improvement. The objective is reduced errors and improved consistency and reliability of work, while being alert to discovering or inventing process improvements.
5. ***Sustain:*** Then we must establish the discipline necessary to follow the rules and practices, improve upon them, and thereby sustain the gains made through five-S. Sort, Store, Shine, and Standardize are all tangible functions. Sustain, however, is intangible from the standpoint of being able to touch it or see it. Sustain, or keeping the five-S philosophy alive and functioning in an organization, is undoubtedly the most difficult of the S's and requires the full support and leadership of the top management team and managers all the way down through the organization. Slipping back into old (pre-five-S) habits must not be allowed, and the expectation for continual improvement must always be understood. The objective of Sustain is to keep five-S alive, functioning, and improving.

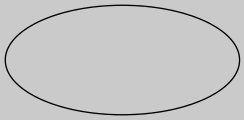
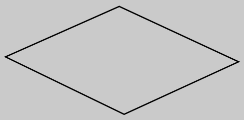
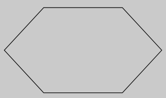
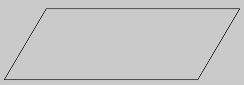
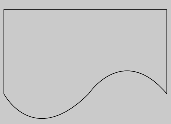
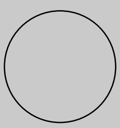
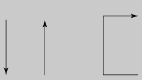
Flowcharts

Both W. Edwards Deming[7] and Joseph Juran[8] promote the use of flowcharts. A *flowchart* is a graphic representation of a process. A necessary step in improving a process is to flowchart it. In this way, all parties involved can begin with the same understanding of the process. It may be revealing to start the flowcharting process by asking several different team members who know the process to flowchart it independently. If their charts are not the same, one significant problem is revealed at the outset; there is not a common understanding of the way the process works. Another strategy is to ask team members to chart how the process *actually* works and then chart how they think it *should* work. Comparing the two versions can be an effective way to identify causes of problems and to suggest improvement possibilities. The most commonly used flowcharting method is to have the team, which is made up of the people who work within the process and those who provide input to or take output from the process, develop the chart. It is important to note that to be effective, the completed flowchart must accurately reflect the *way the process actually works*, not how it should work. After a process has been flowcharted, it can be studied to determine what aspects of it are problematic and where improvements can be made.

You may already be familiar with the flowchart, at least to the point of recognizing one when you see it. It has been in use for many years and in many ways. The application we have in mind here is for flowcharting the inputs, steps, functions, and outflows of a process to more fully understand how the process works, who or what has input to and influence on the process, what its inputs and outputs are, and even what its timing is.

A set of standard flowcharting symbols for communicating various actions, inputs, outflows, and so on, is used internationally. These symbols may be universally applied to any process. The most commonly used symbols are shown in Table 1. To illustrate their use, a simple flowchart using the most common symbol elements is given in Figure 33. Flowcharts may be as simple or as complex as you may need. For example, in Figure 33 the rectangle labeled "Troubleshoot" represents an entire subprocess that itself can be expanded into a complex flowchart. If an intent of the flowchart had been to provide information on the troubleshooting process, then each troubleshooting step would have to be included. Our purpose for Figure 33 was merely to chart the *major* process steps for receiving and repairing a defective unit from a customer, so we did not

TABLE 1 Standard Symbology for Flowcharts

	An oval (or rectangle with rounded ends) is customarily used to denote the *start* or *finish* of a process.
	A rectangle is customarily used to denote a *process step*, an activity, or an operation. It may also represent an entire subprocess.
	A diamond is always used to denote a *decision point*. This is usually a *yes* or *no* function but could also represent an *if/then* statement. The process flow branches off in two or more directions here. The branch followed depends on the decision.
	This symbol denotes preparation.
	A parallelogram denotes an input or output.
	This symbol represents *documentation* or paperwork produced or required by the process.
	A circle is used as a connector (from one chart or page to another, with numbers if necessary).
	A line with an arrow always indicates the *path* and *direction* of flow in the process.

These are the symbols you will use most often, and they will fit virtually any situation.

require subprocess detail. This is a common starting point. From this high-level flowchart, it may be observed that (a) the customer's defective unit is received, (b) the problem is located and corrected, and (c) and the repaired unit is tested. (d) If the unit fails the test, it is recycled through the repair process until it does pass. (e) Upon passing the test, paperwork is completed. (f) Following that, the customer is notified, and (g) the unit is returned to the customer along with a bill for services. With this high-level flowchart as a guide, your next step will be to develop detailed flowcharts of the subprocesses you want to improve. Only then can you understand what is really happening inside the process, see which steps add value and which do not, find out where the time is being consumed, identify redundancies, and so on. Once you have a process flowcharted, it is almost always easy to see potential for improvement and streamlining. Without the flowchart, it may be impossible.

More often than not, people who work directly with a process are amazed to find out how little understanding of their process they had before it had been flowcharted. Working with any process day in and day out tends to breed a false sense of familiarity.

We once took over a large manufacturing operation that was having major problems with on-time delivery of systems worth $500,000 to $2 million apiece. Several reasons accounted for the difficulty, but a fundamental problem was that we were not getting the input materials on time—even with a 24-month lead time for delivery. One of the first things we did was flowchart the entire material system. We started the chart at the signing of our customer's order and completed it at the point where the material was delivered to the stockroom. The chart showed dozens of people involved, endless loops for approval and checking, and flawed subprocesses that consumed time in unbelievable dimensions.

When the flowchart was finished, it was clear that the best case from the start of the order cycle until material could be expected in our hands required 55 weeks. The worst case could easily double that. With this knowledge, we attacked the material process and quickly whittled it down to 16 weeks and from there to 12 weeks. The point is this: Here was a process that had grown over the years to the point that it was no longer tolerable, much less efficient. But the individual players in the process didn't see the problem. They were all working very hard, doing what

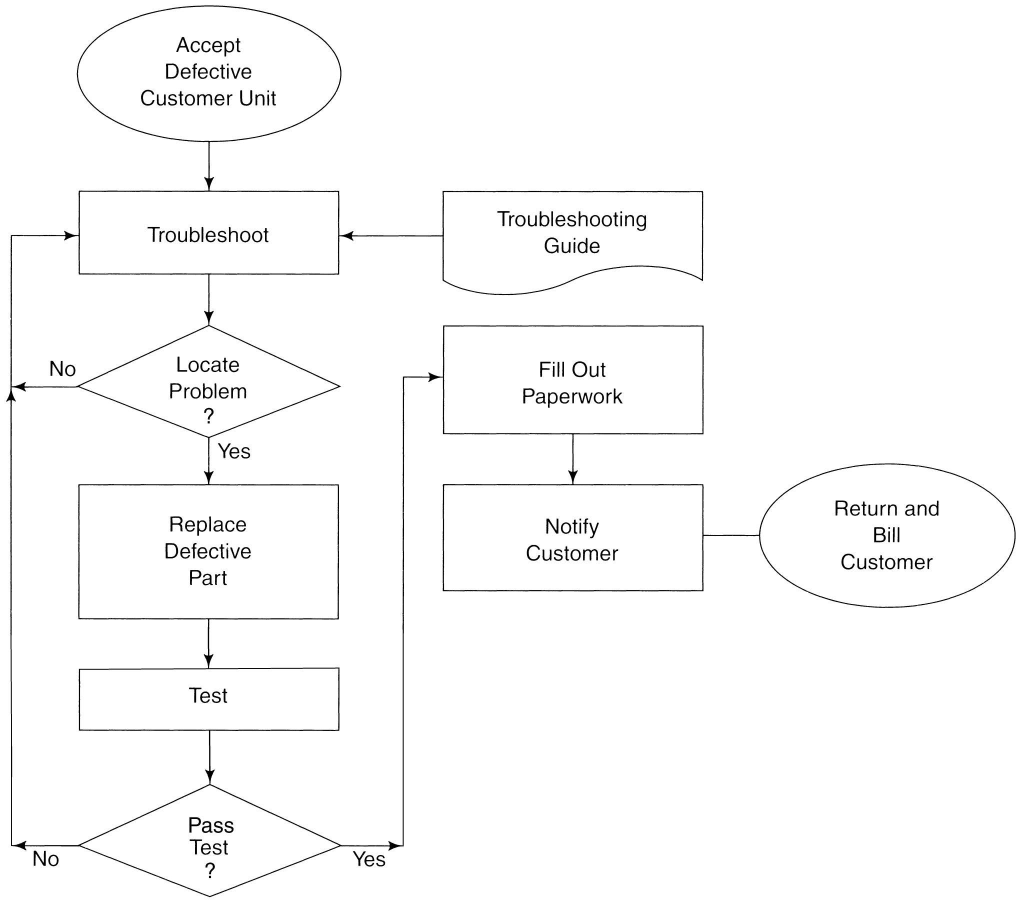


FIGURE 33 Typical Processes Flowchart

the process demanded, and fighting the fires that constantly erupted when needed material was not available. The flowchart illuminated the process problems and showed what needed to be done.

If you set out to control or improve any process, it is essential that you fully understand the process and why it is what it is. Don't make the assumption that you already know, or that the people working in the process know, because chances are good that you don't, and they don't. Work with the people who are directly involved, and flowchart the process as a first step in the journey to world-class performance. Not only will you better understand how the processes work, but also you will spot unnecessary functions or weaknesses and be able to establish logical points in the process for control chart application. Use of the other tools will be suggested by the flowchart as well.

Surveys

At first glance, the survey may not seem to be indispensable. When you think about it, though, all of the tools are designed to present information—information that is pertinent, easily understood by all, and valuable for anyone attempting to improve a process or enhance the performance of some work function. The purpose of a survey is to obtain relevant information from sources that otherwise would not be heard from—at least not in the context of providing helpful data. Because you design your own survey, you can tailor it to your needs. We believe that the survey meets the test of being a total quality tool. Experience has shown that the survey can be very useful.

Surveys can be conducted internally as a kind of employee feedback on problem areas or as *internal customer* feedback on products or services. They can also be conducted with *external customers*, your business customers, to gain information about how your products or services rate in the customers' eyes. The customer (internal or external) orientation of the survey is important because the customer, after all is said and done, is the only authority on the quality of your goods and services. Some companies conduct annual customer satisfaction surveys. These firms use the input from customers to focus their improvement efforts.

Surveys are increasingly being used with suppliers as well. We have finally come to the realization that having a huge supplier base is not the good thing we used to think it was. The tendency today is to cut back drastically on the number of suppliers utilized, retaining those that offer the best *value* (not best price, which is meaningless) and that are willing to enter into partnership arrangements. If a company goes this route, it had better know how satisfied the suppliers are with the past and present working relationship and what they think of future prospects. The survey is one tool for determining this. It is possibly the best initial method for starting a supplier reduction/supplier partnership program.

Even if you are not planning to eliminate suppliers, it is vital to know what your suppliers are doing. It would make little sense for you to go to the trouble of implementing total quality if your suppliers continue to do business as usual. As you improve your processes and your services and products, you cannot afford to be hamstrung by poor quality from your suppliers. Surveys are the least expensive way of determining where suppliers stand on total quality and what their plans are for the future. The survey can also be a not-too-subtle message to the suppliers that they had better "get on the bandwagon."

A typical department in any organization has both internal suppliers and internal customers. Using the same customer-oriented point of view in a survey has proven to be a powerful tool for opening communications among departments and getting them to work together for the common goal rather than for department glory—usually at the expense of the overall company.

The downside of surveys is that the right questions have to be asked, and asked in ways that are unambiguous and designed for short answers. A survey questionnaire should be thoroughly thought out and tested before it is put into use. Remember that you will be imposing on the respondents' time, so make it easy and keep it simple.

Failure Mode and Effects Analysis

Failure mode and effects analysis (FMEA) tries to identify all possible potential failures of a product or process, prioritize them according to their risk, and set in motion action to eliminate or reduce the probability of their occurrence. FMEA cannot by itself bring about this happy ending, since it is an analytical tool, not a problem solver. But it will point to the problems that must be solved through the use of the other tools.

Failure mode and effects analysis—the name itself is enough to scare off the unfamiliar. So you don't give up on FMEA before we get into it, let's simplify the concept. FMEA just tries to identify all the possible types (modes) of failures that could happen to a product or a process before they happen. Once the possible "failure modes" have been identified, the "effects analysis" kicks in and studies the potential consequences of those failures. Next, the consequences of each potential failure are ranked by

- Seriousness/Criticality to the customer
- Probability of the fault's occurrence
- Probability of the fault's detection by the systems responsible for defect prevention or detection

Seriousness of consequence, likelihood of occurrence, and difficulty of detection all work together to determine the criticality of any specific failure mode. Comparing the criticality of all the identified potential failure modes establishes the priority for corrective action. That is the objective of FMEA. FMEA tells the organization where its resources should be applied, and this is very important because all possible failures are not equal and the organization should always deploy its resources to correct the problems that are most critical. Without the benefit of FMEA, it is doubtful that an organization could identify its most critical failure modes very accurately. Remember, usually FMEA addresses problems that have not yet happened. Next time you are cruising at 600 miles per hour at 35,000 feet, consider whether the designers of your airliner should have used FMEA—or the next time you really, really need your brakes to work (Am I going to go over the cliff?)—or when you buy that new $2,000 high-definition TV (So much technology—is it going to be reliable?). We might also consider it if we have to go to a hospital—or when we ship our original, no-copy-available manuscript to our publisher by overnight express. Looking at it from another viewpoint, had FMEA been available, could it have prevented the *Titanic*'s disaster? Given what we now know about the ship's collision with the iceberg, we are convinced that had FMEA been employed, the *Titanic* might have plied the seas through most of the twentieth century. Of course, FMEA did not come along until four decades later.

There are several kinds of FMEA. Design FMEA is employed during the design phase of a product or service, hopefully starting at the very beginning of the project. In this way, the designers will be able to develop a design that has fewer potential failures, and those that cannot be avoided can be made less severe. Also, by using FMEA concurrently with the design activity, it is more likely that test and inspection methods will be able to catch the problems before they get to the customer.

A second version is process FMEA. In this case, FMEA is looking at the potential failures (errors, miscues) of a process. The process might be that of an accounting firm, a hospital, a factory, a governmental agency, or any other entity. One can imagine that in a hospital there are many processes that can have lots of failure modes, some probably not too important, but some as severe as they come. One would hope that FMEA is in every hospital's tool kit.

Ford Motor Company uses FMEA even before it gets to the design stage of a vehicle. As the concept for a new vehicle is being developed, FMEA is employed to make sure that the vehicle will not bring problems related to the concept into the design and production stages.

FMEA can also be used after the fact (as in the case of a product repeatedly failing in the hands of the customer). This may lead to a retrofit or recall of the product if the problem is severe or simply to a design change for future production if the problem is not critical. The procedure is essentially the same for every kind of FMEA.

FMEA is not new, although until recently its use was mainly associated with military and aerospace programs. It was developed by the U.S. military in 1949 and has seen increasing use in industry, especially since the 1980s, its importance being driven by the worldwide quality movement under TQM and ISO 9000 and by litigation in the United States against companies whose products are involved in customer injuries or deaths. FMEA is now considered an invaluable quality tool.

The Language of FMEA FMEA has its own unique set of terms. We have captured most of them in the following list:

Failure mode. The way in which something might fail. For example, a race car's tire might fail by puncture from a sharp object. It might also fail from a blowout resulting from wear. Puncture and blowout are two (of many) tire failure modes.

Failure effect. The failure's consequence in terms of operation, function, or status of the item.

Effects analysis. Studying the consequences of the various failure modes to determine their severity to the customer. Of the two tire failure modes mentioned earlier, the blowout is likely to have the most serious consequence, since when a tire suddenly explodes, the speeding race car usually goes out of control, often with dire consequences. On the other hand, a puncture usually allows the tire pressure to decrease gradually, allowing the driver time to sense the problem before he or she loses control. Neither failure mode is something the driver wants, but of the two, the puncture is preferred.

Failure mode analysis (FMA). An analytical technique used to evaluate failure modes with the intent to eliminate the failure mode in future operations.

Design FMEA. FMEA applied during the design phase of a product or service to ensure that potential failure modes of the new product or service have been addressed.

Process FMEA. FMEA applied to a process (as in a factory or office) to ensure that potential failure modes of the process have been addressed.

Risk assessment factors.

- ***Severity (S):*** A number from 1 to 10, depending on the severity of the potential failure mode's effect: 1 = no effect, 10 = maximum severity.
- ***Probability of occurrence (O):*** A number from 1 to 10, depending on the likelihood of the failure mode's occurrence: 1 = very unlikely to occur, 10 = almost certain to occur.
- ***Probability of detection (D):*** A number from 1 to 10, depending on how unlikely it is that the fault will be detected by the system responsible (design control process, quality testing, etc.): 1 = nearly certain detection, 10 = impossible to detect.
- ***Risk Priority Number (RPN):*** The failure mode's risk is found by the formula $RPN = S \times O \times D$. Said another way, RPN = Severity × Probability of Occurrence × Probability of Detection. RPN will be a number between 1 (virtually no risk) and 1,000 (extreme risk). The auto industry considers an RPN of 75 to be acceptable, although in light of some recent manufacturer recalls for safety related failures, we anticipate that may change.

FMEA Illustration Let's consider a simplified FMEA to illustrate how the process works. We will assume we manufacture bicycles and we are designing a new bike that will be made largely of composite materials. Since this is a new technology for our company, we are using design FMEA to make sure we've considered all the possible problem areas of the design before we go into production. The FMEA team has listed several potential failure modes, one involving sudden, unwarned breakage of the front fork. It is obvious that should the fork fail, the effect on the customer could be severe. Since the rider will probably have no warning before the fork breaks, we rate the severity a 10 ($S = 10$).

We then identify possible causes of the fork failure and conclude that the probability of the most likely cause occurring is moderate, with five occurrences per thousand bikes. We rate the probability of occurrence a 6 ($O = 6$). Of course, it is our intention to detect the defective forks and discard them before they are attached to the bicycle frame. After we examine our fork testing methods, we conclude that the probability of detecting the failure mode flaw in the fork is low. We assign it a 6 ($D = 6$).

Plugging these numbers into our equation, $RPN = S \times O \times D$, we have

$$\begin{aligned} RPN &= 10 \times 6 \times 6 \\ &= 360 \end{aligned}$$

All other failure modes result in RPNs in the range of 40 to 70, so our focus should be on eliminating, or drastically reducing, this potential fork failure mode. We could redesign the fork so that it is more robust, thereby lowering the occurrence value (O), or change the test process so that it is much more likely to detect a fork that might fail, thereby lowering the detection value (D).

Notice that if our fork testing process gave us complete assurance of detecting the fault—say, at the $D = 1$ level—RPN would be 60, and we probably wouldn't need to put a lot of resources on this fault mode. The same could be said if D remained at 6, but the probability of occurrence of the fault mode turned out to be remote ($O = 1$).

When to Use FMEA FMEA should be employed at the following points:

During the design or redesign of a process, product, or service

When improvements are needed or planned for existing processes, products, or services

When existing processes, products, or services are to be used in a new way

During after-the-fact failure analysis

When safety or health is an issue

This is intended to be a brief introduction to FMEA. Going into it more thoroughly is beyond the scope of this text. Should you find that you need more, the Internet is a good source of information, and there are many books dedicated to the subject.

Design of Experiments

Design of experiments (DOE) is a very sophisticated method for experimenting with processes with the objective of optimizing them. If you deal with complicated processes that have multiple factors affecting them, DOE may be the only practical way of bringing about improvement. For example, such a process might be found in a wave soldering machine. Wave solder process factors include the following:

Solder type	Conveyor speed
Flux specific gravity	Solder temperature
Conveyor angle	Wave height
Preheat temperature	PC board layer count
Flux type	PC board groundplane mass

These 10 factors influence the process, often interacting with one another. The traditional way to determine the proper selection or setting was to vary one factor while holding all others fixed. That kind of experimentation led to making hundreds of individual runs for even the simplest processes. With that approach, it is unusual to arrive at the optimum setup because a change in one factor frequently requires adjustment of one or more of the other factors for best results.

The DOE method reduces the number of runs from hundreds to tens as a rule, or by an order of magnitude. This means of process experimentation allows multiple factor adjustment simultaneously, shortening the total process, but equally as important, revealing complex interaction among the factors. A well-designed experiment can be concluded on a process such as wave soldering in 30 to 40 runs and will establish the optimum setting for each of the adjustable parameters for each of the selected factors. For example, optimal settings for conveyor speed, conveyor angle, wave height, preheat temperature, solder temperature, and flux specific gravity will be established for each PC board type, solder alloy, and so on.

DOE also shows which factors are critical and which are not. This information enables you to set up control charts for those factors that matter, while saving the effort that might have been expended on the ones that don't. While design of experiments is beyond the scope and intent of this text, the DOE work of Deming, Taguchi, and others may be of help to you. Remember that DOE is available as a tool when you start trying to improve a complex process.

MANAGEMENT'S ROLE IN TOOL DEPLOYMENT

Management's role is changing from one of directing to one of facilitating. Since the Industrial Revolution, management has supplied the place of work, the machinery and tools, and the work instructions. The concept has been that management knows what the job is and needs only to hire the muscle power to get it accomplished. The workers were there only because management could not get the job done without their labor. Workers were not expected to think about doing things differently but simply to follow the boss's orders. Work was typically divided into small tasks that required minimal training, with little or no understanding on the part of laborers as to how their contribution fit into the mosaic of the whole.

During much of the twentieth century, and certainly since World War II, changes have been creeping into the management–labor relationship. Some people think that the labor unions were responsible for these changes, and they did help obtain better pay, shorter hours, workplace improvements, and other benefits for workers. However, the relationship changes between management and labor have happened largely in spite of the unions. Unions have had at least as difficult a time as management has had in dealing with employee involvement. Nor has management at large been responsible for the changes sweeping across the industrial world today. Certainly, there are champions representing management, but the changes are coming about for one reason and one reason only: They are necessary in order for businesses to survive in an increasingly competitive marketplace.

After World War II, when Deming went to Japan to teach industrialists about quality and the use of statistics for achieving it, Japan had just lost the war. Its industrial base was a shambles. The Japanese needed to resurrect their factories and put people to work quickly. That meant they had to be able to sell their products abroad—to the same people who had defeated them. To do that, it was essential that their products be of high quality. Their survival depended on it. You know the rest of the story.

Not only did the Japanese listen to Deming and Juran, but also they embraced them and their philosophy (whereas in the United States we were abandoning their teaching amid a seemingly insatiable market for manufactured goods). Japan developed its own quality gurus (Ishikawa, Taguchi, Shingo, and others) who expanded the work of Deming and Juran. For 30 years, into the 1980s, Japanese manufacturers perfected their quality and production methods. The 1980s found Japan ahead of the rest of the world, not just the United States, in product quality and value. During that decade, companies in the United States began to wake up to the fact that Japan's products were the best in the world and that they were running roughshod over U.S. companies not only in the world markets, but also right here at home. Whole markets were conceded to Japan as U.S. companies found they could not compete.

The survival mentality finally surfaced. We woke up to the fact that not only our industrial survival but perhaps even our national survival was at stake. Either we became competitive in the global marketplace, or we lost the first war fought without bullets since the invention of gunpowder.

Now that the wake-up call has been received, many people have come to realize that we have been managing poorly for a very long time—say, since 1945. We (those of us who have heard the alarm) have come to understand that management's proper role is to facilitate, not to direct. Management provides the place of work and the machines and tools as before, but in addition, we do everything we can to *help* our employees do the job. That means training. It means listening to their thoughts and ideas—more than that, it means *seeking* their thoughts and ideas. It means acting on them. It means giving them the power to do their jobs without management interference. It means giving them time to think and discuss and suggest and experiment. It means communicating—fully and honestly. No secrets, no smoke screens. It means accepting every employee as a valued member of the corporate team.

This approach does not mean that management abdicates its responsibility to set the direction for the enterprise, to establish the corporate vision, to steer the course. But with the enlistment of all the brain power that had formerly gone untapped, even this job becomes easier than it was before.

It is management's responsibility to train employees to use not only physical tools (and that is very important) but also intellectual tools. The tools discussed in this chapter should eventually be used by most employees—*eventually* because it is a mistake to schedule all employees for training on the tools if they will not be using them very soon. You would not train a person on a new machine a year before the machine arrives because without putting the training to practice, its effect will be lost. So it is with the total quality tools. When a group of people is ready to put some of the tools into practice, that is when the group should be trained. As the total quality concept takes root, it will be only a matter of time until everyone has the need. Train them as required.

Management must also provide the internal experts, often called *facilitators*, to help the new teams get started and to develop their expertise. Facilitation is probably a never-ending function because the total quality envelope is constantly being expanded and there will always be the need for a few to be on the leading edge and to bring the others along.

It is management's responsibility to ensure that the people who are solving the problems have the proper training and facilitation. It is also management's responsibility to make sure the problems being attacked are of interest to the enterprise and not trivial. Management must populate the problem-solving team with the cross-functional expertise the problem requires. The team must be given the power and support necessary to see the effort brought to its conclusion.

Management must be vigilant that data used in problem solving are valid, which is a function that usually falls to the facilitator. Especially when teams are immature in total quality, they have a tendency to grab at the first set of data that comes along. Management must ensure that the data and the statistical techniques employed are appropriate for the problem at hand.

Finally, management must ensure that there are results. Too many problem-solving, process improvement, and related efforts take on a life of their own and go on forever. This cannot be allowed. People are watching. Especially in the early stages, some people will hold the view that "This too shall pass." If results do not come rather quickly, the detractors will be given the ammunition they need to subvert the whole total quality effort. For this reason, it is important that the first projects attempted have a high probability of success, and management must monitor them closely, even to the point of being involved in the activity. As the process matures and successes are tallied, an occasional failure will not be an issue. In fact, people must be given the chance to fail, and failure must be free of repercussions for the team or its members.

Precautions

Implementing the use of statistical tools and the whole concept of process improvement, problem solving by the rank and file, and empowerment—in short, the total quality culture—represents a profound change from the way things have been done in the past. People generally resist change until they see that it will benefit them. For that reason, management must champion change and convince everyone that the effort will benefit all. Those who would undermine the effort must rapidly be converted or removed from the operation. People will be looking to management for evidence that management really believes in total quality. If for no other reason than that, it must be obvious to all that management is using the same techniques the other employees are being taught. Above all, management must support and facilitate the employees as they use the techniques of total quality to solve problems and improve processes.

Communicate. Let everyone know what is going on and what the results are. Help them understand why it is good for them, for the whole enterprise, and, yes, even for the nation.

Never assume that you know it all. The people who live with the processes day in and day out know far more about what is wrong with them and how to improve them than any manager. Never delude yourself that you have learned all you need to know about total quality. It will never happen because total quality is a dynamic and ever-expanding concept.

Start slowly. Don't try to organize an entire factory or office complex into improvement teams and train everyone in sight on day one. Take it one or two steps at a time, training as you go. Be careful to pick early projects that have high prospects for success.

But start. The worst choice a manager could make today is to decide that total quality is not for his or her business. It is for every conceivable kind of business, whether large or small, whether public, private, military, civilian, mass production, job shop, classroom, or office. It would be a tragedy to decide not to start this journey when so much is at stake.

Although results should be evident quickly, do not expect the necessary cultural change to occur overnight.

TABLE 2 Functionality Matrix: Quality Tools

	Cause & Effect Diagram	Check Sheet	Control Chart	Design of Experiments	Five-S	FMEA	Histogram	Pareto Chart	Run Chart	Scatter Diagram	Stratification	Survey	Flowchart
Alert operator to change in process			X						X				
Alert operator to special cause			X										
Analyze by sorting into categories											X		
Analyze potential causes	X							X		X	X		X
Collect data from targeted groups												X	
Determine relationships between variables (correlation)				X						X			
Experiment with a process				X									X
Find patterns in data									X		X		
Frequency distribution (frequency of values to occur)							X						
Identify possible causes	X							X			X		X
Improve/sustain work efficiency					X								
Investigate causes	X							X		X	X		X
Monitor a process (continuing)		X	X						X				
Observe results over time			X						X				
Present information while collecting data		X						X	X				
Process analysis	X	X	X	X		X		X	X	X	X		X
Process capability			X				X						
Process optimization				X			X			X			X
Rank potential product/process failures for elimination						X							
Separate significant from trivial								X					
Study a process	X	X				X	X						X
View process over time			X						X				

This is a long process, requiring several years to get to the point where total quality is considered “just the way we do things” and not some special “project.” Even so, during all that time, problems are being solved, improvements are being made, and efficiency, productivity, and competitiveness are all increased.

SELECTING THE RIGHT TOOL FOR THE JOB

In this chapter, we have discussed 13 quality tools, some in great detail and a few on an introductory basis. Your challenge will be selecting the appropriate tool (or tools) for the task at hand. This can be confusing, especially at first. For that reason, we have included Table 2, a functionality matrix for the tools. It is by no means complete in terms of the possible uses of the tools or tasks that may be required, but it illustrates the common functionality of our tools. For example, if your task is to obtain data from a group of customers, the matrix will point you to the *Survey*. If you are looking for something that will provide useable information in graphic form even as the data are being collected, then the matrix suggests a *Check Sheet*, *Pareto Chart*, or *Run Chart*. Your selection will be determined by which tool you think will best satisfy your requirement. Note that most of the tools are useful in more than one situation. Your knowledge of the task will often make the selection clear, although there may also be some trial and error involved initially. The matrix is intended to illustrate the kinds of functions that may be appropriate for the tools. Once you start using them, you will find the selection to be virtually automatic.

SUMMARY

1. Pareto charts are useful for separating the important from the trivial. They are named after Italian economist and sociologist Vilfredo Pareto, who developed the theory that a majority of problems are caused by a minority of causes. Pareto charts are important because they can help an organization decide where to focus limited resources. On a Pareto chart, data are arrayed along an *x*-axis and a *y*-axis.
2. The cause-and-effect diagram was developed by the late Dr. Kaoru Ishikawa, a noted Japanese quality expert; others have thus called it the Ishikawa diagram as well as the fishbone diagram. Its purpose is to help identify and isolate the causes of problems. It is the only one of the seven basic quality tools that is not based on statistics.
3. The check sheet is a tool that facilitates collection of relevant data, displaying it in a visual form easily understood by the brain. Check sheets make it easy to collect data for specific purposes and to present them in a way that automatically converts them into useful information.
4. Histograms have to do with variability. Two kinds of data are commonly associated with processes: attributes data and variables data. An *attribute* is something that the output product of the process either has or does not have. *Variables data* are data that result when something is measured. A *histogram* is a measurement scale across one axis and a frequency of like measurements on the other.
5. The scatter diagram is arguably the simplest of the seven basic quality tools. It is used to determine the correlation between two variables. It can show a positive correlation, a negative correlation, or no correlation.
6. In the context of the seven total quality tools, run charts and control charts are typically thought of as being one tool together. The *control chart* is a more sophisticated version of the run chart. The *run chart* records the output results of a process over time. For this reason, the run chart is sometimes called a *trend chart*. The weakness of the run chart is that it does not tell whether the variation is the result of special causes or common causes. This weakness gave rise to the control chart. On such a chart, data are plotted just as they are on a run chart, but a lower control limit (LCL), an upper control limit (UCL), and a process average are added. The plotted data stay between the UCL and LCL, while varying about the centerline or average, only so long as the variation is the result of common causes such as statistical variation.
7. Stratification is a tool used to investigate the cause of a problem by grouping data into categories. Grouping of data by common elements or characteristics makes it easier to understand the data and to draw insights from them.
8. Other useful quality tools are five-S, flowcharts, surveys, failure mode and effects analysis (FMEA), and design of experiments (DOE). Five-S is used to eliminate waste and reduce errors, defects, and injuries. Flowcharts are used in a total quality setting for charting the inputs, steps, functions, and outflows of a process to understand more fully how the function works and who or what has input into and influence on the process, its inputs and outputs, and even its timing. The survey is used to obtain relevant information from sources that otherwise would not be heard from in the context of providing helpful data. FMEA tries to identify all possible product or process failures and prioritize them for elimination according to their risk. DOE is a sophisticated method for experimenting with complex processes for the purpose of optimizing them.

KEY TERMS AND CONCEPTS

Attributes data
Cause-and-effect diagram
Check sheet
Common causes
Control chart
Correlation
Design of experiments (DOE)
Effects analysis
Failure mode
Five-S
Flowchart
FMEA
Frequency distribution
Histogram
In statistical control
Lower control limit (LCL)
NPMO
Pareto chart
Pareto Principle
Process average
Process variability
Risk
Risk assessment
Run chart
Scatter diagram
Seriousness of consequence
Shine
Six Sigma
Special causes

Specification limits
Standard deviation
Standardize
Stratification
Survey
Sustain
Total quality tools
Trend chart
Upper control limit (UCL)
Variables data
Variation

FACTUAL REVIEW QUESTIONS

1. Explain the purpose of a Pareto chart. Give an example of when one would be used.
2. Describe the origin and use of cause-and-effect diagrams.
3. How would a check sheet be used in a modern production facility?
4. What is a histogram, and how is one used?
5. What accounts for the disparity in NPMO between the statistical 6 and the popular Six Sigma approach?
6. Describe two methods for improving the yield of a process (i.e., taking it to a higher sigma value).
7. Explain the purpose of the scatter diagram. Give an example of how one would be used.
8. Contrast and compare run charts and control charts.
9. What is the most common use of stratification?
10. What purpose is served by flowcharts?
11. Give an example of how a survey might be used in a modern production setting.
12. What is the purpose of design of experiments?
13. In the context of the five-S philosophy, what is the intent of the word *Standardize*?
14. Explain the difference between design FMEA and process FMEA.
15. What are FMEA's three risk assessment factors?

CRITICAL THINKING ACTIVITIES

Which Tool to Use

As the manager of a department that is beginning to use the total quality tools, Marion thinks a wall chart in the team meeting room would be helpful when the teams decide on which tools to apply to their problem-solving or decision-making efforts. She has listed the most commonly used tools and wants a simple one-line "purpose statement" for each tool, similar to the one she developed for the flowchart. Your task: Develop the rest of the purpose statements for the wall chart here.

Total Quality Tools: What They Are Used For	
Tool	**Purpose Statement**
Flowchart	Helps us understand our processes; facilitates thinking about improving them.
Pareto chart	
Cause-and-effect diagram	
Histogram	
Stratification	
Run chart	
Control chart	
Scatter diagram	
Check sheet	
Survey	

Constructing a Flowchart: Scheduling a Meeting

Marion read that even the most routine tasks can be flowcharted and that when they are, the diagram may reveal complexity that is both surprising and unnecessary. She thought she would test this by flowcharting a process that seemed to be the most used in her organization, scheduling a meeting. She convened a meeting of her direct subordinates, and together they have listed the steps involved in scheduling a meeting. Now they are ready to develop the chart. You are the facilitator. Lead them through the diagramming process. (Draw the flowchart.)

Steps in Scheduling a Meeting	The Flowchart
• Select a topic.	
• Select participants.	
• Select date.	
• Select time.	
• Select place (accommodate any conflicts in the earlier steps).	
• Prepare draft agenda.	
• Distribute draft for comments.	
• Review comments (accommodate as appropriate).	
• Prepare meeting room.	
• Hold meeting.	

Selecting Improvement Subjects Using Pareto Charts and Stratification

Starlight Homes Inc. is a building contractor specializing in upscale homes in the Southwest. Before each new home is sold, Starlight conducts a final inspection of the home and repairs any defects. In addition, Starlight receives a "punch list" of defects (to be corrected) compiled by the buyers following the sale. Ricardo Alvarez, Starlight's lead supervisor, has concluded that even if it should cost more to do the work right in the first place, it will be a lot cheaper than going back later to fix the defects. In an effort to reduce costs, improve the quality of Starlight's homes, and reduce the number of complaints after the sale, Ricardo has assembled data from his final inspections and the punch lists for the last 20 homes sold. These data are listed in the following chart:

Defect Type	Occurrences	Defect Type	Occurrences
Damaged walls	13	Doors	14
Exterior paint	5	HVAC	11
Plumbing	33	Roof	3
Caulking	28	Masonry	2
Electrical	25	Interior paint	61
Cabinetry	12	Landscaping	16
Woodwork	46	Fixtures	7

Construct a Pareto chart to illustrate the defect types by number of defects. Which two defect types appear to be the most significant? Should Ricardo focus his attention on these two categories of defects? Ricardo decided to stratify the Pareto chart by cost before making any decision. His bookkeeper developed the average cost per repair event per category. The data are shown here:

Average Cost per Repair Event			
Defect Type	Average Cost	Defect Type	Average Cost
Damaged walls	$126	Doors	$11
Exterior paint	25	HVAC	110
Plumbing	78	Roof	72
Caulking	7	Masonry	290
Electrical	74	Interior paint	4
Cabinetry	88	Landscaping	34
Woodwork	5	Fixtures	31

The second-level chart developed from these numbers should show Ricardo which two or three defect types are the most significant in terms of cost, enabling him to put his efforts where they will do the most good. What are they? Was Ricardo justified in going to the second level (of stratification) before making a decision on where to focus his efforts? Why?

Constructing a Cause-and-Effect Diagram

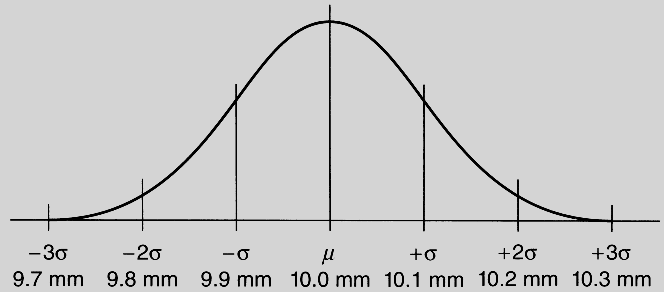
Your team has been given the charter to make recommendations for improving the cleanliness of the company's restrooms. The team has finished compiling a list that it considers to be the possible contributors to less than desirable restroom cleanliness:

Janitor service	Use of paper towels	Lack of paper towels
Slobs	User carelessness	User attitude
Janitor attitude	Paper dispensers	Poor lighting
Too small	Unreliable plumbing	Type of floor material
Janitor pay	Management inattention	Janitor supervision
Air conditioning	Insufficient exhaust	In-house plumbers
Cleaning materials	Cleaning equipment	Paper receptacles
Maintenance	Cleaning schedule	Leaking faucets
Janitor procedures		

Construct a cause-and-effect diagram incorporating all these ideas.

Translating Your Histogram

Your process has a normal histogram with μ located at 10 millimeters, 1s points at 9.9 and 10.1 millimeters, 2s points at 9.8 and 10.2 millimeters, and 3s points at 9.7 and 10.3 millimeters.



If your customer will accept parts measuring between 9.7 and 10.3 millimeters, how many parts of every 1,000 produced would you expect to scrap? If your customer notified you that henceforth it would accept only parts between 9.9 and 10.1 millimeters, what would you anticipate your scrap rate to be? What would have to be done to bring the scrap rate at this new customer requirement back down to what it had been at the former customer specification? Compared with the bell curve above, what would the new histogram have to look like?

DISCUSSION ASSIGNMENT 1

Reacting to a Process Gone Wrong

Cignet Plastics Corporation is a contract plastics die-casting house serving a wide range of clients. Over the years, Cignet has been a favored supplier of precision die castings for a major producer of model airplane kits. In recent days the defect rate of these parts has increased. (Acceptance is based on a visual inspection of the parts for appearance.) After a thorough audit of the process, Quality Assurance has concluded that there has been no change to the process. It claims that the increase in defects must be variation that is related to some assignable cause. The president of Cignet Plastics does not have a clue as to what that means, and he has called you in for an explanation.

DISCUSSION QUESTIONS

Discuss the following questions in class or outside of class with your fellow students:

1. What will you tell the president?
2. He wants you to change the process to reduce the number of defects, but you know that is the wrong approach. How do you talk him out of it?
3. What approach would you use to get the operation back to normal?

ENDNOTES

1. Kaoru Ishikawa, *Guide to Quality Control* (Tokyo: Asian Productivity Organization, 1976).
2. The 80–20 rule is an approximation, and one should not expect the numbers to land exactly at 80% or 20%.
3. Ishikawa, *Guide to Quality Control*, 24–26.
4. W. Edwards Deming, *Red Bead Experiment*. Retrieved from www.redbead.com on July 7, 2010.
5. W. W. Scherkenbach, *The Deming Route to Quality and Productivity* (Rockville, MD: Mercury, 1991), 100.
6. Kaoru Ishikawa, *What Is Total Quality Control*? (Upper Saddle River, NJ: Prentice Hall, 1985), 198.
7. Scherkenbach, *The Deming Route*, 104.
8. Joseph M. Juran, *Juran on Planning for Quality* (New York: Free Press, 1988), 18.