5

QUALITY CONTROL

5.1 DEFINITION OF CONTROL

As used in this book, *control* refers to the process employed to meet standards consistently. The control process involves observing actual performance, comparing it with some standard, and then taking action if the observed performance is significantly different from the standard.

The control process is a feedback loop (Figure 5.1). Control involves a universal sequence of steps as follows:

1. Choose the control subject, i.e., choose what we intend to regulate.
2. Establish measurement.
3. Establish standards of performance: product goals and process goals.
4. Measure actual performance.
5. Compare actual measured performance to standards.
6. Take action on the difference.

This universal sequence applies to individuals at all levels from the chief executive officer to members of the workforce. The sequence can be applied as a framework for helping supervisors and work teams to understand and run everyday work processes. Such a framework becomes increasingly important as the team concept—particularly self-directed teams—emerges as an important form of business life. Chapter 7 explains several types of teams and the roles of a team leader, team facilitator, and team members.

When the natural work team in a department puts the control process into practice, three purposes are served:

- Maintain the gains from improvement projects.

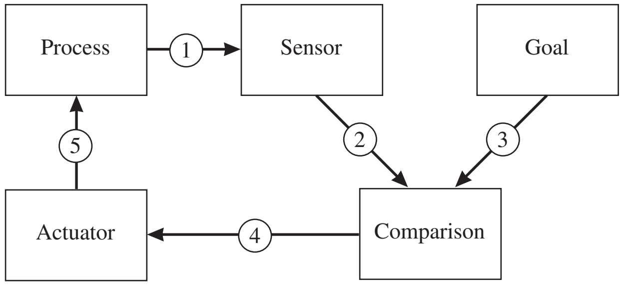

FIGURE 5.1
The feedback loop.

- Promote analysis of process variation, based on data, to identify improvement opportunities.
- Allow team members to clarify their responsibilities and work to achieve a state of self-control.

The first three steps in the control process (choose the subject, establish measurement, and establish standards) require the *participation* of the department work team. The last three steps (measure, compare to standards, and take action) can be the *responsibility* of the department work team.

Control, one of the trilogy of quality processes, is largely directed at meeting goals and preventing adverse change, i.e., holding the status quo. In contrast, improvement focuses on creating change, i.e., changing the status quo. The control process addresses sporadic quality problems; the improvement process addresses chronic problems.

5.2 MEASUREMENT

Quality measurement is central to the process of quality control: "What gets measured, gets done." Measurement is basic for all three operational quality processes and for strategic management: For quality control, measurement provides feedback and early warnings of problems; for operational quality planning, measurement quantifies customer needs and product and process capabilities; for quality improvement, measurement can motivate people, prioritize improvement opportunities, and help in diagnosing causes; and for strategic quality management, measurement provides input for setting goals and later supplies the data for performance review.

Figure 5.2 shows the far-reaching impact of measurement in quality management. Note how measurement provides both alignment and linkages at several levels from daily work to strategic quality planning. These elements, in turn, become drivers to encourage the use of measurements for quality. This chapter presents concepts

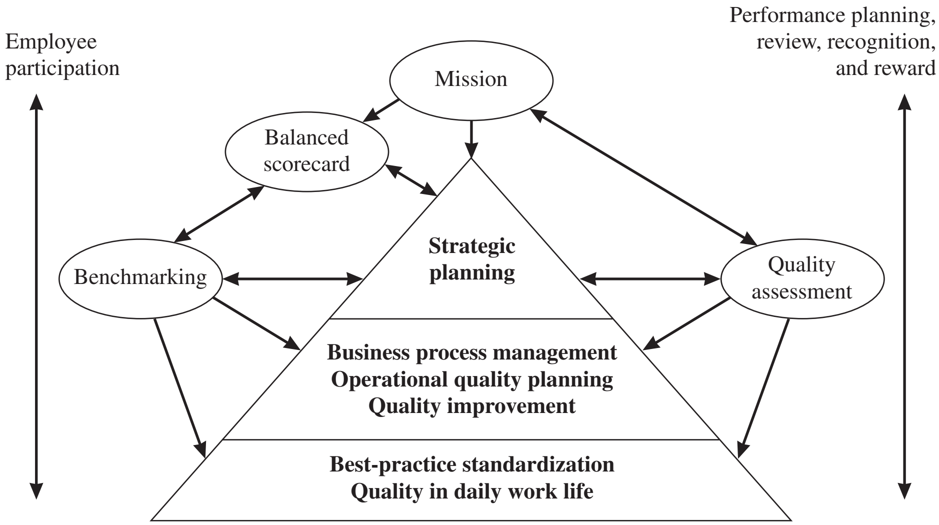

FIGURE 5.2
Measurement drivers. (*Reprinted by permission of John Wiley & Sons, Inc.*)

underlying measurement; later chapters present examples of quality measurement at both the operational and strategic levels.

The following principles can help to develop effective measurements for quality:

1. Define the purpose and use that will be made of the measurement. An example of particular importance is the application of measurements in quality improvement. Final measurements must be supplemented with intermediate measurements needed for diagnosis.
2. Emphasize customer-related measurements; be sure to include both external and internal customers.
3. Focus on measurements that are useful—not just easy to collect. When quantification is difficult, surrogate measures can at least provide a partial understanding of an output.
4. Provide for participation from all levels in both the planning and implementation of measurements. Measurements that are not used will eventually be ignored.
5. Provide for making measurements as close as possible to the activities they impact. This timing facilitates diagnosis and decision making.
6. Provide not only concurrent indicators but also leading and lagging indicators. Current and historical measurements are necessary, but leading indicators help to look into the future.
7. Define, in advance, plans for data collection and storage, analysis, and presentation of measurements. Plans are incomplete unless the expected use of the measurements is carefully examined.
8. Seek simplicity in data recording, analysis, and presentation. Simple check sheets, coding of data, and automatic gaging are useful. Graphical presentations can be especially effective.

9. Provide for periodic evaluations of the accuracy, integrity, and usefulness of measurements. Usefulness includes relevance, comprehensiveness, level of detail, readability, and interpretability.
10. Realize that measurements alone cannot improve in products and processes. Measurements must be supplemented with the resources and training to enable people to achieve improvement. For elaboration on these and other principles of measurement systems, see *JQH5,* Section 9, and Zairi (1994).

This chapter presents concepts underlying measurement, but measurement is spread throughout the book. For example, Chapter 2 discusses measurements for broad quality assessment; Chapter 8 addresses strategic measurement, including the balanced scoreboard; Chapters 11, 12, 13, and 14 present examples of functional measurements. Thus measurements are for both product process control and management control.

5.3 SELF-CONTROL

Ideally, quality planning for any task should put the employee into a state of self-control. When work is organized so that a person has full mastery over the attainment of planned results, that person is said to be in a state of self-control and can therefore be held responsible for the results. Self-control is a universal concept, applicable to a general manager responsible for running a company division at a profit, a plant manager responsible for meeting the various goals set for that plant, a technician running a chemical reactor, or a bank teller serving customers.

To be in a state of self-control, people must be provided with

1. Knowledge of what they are supposed to do, e.g., the budgeted profit, the schedule, and the specification.
2. Knowledge of their performance, e.g., the actual profit, the delivery rate, the extent of conformance to specification (this is quality measurement).
3. Means of regulating performance if they fail to meet the goals. These means must always include both the authority to regulate and the ability to regulate by varying either (a) the process under the person's authority or (b) the person's own conduct.

If all the foregoing parameters have been met, the person is said to be in a state of self-control and can properly be held responsible for any deficiencies in performance. If any parameter has not been met, the person is not in a state of self-control and, to the extent of the deficiency, cannot properly be held responsible.

In practice, these three criteria are not fully met. For example, some specifications may be vague or disregarded (the first criterion); feedback of data may be insufficient, often vague, or too late (the second criterion); people may not be provided with the knowledge and process adjustment mechanisms to correct a process (the third criterion). Thus if we have a quality problem and we fail to meet any of the three criteria, the problem is "management controllable" (or "system controllable"); if we have a quality problem and if all three criteria are fully met, the problem is "worker controllable." Chapters 13 and 14 apply the concept of self-control to manufacturing and service industries.

TABLE 5.1
Classical control and self-control

Classical control	Self-control
Standard or goal	Knowledge of what people are supposed to do
Measurement	Knowledge of performance
Action on the difference	Means of regulating a process
Primary emphasis during execution	Primary emphasis before execution

Classical control and self-control are complementary (Table 5.1). An important difference, however, involves timing. Classical control takes place *during* the execution of a task; self-control provides useful criteria for evaluating plans *before* a task is executed.

Kondo and Kano (1999, p. 41.3) submit that there is a relationship among the control process; the "plan, do, check, act" cycle; and the concept of self-control. Figure 5.3*a* depicts the plan, do, check, act cycle, which corresponds to the main elements of the feedback loop (Figure 5.1) of the control process. They observe that individual worker performance during the "do" step comprises a plan, do, check, act cycle (Figure 5.3*b*). The extent to which the task of the worker is adequately planned reflects the degree to which the worker is placed in a state of self-control. The plan, do, check, act cycle is often called the "Deming cycle."

Some authors refer to the cycle as plan, do, study, act. Gitlow et al. (1995) emphasize that the cycle repeats over and over and provides a means of never-ending improvement.

For both self-control and the Deming cycle, the concept of standardization of work practices is important. Here employees apply a standardize, do, study, act (SDSA) cycle. Employees analyze the process to develop best-practice methods, use the best-practice methods on a trial basis, evaluate the effectiveness of the best practices, and document the standardized process. This standard process helps to stabilize the process and reduce variation. For elaboration, see Gitlow et al. (1995) and Imai (1986). One tool of standardization is the "5S method" for achieving an organized workplace. This method is discussed in Chapter 13 under "Plan for Neat and Clean Workplace."

Schonberger (1999) describes the concept of a self-adjusting system where frontline personnel employ simple, direct methods continuously. He proposes four elements: (1) process capacity management to minimize queues ("kanban"), (2) operator plotting of process data ("statistical process control"), (3) prevention of errors ("failsafing"), and (4) quality checks before passing work output to the next worker ("source inspection"). As with self-control, Schonberger's concept aims to provide personnel with all that is needed for them to control their work output directly.

Be aware that another concept, self-inspection, is *not* the same as self-control. Self-inspection addresses the examination of the product; self-control addresses the process of accomplishing a task. Self-inspection is discussed in Chapter 13.

We now proceed with an examination of the steps in the control sequence.

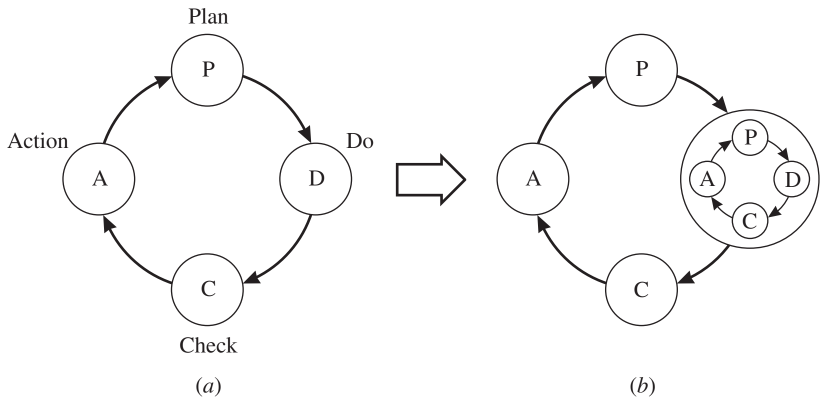

FIGURE 5.3
Deming's cycle. (*From JQH5, p. 41.4.*)

5.4
THE CONTROL SUBJECTS FOR QUALITY

Control subjects for quality are the critical parameters. At the technological level each division of a product—components, units, subsystems, and systems—has quality characteristics. Processing conditions (e.g., time to pay an insurance claim, oven temperature) and processing facilities also have quality characteristics. In addition, input materials and services have quality characteristics. Still more quality control subjects are imposed by external forces: clients, government regulations, and standardization bodies.

Beyond technological quality control subjects are managerial quality control subjects. These are mainly the performance goals for organization units and the associated managers. Managerial goals extend to nontechnological matters such as customer relations, financial trends (e.g., progress in reducing the cost of poor quality), employee relations, and community relations.

To identify and choose quality control subjects, several principles apply:

1. Quality control subjects should be aligned and linked with customer parameters, that is, the subjects should directly measure customer needs, satisfaction, and loyalty or measure product and process features that correlate with these customer parameters. External customers who affect sales income are paramount; equally important are internal customers, who affect internal costs such as the cost of poor quality. But let's face reality. Sometimes our control subjects are incomplete. For example, although advances have been made in measuring the quality of medical care, it is difficult to measure whether a physician detects a medical problem as early as possible.

   Table 5.2 shows examples of quality control subjects from different organizations. Later in this chapter, we specify these categories further by defining the units of measure.

TABLE 5.2
Control subjects

Electronics manufacturer	A bank
Document quality	Operations—timeliness
Software quality	Retail banking—accuracy
Hardware quality	Commercial banking—loan payment posting
Process quality	Credit card and ATM cards—transactions
System quality	Financial and investments—transactions Human resources—personnel requisitions Information services—system downtime Administrative—work order status

2. Defining quality control subjects for work processes starts with defining work processes in terms of objectives, process steps, process customers, and customer needs.
3. Quality control subjects should recognize both components of the definition of quality, i.e., freedom from deficiencies and product features. The number of errors per thousand lines of computer code (KLOC) is important, but even perfect code does not mean that a customer will be satisfied with the software.
4. Potential quality control subjects can be identified by obtaining ideas from both customers and employees. Customers can be asked, "How do you evaluate the product or service that you receive from me?" A focus group of customers can provide valuable responses. Again, we are addressing both external and internal customers. All employees are sources of ideas, but employees who have direct contact with external customers can be a fertile source of imaginative ideas on quality control subjects.
5. Quality control subjects must be viewed by those who will be measured as valid, appropriate, and easy to understand when translated into numbers. These are nice notions, surely. But in the real world they can be pretty elusive.

Next we must establish the measurement process for these control subjects.

5.5 ESTABLISH MEASUREMENT

To quantify, we must create a system of measurement consisting of

- *A unit of measure:* the unit used to report the value of a control subject, e.g., pounds, seconds, dollars
- *A sensor:* a method or instrument that can carry out the evaluation and state the findings in terms of the unit of measure.

Units of measure for product and process performance are usually expressed in technological terms, for example, fuel efficiency is measured in terms of distance traveled per volume of fuel; timeliness of service is expressed in minutes (hours, days, etc.) required to provide service.

Units of measure for product deficiencies usually take the form of a fraction:

$$\frac{\text{Number of occurrences}}{\text{Opportunity for occurrence}}$$

The numerator may be in such terms as defects per million, number of field failures, or cost of warranty charges. The denominator may be in such terms as number of units produced, dollar volume of sales, number of units in service, or length of time in service.

Units of measure for product features are more difficult to create. The number and variety of these features may be large. Sometimes inventing a new unit of measure is a fascinating technical challenge. In one example, a manufacturer of a newly developed polystyrene product had to invent a unit of measure and a sensor to evaluate an important product feature. It was then possible to measure that feature of both the product and of competitors' products before releasing the product for manufacture. In another case, the process of harvesting peas in the field required a unit of measure for tenderness and the invention of a "tenderometer" gauge. A numerical scale was created, and measurements were taken in the field to determine when the peas were ready for harvesting.

Table 5.3 shows examples of units of measure for a manufacturing organization and for a service organization. It should be noted that for many service industries, the *time* taken to deliver a service to an external customer is the decisive control subject for measurement.

Often a number of important product features exist. To develop an overall unit of measure, we can identify the important product features and then define the relative importance of each feature. In subsequent measurement, each feature receives a score. The overall measure is calculated as the weighted average of the scores for all features. This approach is illustrated in Table 2.4. In using such an approach for periodic or continuous measurement, some cautions should be cited (Early, 1989). First, the relative importance of each feature is not precise and may change greatly over time. Second, improvement in certain features can result in an improved overall measure but can hide deterioration in one feature that has great importance.

Measurement scales are part of a system of measurement. The most useful scale is the *ratio scale* in which we record the actual amounts of a parameter such as weight. An *interval scale* records ordered numbers but lacks an arithmetic origin such as zero—clock time is an example. An *ordinal scale* records information in ranked categories—an example is customer preference for the flavor of various soft drinks. An unusual example of a measurement scale is the Wong-Baker FACES pain rating scale used widely in hospitals for children to communicate the intensity of pain felt to nurses (Wong and Baker, 1998). The scale shows six faces to which a child can point, ranging from a very happy face (to indicate no hurt) to a very sad face (hurts most). Finally, the *nominal scale* classifies objects into categories without an ordering or origin point—an example is the count of population in each state. The type of measurement scale determines the statistical analysis that can be applied to the data. In this regard, the ratio scale is the most powerful scale. For elaboration, see Emory and Cooper (1991).

TABLE 5.3
Units of measure—examples

Electronics manufacturer	A bank
Document quality Defects per thousand formatted output pages	Operations Number of statements mailed late / Total number of statements processed
Software quality Defects corrected per thousand noncomment source statements	Retail banking Number of teller entry errors / Total number of teller entries
Hardware quality Field removal rate	Commercial banking Loan payments posted incorrectly / Total loan payments
Process quality Functional yields	Credit card and ATM cards Number of mispostings / Total number of transactions
System quality Total outages	Financial/investments Number of trading corrections / Number of trades made
	Human resources Requisitions not filled in 30 days / Total number of requisitions
	Information services Customer information system (CIS) downtime / Total CIS time
	Administrative Number of work orders not completed within 10 days / Number of work orders completed

The Sensor

The sensor is the means used to make the actual measurement. Most sensors are designed to provide information in terms of units of measure. For operational control subjects, the sensors are usually technological instruments or human beings employed as instruments (e.g., inspectors, auditors); for managerial subjects, the sensors are data systems. Choosing the sensor includes defining how the measurements will be made—how, when, and who will make the measurements—and the criteria for taking action. This information can be conveniently summarized in a control spreadsheet (see Figure 5.4a and b).

There has been a continuing trend toward providing sensors with additional functions of the feedback loop: data recording, data analysis, comparison of performance with standards, and initiating corrective action. A useful tool for operationalizing self-control and the feedback loop is the control plan, also called a process control plan. It can be used both as a blueprint to plan for control and as a work procedure to implement self-control and the feedback loop. An example of a control plan for the timely distribution and order entry of faxed expedite orders at a customer care center (CCC) is shown in Figure 5.4a.

Expedite Order Entry Control Plan

Process Name: Processing of Expedite Orders | **Date: 4/14/2003** | **Revision Level:** | **Approved By:**

Control subject	**Subject goals**	**Unit of measure**	**Sensor**	**Frequency of measurement**	**Sample size**	**Recording of measurement/ tool used**	**Measured by whom**	**Criteria for action (when to take)**	**What actions to take**	**Who decides**	**Who acts**	**Record of actions taken**	**Comments**
Processing and entry of expedite orders	90% on-time entry of expedite orders	% expedite orders not entered before 12:30p.m.	Sorter	Calculate daily	All expedite orders	P-Chart	Sorter/ supervisor	Performance level drops below 90%	Investigate and determine cause. Adjust process as necessary	Management	Supervisor	Process SOPs, Standard work	
Adequate fax machine paper level to print faxes	No late orders due to fax machine out of paper	N/A	Sorter	Four times per day	Population (two fax machines)	N/A	Sorter	Add paper at 8:00a.m. 11:00a.m. 12:00p.m. 3:00p.m.	Re-fill paper at every check.	Sorter	Sorter	N/A	See Sorter SOP
Adequate fax machine toner level to print faxes	No late orders due to fax machine out of toner	N/A	Sorter	Four times per day	Population (two fax machines)	N/A	Sorter	Low toner indicator illuminated	Replace toner cartridge	Sorter	Sorter	N/A	See Sorter SOP

Distribution of faxed expedite orders to CCC's	Sort and distribute all submitted expedites every 30 min before 10:30a.m. Every 15 min. 10:30 to 12:00	Elapsed time	Clock watch	One delivery per 30 min. One delivery per 15 min.	All faxed orders on two fax machines	Sorter stamps date/time of distribution on orders	CCCs	CCC does not receive any orders for more than 30 min. Undistributed orders remain at 12:00p.m.	Investigate status of sorter. Refer to sorting of expedites SOP	CCC or supervisor	CCC/ supervisor	N/A	See sorter SOP
Usage of message board when CCC is not available	Return time of CCC indicated on message board for every absence >15 min.	Message board used per absence	Sorter	Check every fax distribution cycle	All fax distribution cycles	N/A	Sorter	Message board is blank and CCC is not available	Hand off order to another CCC. Refer CCC to nessage board SOP	Sorter/ supervisor	Supervisor	N/A	See message board SOP
Elapsed time to enter order	CCC/keyer enters within 30 minutes of receipt (delivery by sorter)	Elapsed time	Stamped time and JDE entry time	Whenever performance level drops below 90% on a given day	30 expedite orders	Data collection form	Supervisor	When the median time for entering orders is greater than 60 minutes	Investigate and determine cause. Adjust process as necessary	Supervisor	Supervisor	N/A	Expedites process SOP

FIGURE 5.4a

Control plan for distribution and order entry of faxed expedite orders.
(*Courtesy of Merillat Industries, Inc.*)

Process control features / Control subject	Unit of measure	Type of sensor	Goal	Frequency of measurement	Sample size	Criteria for decision making	Responsibility for decision making	. . .
Wave solder conditions Solder temperature	Degree F (F)	Thermo-couple	505 F	Continuous	N/A	510ºF reduce heat 500ºF increase heat	Operator	. . .
Conveyor speed	Feet per minute (ft/min)	Timer	4.5 ft/min	1/hour	N/A	5 ft/min reduce speed; 4 ft/min increase speed	Operator	. . .
Alloy purity	% total contaminates	Lab chemical analysis	1.5% max	1/month	15 grams	At 1.5%, drain bath, replace solder	Process engineer	. . .
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	

FIGURE 5.4b
Spreadsheet for who does what.
(*Making Quality Happen, Juran Institute, Inc., senior executive workshop, p. F-8, Wilton, CT.*)

Despite the large number of control subjects, relatively few human beings are needed to carry out the control process. Imagine a pyramid of control subjects: A few vital controls are carried out by supervisors and managers; another segment is carried out by the workforce; the remaining majority of control subjects is handled by non-human means (stable processes, automated processes, servomechanisms).

Clearly, sensors must be economical and easy to use. In addition, because sensors provide data that can lead to critical decisions on products and processes, sensors must be both accurate and precise. The meaning, measurement, and impact of accuracy and precision are discussed in Chapter 15.

5.6 ESTABLISH STANDARDS OF PERFORMANCE

Each control subject must have a quality goal. Table 5.4 shows examples of control subjects and associated goals for a variety of control subjects ranging from those for products, processes, and departments to that of an entire organization.

This chapter concentrates on goals at operational levels; Section 8.5, "Development of Goals," discusses overall company quality goals.

To set operational goals, certain criteria must be met. The goals should be

- *Legitimate:* have official status.
- *Customer focused:* external and internal.
- *Measurable:* numbers.
- *Understandable:* clear to all.
- *In alignment:* integrated with higher levels.
- *Equitable:* fair for all individuals.

Goals for product features and process features are based on technological analysis. To encourage continuous improvement, goals should be based on high levels achieved by others (see Chapter 8 under "Benchmarking"). The deployment and alignment of company quality goals to operational goals is discussed in Chapter 8 under "Deployment of Goals."

TABLE 5.4
Control subjects and goals

Control subject	Goals
Mean time between failures	Minimum of 5000 hours
Solder temperature of soldering process	500° F
Overnight delivery	99.5% delivered prior to 10:30 a.m. next morning
Relative quality ranking	At least equal in quality to competitors A and B
Customer retention	95% of key customers from year to year

5.7
MEASURE ACTUAL PERFORMANCE

In organizing for control, a useful technique is to establish a limited number of control stations for measurement. Each such control station is then given the responsibility for carrying out the steps of the feedback loop for a selected list of control subjects. A review of numerous control stations discloses that they are usually located at one of several principal junctures:

- At changes of jurisdiction, e.g., where products are moved between companies or between major departments.
- Before embarking on an irreversible path, e.g., setup approval before production.
- After creation of a critical quality.
- At dominant process variables, e.g., the vital few.
- At natural windows, for economical control.

The choice of control stations is aided by preparation of a flow diagram that shows the progression of events through which the product is produced.

It is essential to measure both the quality of the output going to the external customer ("final yield") and the quality at earlier points in the process, including the "first-time yield."

In Figure 5.5, 100 units of input enter a process. After operations A, B, and C, an inspection is conducted; 87 acceptable units continue on to operation D, 8 units are reprocessed at previous operations, and 5 units are discarded. The first-time yield is thus 87%. After operations D and E, a second inspection is conducted; 82 acceptable units (of the 87) are available for delivery, 2 units are reprocessed, and 3 units are discarded. Assuming that all reprocessed units are acceptable, the final yield is 92 (82 + 8 + 2), or 92% of the original input. Note how the measurement of yield at several places highlights several opportunities for improvement. This concept applies to

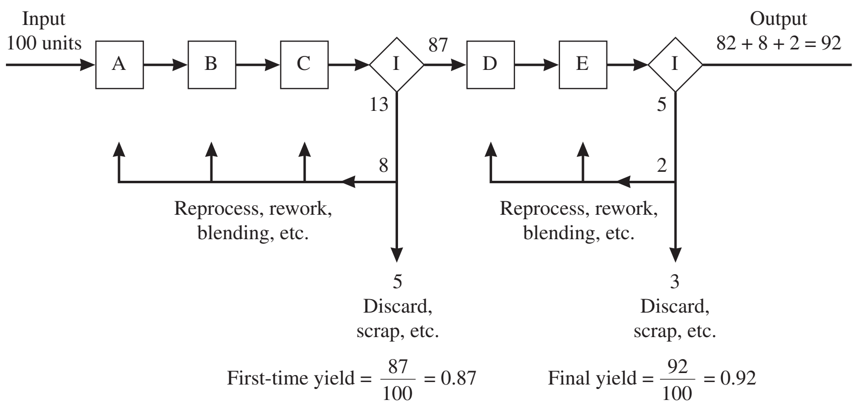

FIGURE 5.5
First-time yield and final yield (A, B, C, D, E = operations or tasks; I = inspections, checks, reviews).

both manufacturing and nonmanufacturing processes. Don't let different terminology (e.g., inspection versus checking) obscure the concept. For example, in a software development organization, the average number of software errors was about two errors per thousand lines of code, just before delivery to the customer. The average level of errors, however, when measured earlier in the development process, was 50 errors per thousand lines of code. Huge resources were needed to screen out these errors. Ironically, the head of the organization was unaware of this first-time yield until it was revealed by a consultant.

For each control station, it is necessary to define the work to be done: which control subjects are to be measured; goals and standards to be met; procedures, instruments to be used; data to be recorded; and decisions to be made, including the criteria and responsibility for making each decision.

See the example of a control spreadsheet in Section 5.5, "Establish Measurement." Keep in mind that control subjects include measurements on both product parameters and process variables. With all of this information, the feedback loop can function well.

The "flag diagram" (Figure 5.6) is an innovative illustration of how measurement can be combined with control subjects for tracking improvement. This diagram uses measurement data in combination with the Pareto concept and the cause-and-effect diagram (both discussed in Chapter 3).

The overall control subject (reduction of machining time) is divided into five major subjects, e.g., improving machining procedure. Each major subject is then further divided into secondary subjects, e.g., improving operation. Goals for each subject are shown as dotted lines on the charts and then performance is plotted on the same charts. The diagrams become a basis for review by the responsible manager and for action if there is a significant deviation from a goal.

5.8
COMPARE TO STANDARDS

This phase of the control process consists of comparing the measurement to the goal and deciding if any difference is significant enough to justify action. The criteria for taking action (or not taking action) should be numerically defined before measurements are taken, and training should be provided to ensure that the criteria are properly applied. Often the criteria can be simply stated: If a solder temperature exceeds 510°F, decrease the heat; if the temperature is between 500°F and 510°F, then take no action on temperature. Other cases present a need to distinguish between real and apparent differences in measurements on a product or process. This task can be done by using the concept of statistical significance.

Statistical Significance

An observed difference between performance and a goal can be the result of (1) a real difference due to some cause or (2) an apparent difference arising from random variation. Further, differences between a measurement and a goal should not be viewed

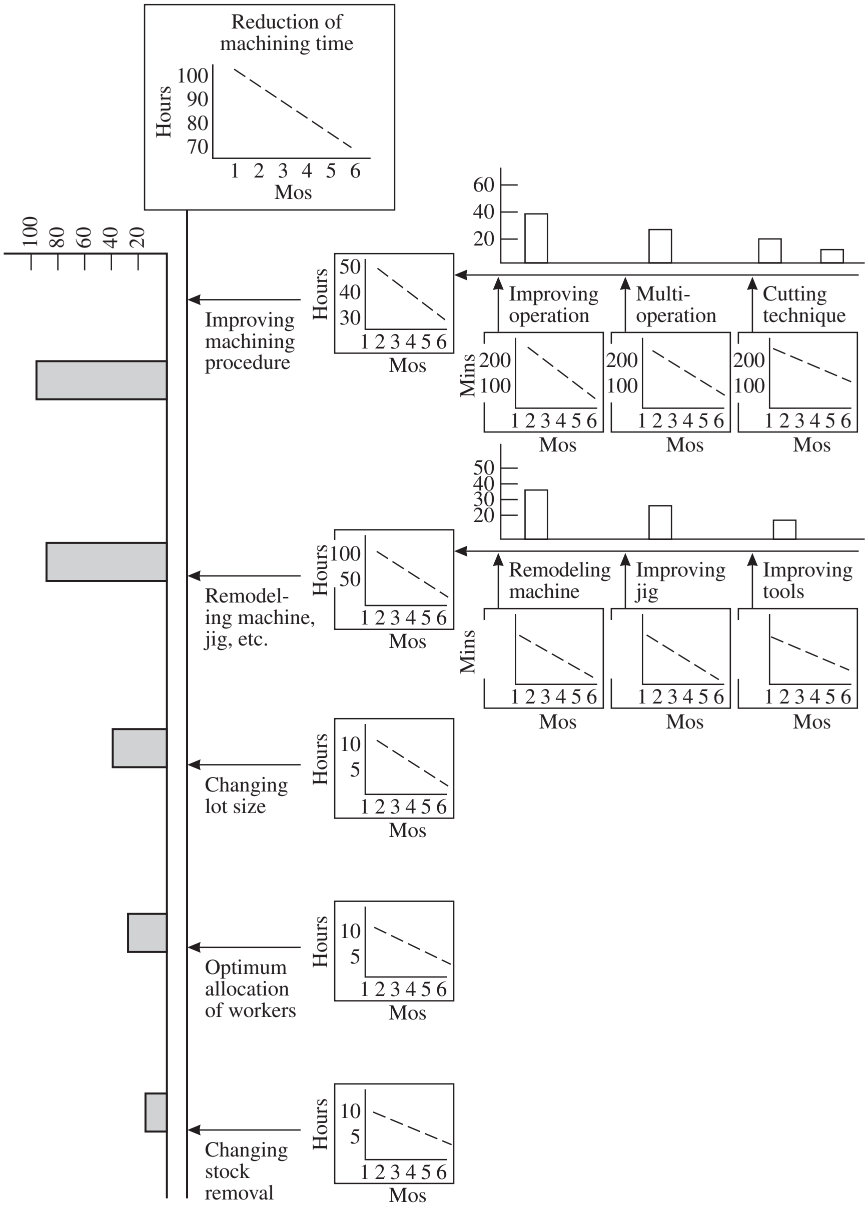

FIGURE 5.6
Example of a "flag diagram." (*Adapted from Kondo and Kano, 1999, p. 41.17.*)

individually. Knowing the pattern of differences over time is essential to drawing correct conclusions. In Figure 5.7, the measurements at A and B and the trend at C represent real ("statistically significant") differences from the goal; the other measurements are due to random variation. Figure 5.7 is a statistical control chart—one of the elegant statistical tools used to evaluate statistical significance.

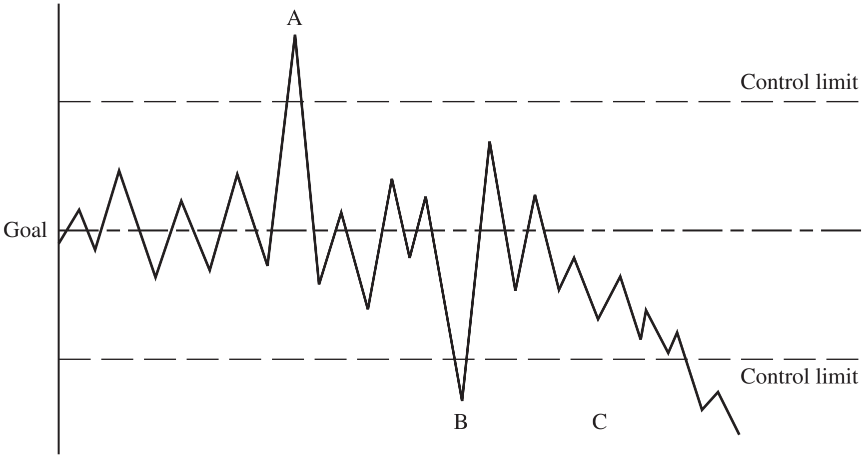

FIGURE 5.7
Control chart.

A control chart is a graphic comparison of process performance data to computed "control limits" drawn as limit lines on the chart. The process performance data usually consist of groups of measurements ("rational subgroups") selected in regular sequence of production.

A prime use of the control chart is to detect assignable causes of variation in the process. The term *assignable causes* has a special meaning, and understanding this meaning is a prerequisite to understanding the control chart concept (see Table 5.5).

Process variations are traceable to two kinds of causes: (1) random, i.e., due solely to chance; and (2) assignable, i.e., due to specific "special" causes. Ideally, only random (also called "common") causes should be present in a process. A process that is operating without assignable causes of variation is said to be "in a state of statistical control," which is usually abbreviated to "in control."

The control chart distinguishes between random and assignable causes of variation through its choice of control limits. These are calculated from the laws of probability so that highly improbable random variations are presumed to be due not to random causes, but to assignable causes. When the actual variation exceeds the control limits, it is a signal that assignable causes entered the process and the process should be investigated. Variation within the control limits means that only random causes are present.

The important advantages of statistical control and the methodology of constructing and interpreting control charts are given in Chapter 20, "Statistical Process Control."

The control chart not only evaluates statistical significance but also provides an early warning of problems that could have major economic significance.

Random causes are usually chronic, associated with many minor variables, and thus difficult to diagnose and fix; assignable causes are typically sporadic and often originate in single variables, making diagnosis easier. A problem that exists when only random causes are present requires a basic analysis using quality improvement concepts

TABLE 5.5
Distinction between random and assignable causes of variation

Random (common) causes	Assignable (special) causes
Description	
Consists of many individual causes.	Consists of one or just a few individual causes.
Any one random cause results in a minute amount of variation (but many random causes act together to yield a substantial total).	Any one assignable cause can result in a large amount of variation.
Examples are human variation in setting control dials; slight vibration in machines; slight variation in raw material.	Examples are operator blunder, a faulty setup, or a batch of defective raw material.
Interpretation	
Random variation cannot be eliminated from a process economically.	Assignable variation can be detected; action to eliminate the causes is usually economically justified.
An observation within the control limits of random variation means that the process should not be adjusted.	An observation beyond control limits means that the process should be investigated and corrected.
With only random variation, the process is sufficiently stable to use sampling procedures to predict the quality of total production or do process optimization studies.	With assignable variation present, the process is not sufficiently stable to use sampling procedures for prediction.

(see Chapter 3, "Quality Improvement and Cost Reduction") or quality planning concepts (see Chapter 4, "Operational Quality Planning and Sales Income"). For example, a process may be in statistical control but does not have the inherent process capability (i.e., small variation) to meet a customer specification. A study is needed to improve the process capability. If a problem exists when assignable causes are present, then the quality control concepts in this section are appropriate. For example, a sudden increase in errors in processing insurance claims may be traced to one untrained person. We elaborate on these ideas in Chapter 20 under "Advantages of Decreasing Process Variability" and in Chapter 15 under "Conformance to Specification" and "Fitness for Use."

Economic Significance

Tools such as the statistical control chart serve several purposes—e.g., they document process performance and identify special situations such as assignable causes or trends. This type of tool provides an early warning of impending problems in the product. But identifying a statistically significant difference between a measurement and a goal does not always lead to corrective action. The presence of assignable causes does mean that the process is unstable, but sometimes assignable causes are so numerous that it is necessary to establish priorities for action based on economic significance and related parameters. When product problems are serious and/or frequent, then setting up a formal quality improvement project or taking other action is warranted.

5.9
TAKE ACTION ON THE DIFFERENCE

In the closing step of the feedback loop, action is taken to restore the process to a state of meeting the goal. Action may be needed for three types of conditions:

1. *Elimination of chronic sources of deficiency.* The feedback loop is not suitable for dealing with such chronic problems. Instead, the quality improvement process described in Chapter 3 or the operational quality planning process described in Chapter 4 should be employed.
2. *Elimination of sporadic sources of deficiency.* The feedback loop is well designed for this purpose. In these cases, the cardinal issue is determining which changes caused the sporadic difference. Discovery of those changes, plus action to restore control, can usually be carried out by local operating supervisors using troubleshooting procedures (see below).
3. *Continuous process regulation to minimize variation.* This situation requires linking each product characteristic to one or more process variables, providing a means for convenient adjustment of the setting for the process variables, and determining the relationship between the change in the setting of a process variable and the resulting effect on the product characteristic. These matters are discussed in Section 13.2 under "Correlation of Process Variables with Product Results" and in Chapter 20, "Statistical Process Control."

Section 13.10 provides guidance to operations on when to take action in the form of troubleshooting (quality control), quality improvement, or operational quality planning.

Troubleshooting

Troubleshooting (also called "firefighting") is the process of dealing with sporadic problems and restoring quality to the original level. For organizations that do not have a formal effort to reduce chronic and sporadic problems, operations managers often spend 30% of their time on troubleshooting; for the supervisors reporting to these managers, the time consumed frequently exceeds 60%. In a moment of jest, an executive once said: "Managers who are good at putting out fires can become heroes. I think some of our managers may be arsonists."

Troubleshooting is diagnostic and remedial action applied to sporadic problems and involves three steps:

1. *Identify the problem.* Identification means pinpointing the problem in terms of a single process indicator, the time of occurrence, and its effect. For example, the billing process at a hospital requires an average of 5.2 working days from patient discharge to mailing a final bill. For one week, the average time was 6.7 days, exceeding an upper control limit of 5.9 days on a control chart (Juran Institute, 1995).
2. *Diagnose the problem.* Diagnosis means investigating, developing, and testing theories for the cause of the problem. Analysis of the bills for the particular week

revealed one specific set of bills that was delayed. The bills for that week were then classified by hospital department, payer, clerk preparing the bill, and discharging nursing unit. A Pareto diagram plotted percentage of all bills over seven days versus payer organization. This diagram showed that two-thirds of the delayed bills were for services to be paid for by a particular managed care plan. Further investigation revealed that the plan had just made significant revisions in procedures for submitting bills. These changes resulted in difficulty in the billing department and turned out to be the primary cause of the delayed bills for that week.

3. *Take remedial action.* Remediation requires taking steps to remove the cause identified in step 2. In this case, immediate action was taken to modify the new procedures, change certain software, and identify a single point of contact with the insurance plan until the problem was resolved.

Note that the diagnostic and remedial journeys for troubleshooting are similar to those for quality improvement (see Chapter 3, "Quality Improvement and Cost Reduction"). The approach to troubleshooting is usually less complex because the problem is localized to a specific sporadic time; in contrast, chronic problems are present for a sustained period of time.

Troubleshooting can be made more effective by anticipating problems and planning in advance for troubleshooting. A contingency planning matrix (see Figure 5.8) can be useful in this regard. Note how the planning tries to prevent problems and provide for action, when necessary, in a billing process. In manufacturing operations, each product characteristic (quality control subject) must be linked to one or more process variables so that employees have a contingency plan to adjust the process when necessary. For elaboration, see Chapter 14 under "Review of Process Design."

Example: billing department				
Process indicator: average days to bill				
Condition: weekly average exceeds 5.9 days				
Who	What	Where	When	How
Supervisor	If weekly bill volume is more than 800, add hours to part-time billing clerks	Weekly volume report	By 8:30 a.m. Monday	Inform both clerks and personnel
	Otherwise, convene troubleshooting team	Supervisor's office	By 11:00 am. Monday	By telephone
Troubleshooting team—supervisor, system-support technician, discharge planner	Troubleshoot the problem	—	Begin by 11:00 a.m. Monday	Standard methods

FIGURE 5.8
Contingency planning matrix.

5.10 A PROCESS CONTROL SYSTEM THAT USES THE SIX SIGMA CONCEPT

The GE Capital Mortgage Insurance Corporation provides us with an example of a process control system in the service industry. The company offers mortgage insurance to major lenders of mortgage funds for individual home buyers. Four key processes are involved: underwriting, billing, claims, and sales. The process control system employs both customer information and internal measurements. The elements of the process control system are illustrated in the six-step feedback loop discussed in this chapter.

1. *Choose the control subjects.* Figure 5.9 calls these subjects "measurement categories," e.g., a measurement category (control subject) for the underwriting process is turnaround time. A flow diagram documents the process and helps to identify process measures and outcome indications (process and product features).
2. *Establish measurement.* Nine units of measure (metrics) are employed, e.g., average turnaround time for underwriting.

Quality score card 1st quarter 1997

Measurement category	Customer specifications	Actual performed	Actual σ	Evaluation Excellent ⟷ Poor
Underwriting				
Turnaround time	4 hours	99.9%	4.6 σ	(5) 4 3 2 1
Accessibility	100%	99.5%	4.2 σ	5 (4) 3 2 1
Knowledgeable	Consistent application of guidelines	95.5%	3.2 σ	5 (4) 3 2 1
Billing				
Timeliness	3rd – 5th of month	99.9%	4.6 σ	(5) 4 3 2 1
Completeness	100%	98.9%	3.8 σ	5 (4) 3 2 1
Claims				
Timely payments	30 days	84%	2.5 σ	5 (4) 3 2 1
Work out cycle time	To guidelines 100%	95%	3.1 σ	5 (4) 3 2 1
Sales				
Meeting frequency	Monthly/ quarterly	100%	6+ σ	(5) 4 3 2 1
Knowledge	Answer questions when asked	86%	2.6 σ	5 (4) 3 2 1

FIGURE 5.9
Quality scorecard. (*Reprinted with permission by the ASQ.*)

3. *Establish standards of performance.* For each metric, customers provide input to establish a numerical specification, e.g., turnaround time for underwriting is four hours.
4. *Measure actual performance.* Data collection includes the percentage of transactions meeting the specification, the actual sigma, and a customer evaluation (on a scale of 5 to 1 with 5 meaning excellent). For turnaround time on underwriting, actual performance is 99.9%, which is at the 4.6 sigma level, with a customer evaluation rating of 5. At the 4.6 sigma level, the average opportunity for defects is about 970 defects per million opportunities; at the 6.0 sigma level, the average opportunity is only 3.4 defects.
5. *Compare to standards.* Control charts monitor the processes and provide the linkage between top-level measurements and lower level process indicators. These charts along with the process flow diagram are displayed in the business area. A scorecard with data trends is presented to the customer (the major lenders).
6. *Take action on the difference.* Data are constantly reviewed to achieve process improvements aimed at a 6.0 sigma level by the year 2000. Periodic meetings with customers are held to review numerical performance and identify any changing customer needs.

For elaboration of this system, see Pautz (1998).

The elements of the feedback loop discussed in this chapter are universal. The concepts apply not only to manufacturing and service industries but also to executive and operational activities within all industries.

SUMMARY

- Control is the process we employ to meet standards.
- Control involves a universal sequence of steps: choosing the control subject, choosing a unit of measure, setting a goal, creating a sensor, measuring performance, interpreting the difference between actual performance and the goal, and taking action on the difference. Measurement is a quiet source of action.
- Self-control involves three elements: People must have knowledge of what they are supposed to do, knowledge of their performance, and means of regulating their performance.
- Troubleshooting is diagnostic and remedial action applied to sporadic troubles.

PROBLEMS

5.1. Select a specific task that you have regularly performed for an organization. Evaluate the degree to which this task meets the three criteria for self-control.

5.2. Interview someone who regularly performs a specific task for an organization. Explain the three criteria of self-control to that person and document the degree to which this task meets the criteria, as viewed by the person performing the task.

5.3. Place yourself in the role of a customer for any product—a good or a service. Identify at least four quality control subjects that are important to you as a customer and that the supplier should measure. For each quality control subject, propose a unit of measure.

5.4. Place yourself in the role of upper management for any organization producing goods or service. Identify at least four quality control subjects that are important to internal organizational performance and that the organization should measure. For each quality control subject, propose a unit of measure.

5.5. Select one process consisting of a series of tasks within an organization. Identify the location and the data that are collected on quality-related control subjects throughout the process.

5.6. Interview someone who regularly performs a manufacturing task that includes taking periodic measurements on a product or process characteristic and comparing the result to a specification. Determine how the person makes the following decisions:
(a) How large a deviation of a measurement from a specification is permitted before the person takes action to adjust the process?
(b) If a process adjustment is needed, what *amount* of adjustment is made?

5.7. You are designing process controls for the replacement of lost or stolen credit cards. Customers are concerned about responsibility for charges and quick replacement of cards. Identify two potential control subjects that will help manage the process while meeting customer needs. Then define a unit of measure and a sensor for each control subject.

5.8. A major hotel chain is the site for many business conferences. A key customer need is for comfortable meeting rooms that have adequate lighting, temperature control, and visual aid equipment. Identify two control subjects and a unit of measure and sensor for each subject.

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