SECTION 22
OPERATIONS

Frank M. Gryna

INTRODUCTION

The word *operations* as used in this handbook encompasses two areas: manufacture in the manufacturing sector and backroom activities in the service sector. In manufacturing industries, operations are those activities, typically carried out in a factory, which transform material into the final product. In service industries, operations are those activities which process customer transactions but which do not involve direct contact with external customers (e.g., backroom activities such as customer order preparation and payment processing). These two industry sectors have their own special needs. The discussion in this section covers both the planning and the execution of operations activities.

Activities that involve direct contact with external customers are clearly of high priority. In this handbook, such activities are discussed in Section 25, Customer Service, and in the group of industry sections, Sections 27 to 34.

I will use *product* to denote goods or services.

QUALITY IN THE OPERATIONS FUNCTION OF THE FUTURE

For many industries—manufacturing and service—emerging factors demand different approaches to quality in the twenty-first century. This galaxy of factors includes

1. *Demand for lower levels of defects and errors:* As products and processes have become more complex, new "world-class quality" levels are increasingly common. For many products, levels of 1 to 3 percent are being replaced by 1 to 10 parts per million. Also, many processes must meet "good manufacturing practices" and other forms of regulation.
2. *Emphasis on reduced inventory levels:* Under the "just-in-time" (JIT) production system, the concept of large lot sizes is challenged by reducing setup time, redesigning processes, and stan-

dardizing jobs. The results can be smaller lot sizes and substantial reductions in inventory. Such a system relies on a process that is capable of meeting quality requirements because little or no inventory exists to replace defective product. Thus JIT is not viable unless product quality is acceptable. Schonberger (1996) explains JIT and the impact on product quality.

3. *Time-based competition:* Performance is now measured not only by costs and quality but also by responsiveness to customer needs. This responsiveness means offering more products (i.e., product features) at lower cost and in less time. The time parameter puts pressure on the product development process, which can result in inadequate review of new designs. Increasingly, however, managers realize that quality problems can be on a critical path that will slow down the delivery process. Stalk and Hout (1990) examine a variety of issues, not only issues of quality, on the impact of time-based competition.
4. *Impact of technology:* Technology (including computer information systems) is clearly improving the quality of goods and services by providing (a) a wider variety of outputs and (b) more consistent output. One of the effects has been to reduce the emphasis on direct labor efficiency in operations. The infusion of technology makes some jobs more complex, thereby requiring extensive job skills and quality planning; technology also makes other jobs less complex but may contribute to job monotony.
5. *Agile competition:* This term refers to competition based on a group of correlated concepts that includes responding to constantly changing customer opportunities, being able to change over from one product to another quickly, manufacturing goods and producing services to customer order in arbitrary lot sizes, customizing goods and services for individual customers, and drawing on the expertise of people and facilities within a company or among groups of cooperating companies. Clearly, the impact on both product features and defect levels will be far reaching. Goldman, Nagel, and Preiss (1995) describe the concept and include examples. To cite one example from the apparel industry, a blouse and skirt were designed, cut to customer size order, printed, sewn, and distributed—at a trade show.
6. *Outsourcing:* Many organizations have reduced their total personnel by transferring complete functions to a supplier (outsourcing). In one survey, 86 percent of firms used outsourcing in 1995 versus 58 percent in 1992 (*Business Week*, April 1, 1996). In a financial services firm of about 8000 people, 74 percent are "contract" personnel, most of whom come from one supplier. Extensive steps are taken to ensure the quality of the services. Examples of activities for outsourcing include manufacturing operations, billing, service, and human resource tasks. Clearly, steps must be taken to ensure the quality of these tasks. Bettis, Bradley, and Hamel (1992) examine the implications of outsourcing on competitiveness and offer cautions and suggestions. The impact of contract workers and outsourcing on quality has been selected as a research project by the National Science Foundation.

These "lean manufacturing" factors, which are not independent, suggest that quality during operations can no longer focus on inspection and checking. We must recognize these factors as we pursue universal—and intoxicating—principles such as customer focus, continuous improvement, and employee empowerment in the operations function.

Schonberger (1996) explores the future of world-class manufacturing; Godfrey (1995) identifies critical issues in service quality.

PLANNING FOR QUALITY DURING OPERATIONS

Increasingly, planning for quality *before* the execution of operations is seen as essential. International standards such as the ISO 9000 and ISO 14000 series provide a minimum framework for planning (for elaboration, see Section 11, The ISO 9000 Family of International Standards). These standards cover important matters such as process control, inspection and testing, material control, product traceability, control of measuring equipment, control of nonconforming product, quality documentation, process environmental conditions, and the impact of processes on the external environment.

Responsibility for Planning. The responsibility for this planning varies by industry. In the mechanical and electronics industries, the work is usually performed within the manufacturing function by a specialist department (e.g., manufacturing engineering, process engineering). For process industries, the work is usually divided into two parts. Broad planning (e.g., type of manufacturing process) is performed within the research and development function; detailed planning is executed within the manufacturing function. Similarly, the service industries show variety in assigning the planning responsibility. For example, in backoffice operations of the financial services industry the local operations manager handles the planning, whereas in the fast-foods industry planning for food preparation is usually handled by a corporate planning function.

The main factors influencing the decision on responsibility are the complexities of the products being made, the anatomy of the manufacturing process, the technological literacy of the work force, and the managerial philosophy of reliance on systems versus reliance on people.

Some industrialized countries delegate only a small amount of manufacturing planning to departmental supervision or to the work force. In the United States, this situation is largely a residue of the Taylor system of separating manufacturing planning from execution. This system gave rise to separate departments for manufacturing planning.

The Taylor system was proposed early in the twentieth century, at a time when the educational level of the work force was low, while at the same time products and manufacturing technology were becoming more complex. The system was so successful in improving productivity that it was widely adopted in the United States. It took firm root and remains as the dominant approach to manufacturing planning not only interdepartmentally but within departments as well.

Times have changed. A major premise of the Taylor system, i.e., technological illiteracy of the work force, is obsolete because of the dramatic increase in the educational levels of the work force. Many companies recognize that extensive job knowledge resides in the work force and are taking steps to use that knowledge. Manufacturing planning should be a collaborative effort in which the work force has the opportunity to contribute to the planning. In the United States, this collaboration is slow-moving because of the widespread adoption of the Taylor system and the vested interests that have been created by that approach.

Some companies are taking dramatic organizational steps to integrate quality matters into manufacturing planning. In one case, a separate quality department was eliminated, and the personnel and their activities were merged within the research and engineering department (Kearney 1984). A formal "manufacturing plan of control" was established for each operation by analyzing the material and process variables that affected key product properties. This document was prepared by a team of people from research and engineering (including quality professionals) and various areas of manufacturing. Each product grouping made use of such a team.

INITIAL PLANNING FOR QUALITY

Planning starts with evaluating emerging technologies for operations, a review of product designs, determining the importance of product characteristics, documenting processes with process diagrams, and correlating process variables with product results.

Emerging Technologies. Sometimes an organization is faced with evaluating emerging operations technologies that it must develop concurrently with overall business planning. When this is the case, a number of issues arise. These include compatibility of the technology with existing operations, difficulties in launching new products, flexibility to accommodate volume and model mix changes, personnel requirements, and of course, the investment required. A four-step approach (Figure 22.1) is presented by Scharlacken (1992). This approach starts with a multidisciplinary team representing all the groups that will be affected by the new technology. The team develops a 3- to 5-year *technology profile* that reflects management's strategy to grow, maintain, or harvest the key product lines. In evaluating alternative technologies (task 2), note subtask 3. This subtask calls for modeling a proposed process on a computer using simulation software. The simulation reveals information about process characteristics such as output, reliability, bottlenecks, and downtime—before

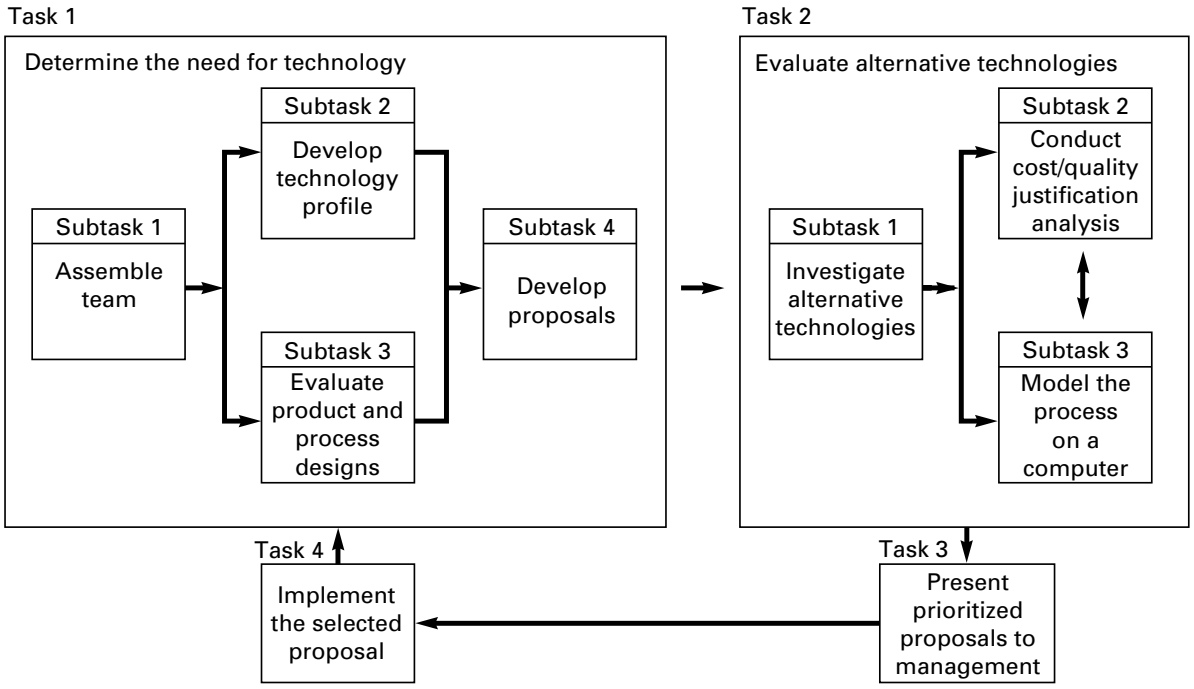

FIGURE 22.1 The approach to MTP. (*Adapted from Scharlacken 1992.*)

resources are committed to the process. This four-step approach, developed for manufacturing technology planning, also applies to the service sector.

Review of Product Designs Prior to Operations. In both the manufacturing and service sectors, there is a clear advantage to having a new product design reviewed for feasibility by operations personnel before the design is finalized for the marketplace. In practice, the extent of such a review varies greatly—from essentially nothing ("tossing it over the wall" to the operations people) to a structured review (using formal criteria and follow-up on open issues). For physical goods, the design requirements are summarized in a product specification that is examined by a *design review* process (see also Section 19, under Designing for Reliability). The emphasis is on the evaluation of the product design for the adequacy of field performance. For backoffice operations in the service sector, requirements for a new service product may be described in a *service-level agreement.* This agreement summarizes the type and amount of service to be provided in the backoffice to satisfy the needs of the customer. Hart (1995) describes the concept of *internal guarantees,* e.g., a promise by one part of an organization to deliver a good or service to the complete satisfaction of an internal customer at the risk of incurring a monetary or other type of penalty.

Design review must include an evaluation of producibility to cover the following operational matters:

1. *Clarity of all requirements.*
2. *Relative importance of various product characteristics.*
3. *Design for manufacturability:* This technique focuses on simplifying a design to make it more producible. The emphasis is on reducing the total number of parts, the number of different parts, and the total number of manufacturing operations. This type of analysis is not new—*value engineering* tools have been useful in achieving design simplification [see, for example, Cooper and Slagmulder (1997)]. What is new, however, is the computer software available for analyzing a design and identifying opportunities for simplifying assembly products. Such software dissects the assembly step by step, poses questions concerning parts and subassemblies, and provides a summary of the number of parts, the assembly time, and the theoretical minimum number of parts or subassemblies. Use of such software enables the designers to learn the principlesfor ease of manufacturing analogous to reliability, maintainability, and safety analyses. In

one example, the proposed design of a new electronic cash register was analyzed with design for manufacturabilty (DFM) software. As a result, the number of parts was reduced by 65 percent. A person using no screws or bolts can assemble the register in less than 2 minutes—blindfolded. This simplified terminal was put onto the marketplace in 24 months—a record. Such design simplification reduces other sources of quality problems during manufacture.

4. *Process robustness:* A process is *robust* if it is flexible, easy to operate, and error-proof and its performance will tolerate uncontrollable variations in factors internal and external to the process. Such an ideal can be approached by careful process planning. Snee (1993) provides examples of actions that can be taken to create robust processes. See also Section 47, under Taguchi Off-Line Quality Control, for a discussion of the Taguchi approach for achieving robust processes to minimize process variation
5. *Availability of processes to meet requirements:* In manufacturing industries, this means processes that have the capability to manufacture products with basic and special characteristics. Specification limits on these characteristics usually have important technical and economic aspects to evaluate. In service industries, backoffice processes are needed with the capability to produce accurate results often within a specified time.
6. *Identification of special needs,* e.g., handling, transportation, and storage during manufacture.
7. *Availability of measurement to evaluate requirements:* In manufacturing, this may involve basic and special quality information equipment. The service sector often requires measurement of time, e.g., waiting time for service and elapsed time to complete the service.
8. *Special skills required of operations personnel.*

Specific criteria should be developed for each of these matters. This review of the product design must be supplemented by a review of the *process* design, which is discussed later in this section. These reviews provide an early warning to anticipate difficulties during operations.

Relative Importance of Product Characteristics. Planners are better able to allocate available time and money where they will do the most good when they are well informed about the relative importance of the diverse characteristics of the product. Two useful techniques are the identification of critical items and the classification of characteristics of the product.

Identification of Critical Items. *Critical items* are those features of a product which require a high level of attention to ensure that all requirements are achieved. At one company, part of a procedure to identify "quality-sensitive parts" uses specific criteria such as part complexity and high-failure-rate parts. For each such part, special planning for quality is undertaken, e.g., supplier involvement before and during the contract, process capability studies, reliability verification, and other activities.

Classification of Characteristics. Under this system, the relative importance of individual features or properties of a product is determined and indicated on drawings and other documents. The classification can be simply "functional" or "nonfunctional" or can include several degrees of importance. An example of the latter is a system featuring four classes of seriousness: critical, major, minor, and incidental. The classification uses criteria based on the impact of the quality characteristic on safety, operating failure, performance, service, and manufacture. The input data are derived from study of the part and its application, field and test data, reliability design analysis, warranty experience, and past experience on similar designs. Shenoy (1994) explains how various customer needs relate to product control characteristics in terms of strong, medium, or weak relationships (see Table 22.1). Somerton and Mlinar (1996) explain how to obtain, organize, and prioritize customer-based data to determine key product and process characteristics. Many tools such as quality function deployment and failure mode, effects, and criticality analysis are employed in their process.

The classifications should be made by personnel with sufficient background in the functioning of the product. For most products, this must include technical personnel from the product development function. However, they frequently voice two objections to spending time on classifying characteristics:

TABLE 22.1 Relationship Matrix: Final Product Control Characteristics

Customer needs	GSM	Moisture	Brightness	Tensile index	Burst index	Tear index	Stretch	Acidity	Coating
Grade	@		0	Δ	Δ	Δ			0
Thickness	@								0
Smoothness			Δ						@
Whiteness				@					0
Ink drying property		0						@	Δ
Dimensional stability		0		Δ	Δ	0	@		
Folds				@	0	@			
Durability					@	@	@		

Note: @, strong; 0, medium; Δ, weak.
Source: Shenoy (1994).

1. "All the characteristics are critical." The realities, however, are that the multitude of characteristics inevitably requires setting priorities for manufacturing and inspection efforts. Setting these priorities requires knowledge of the relative importance of characteristics. If this knowledge is not provided by the development engineer, the decisions will, by default, be made by others who have less background in the design.
2. "The size of the tolerance range already provides a classification of relative importance." In fact, the criticality depends not so much on the allowable range of dimension as on the effect a substantial departure from that range might have on the function of the assembled system. For example, say the dimension under study is 2.000 cm ±. 010 cm. The design engineer may be asked to predict the functional effect on the system if the part dimension were 2.020 cm (a variation from target of *twice* the design tolerance). A factor of 2.0 provides a significant enough step for the engineer to form an opinion on the importance of the characteristic.

A classification approach also can be applied to the manufacturing process using the process capability index as a criterion (see below under Process Capability: The Concept). Product-process combinations can then be studied to identify high-risk areas, e.g., critical-critical, critical-major, and major-critical.

The classification of characteristics often leads to a useful dialogue between the Product Development and Manufacturing Planning Departments before the start of production. For example, a characteristic was classified by the designer as "incidental" but required a costly process to meet the specification range. After discussions, the design engineer increased the range and also reclassified the characteristics. The expanded range permitted the substitution of a less costly process. For further discussion of classifying characteristics, see Section 3, under Design for Critical Factors and Human Error.

In the service sector, an overnight delivery service has not only identified but also assigned importance weights to 12 service quality indicators (Table 22.2). These measures are tracked every day, both individually and in total.

Process Diagram. Understanding the process can be aided by laying out the overall process in a flow diagram (similar diagrams use the terms *map, logic,* or *blueprint*). Several types are helpful.

One type of flow diagram shows the work paths followed by the materials through their progression into finished product. Planners use such a diagram to divide the flow into logical sections called *workstations.* For each workstation they prepare a formal document listing such items as operations to be performed, sequence of operations, facilities and instruments to be employed, and the process conditions to be maintained. This formal document becomes the plan to be carried out by production supervision and work force. It serves as the basis for control activities by the inspectors. It also becomes the standard against which the process audits are conducted. An example of a flow diagram for a coating process is shown in Figure 22.2.

TABLE 22.2 Federal Express Service Quality Indicators

Indicator	Weight	Indicator	Weight
Abandoned calls	1	Missed pickups	10
Complaints reopened	5	Missing proofs of delivery	1
Damaged packages	10	Overgoods (lost and found)	5
International	1	Right-day late deliveries	1
Invoice adjustments requested	1	Traces	1
Lost packages	10	Wrong-day late deliveries	5

Source: American Management Association (1992).

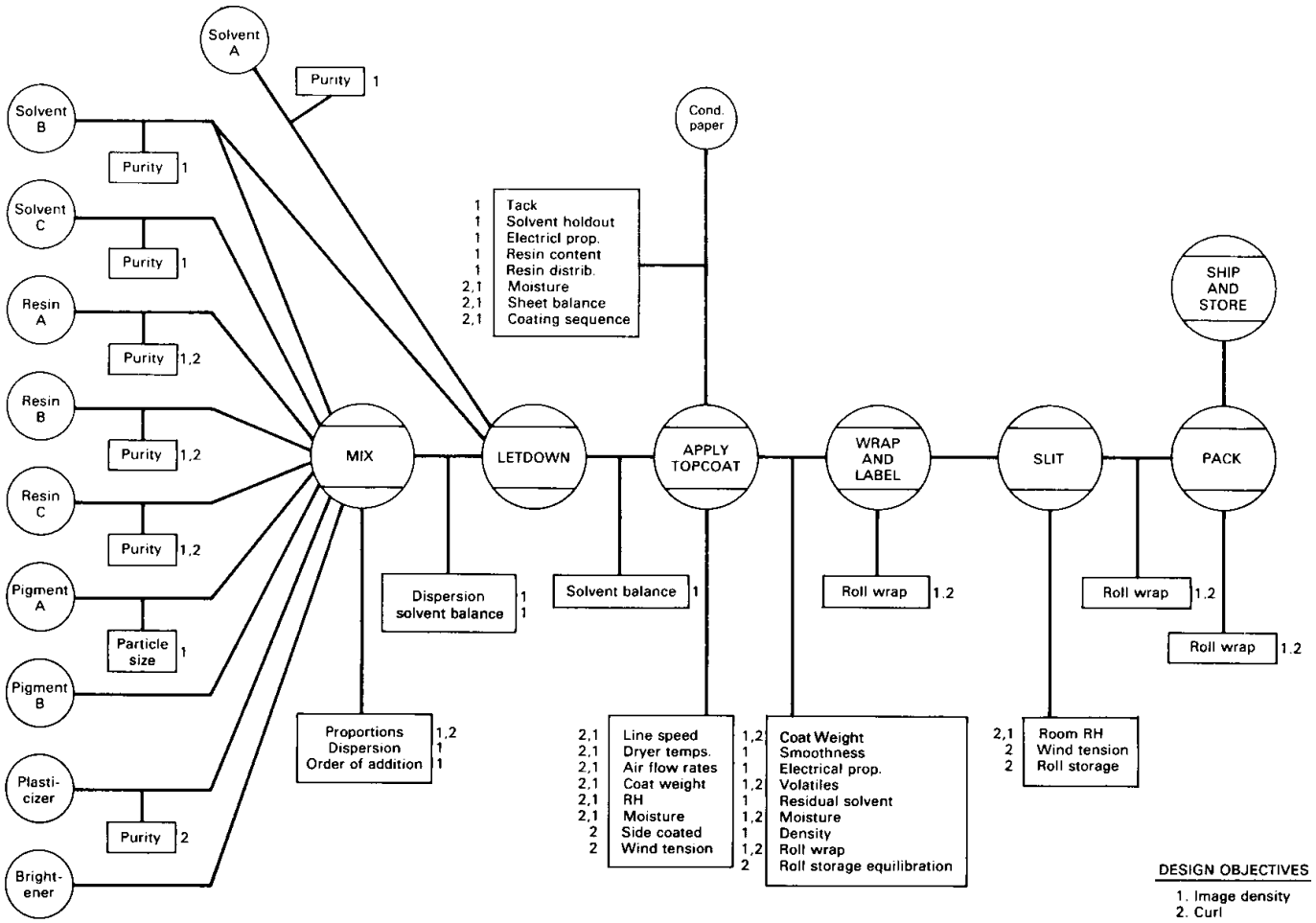

FIGURE 22.2 Strategic plan of control. Product and process analysis chart (P-PAC).

From the service sector, Figure 22.3 shows a flow diagram (called a *blueprint*) for processing a transaction at a discount brokerage house. Note the separation of customer contact activities ("tangible service evidence") from the backroom activities below the "line of visibility." The symbol *F* identifies "fail points"—those steps likely to cause problems and which require special attention through extra staffing, facility layout, or other means. Also note that service time standards are shown for selected activities.

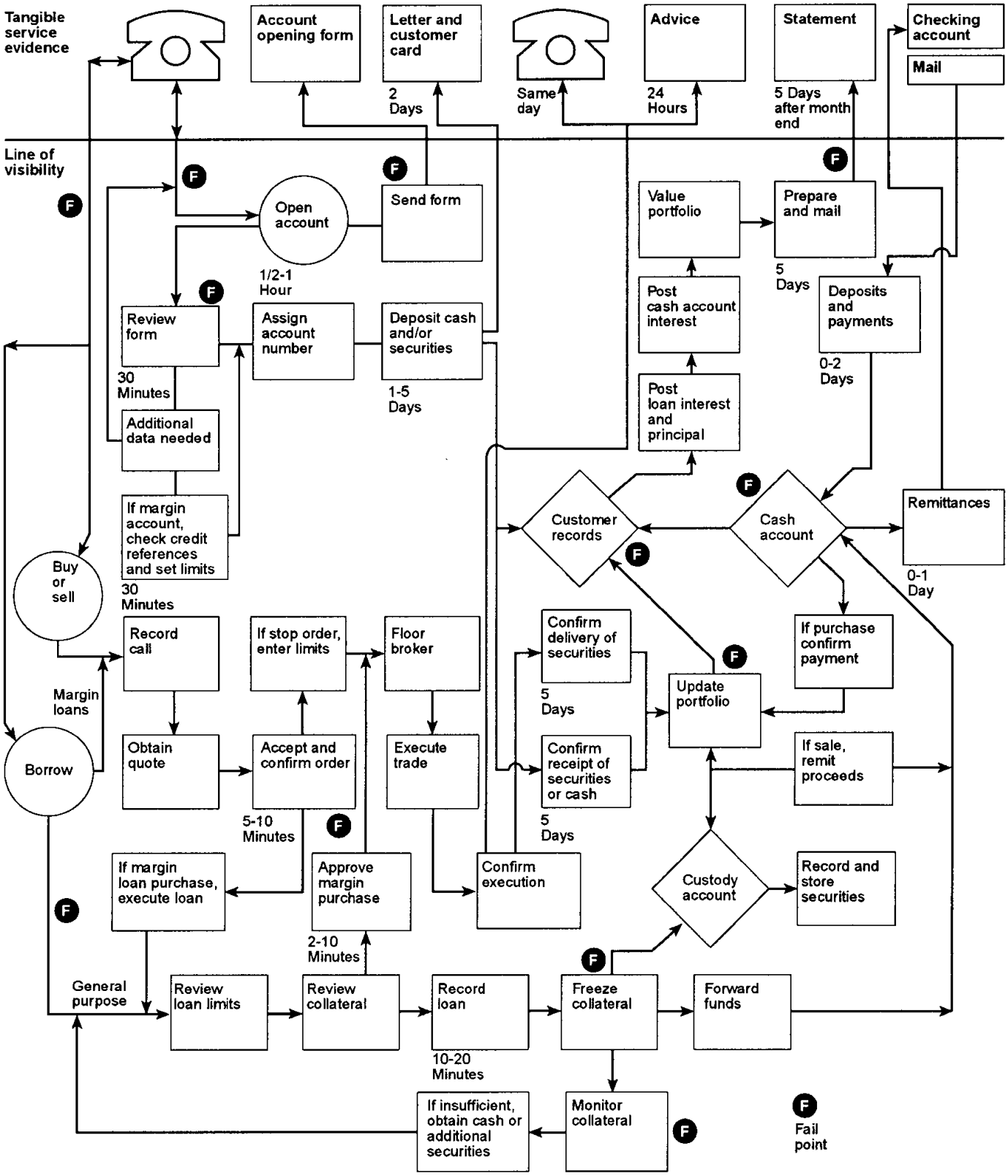

FIGURE 22.3 Blueprint for a service delivery system of a discount brokerage operation. (*Shostack 1984.*)

The flow diagram in Figure 22.4 shows the major functions and key activities in a billing process. The diagram shows not only the process flow in time (top to bottom) but also the flow across organizational boundaries (left to right). Note that each block in the flow diagram is numbered to reference more detailed flow diagrams or work instructions that describe the activity (Juran Institute 1995).

Correlation of Process Variables with Product Results. A critical aspect of planning during manufacture is to discover, by data collection and analysis, the relationships between process variables or parameters and product results. Such knowledge enables the planner to specify various controls on the variables to achieve the specified product results. In Figure 22.2, process variables are shown in a rectangle attached to the circle representing the operation; product characteristics are listed in a rectangle between operations, at the point where conformance can be verified. Some characteristics (e.g., coat weight) are both a process variable and a product characteristic. For each control station in a process, designers identify the numerous control subjects over which control is to be exercised. Each control subject requires a feedback loop made up of multiple process control features. A process control spreadsheet helps to summarize the detail. An example is shown in Figure 22.5. For elaboration, see Juran (1992, p. 286). For a thorough discussion of planning for quality, including the identification of critical control points during manufacture, see Clark and Milligan (1994). They apply many useful quality tools to the manufacture of a simple product—honey.

Determining the optimal settings and tolerances for process variables sometimes requires much data collection and analysis. Carpenter (1982) discusses a case involving a statistical analysis of data on 33 parameters to pinpoint the key process variables in a copper ore roasting operation. Dodson (1993) presents a procedure, with tables, to determine the optimal target value for a process with upper and lower specification limits where the economic value of the product is considered.

The consequences of a lack of knowledge (of the relationship between process variables and product results) can be severe. In electronic component manufacturing, some yields are low and will likely remain that way until the process variables are studied in depth. In all industries, the imposition of new quality demands (e.g., reduction in weight of automotive components) can cause a sharp

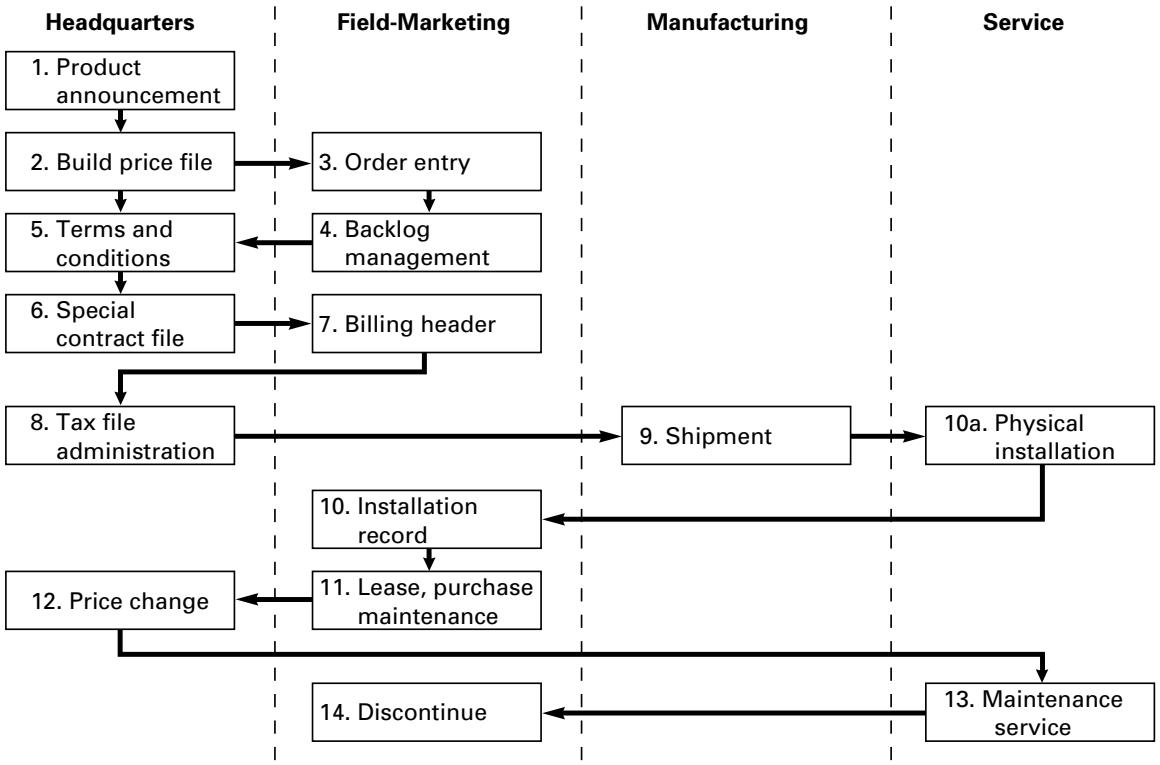

FIGURE 22.4 Billing process.

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 temp.	°F	Thermo-couple	505°F	Continuous	N/A	510°F reduce heat 500°F increase heat	Operator	
Conveyor speed	Ft/Min (fpm)	fpm meter	4.5 fpm	1/hour	N/A	5 fpm reduce speed 4 fpm increase speed	Operator	
Alloy purity	% con-tamin-ants	Lab chemical analysis	1.5% max.	1/month	15 grams	At 1.5% drain bath, replace solder	Process Engineer	

FIGURE 22.5 A process control spreadsheet. (*Juran 1992*.)

rise in scrap (and hence in costs) because not enough is known about the process variables to adapt promptly to the new demands.

Only upper management can supply the missing essentials, which consist of

1. The budget for personnel needed full time to assist by analyzing existing data, determining the need for additional studies, designing the experiments, collecting the new data, analyzing, and so on.
2. The budget for training in the quality disciplines. The full-time analysts should, of course, have this training in depth. In addition, it is helpful for the process engineers to become knowledgeable as well. The necessary training programs are widely available.

The return on these investments is in the form of higher yields, higher productivity, lower costs, and better quality.

Some industries must meet explicit government regulations concerning manufacturing practices, and these must be recognized during manufacturing planning. An example is the good manufacturing practices (GMP) regulations in health-related industries.

PROCESS CAPABILITY: THE CONCEPT

Process capability is the measured, inherent reproducibility of the product turned out by a process.

Basic Definitions. Experience has taught us that each key word in this definition must itself be clearly defined.

Process: This refers to some unique combination of machine, tools, methods, materials, *and people* engaged in production. The output of the process may be a physical good, such as an integrated

circuit chip or a chemical; the output may be a service product, such as a credit card statement or answers provided on a consumer hot line.

Capability: This word is used in the sense of a competence, based on tested performance, to produce quality products.

Measured: Process capability is quantified from data which, in turn, are the results of measurement of work performed by the process. The measurement may be made on a physical property such as the pH value of a chemical. The measurement on a service product may be the time required to generate a credit card statement.

Inherent reproducibility: This refers to the product uniformity resulting from a process that is in a state of statistical control, e.g., in the absence of time-to-time "drift" or other assignable (special) causes of variation.

Product: The measurement is made on the product (goods or service) because it is product variation, which is the end result, that we use to quantify process capability.

Machine capability versus process capability: Some practitioners distinguish between these two terms. *Machine capability* refers to the reproducibility under one set of process conditions (e.g., one operator, homogeneous raw materials, uniform manufacturing practice). *Process capability* refers to the reproducibility over a long period of time with normal changes in workers, materials, and other process conditions.

Uses of Process Capability Information. Process capability information serves multiple purposes:

1. Predicting the extent of variability that processes will exhibit. Such capability information, when provided to designers, provides important information in setting realistic specification limits.
2. Choosing, from among competing processes or equipment, that which is best to meet the specifications.
3. Planning the interrelationship of sequential processes. For example, one process may distort the precision achieved by a predecessor process, as in hardening of gear teeth. Quantifying the respective process capabilities often points the way to a solution.
4. Providing a quantified basis for establishing a schedule of periodic process control checks and readjustments.
5. Testing theories of causes of defects during quality improvement programs.
6. Serving as a basis of quality performance requirements for purchased product or equipment. In certifying suppliers, some organizations use a capability index (see below) as one element of certification criteria. In these applications, the value of the capability index desired from suppliers can be a function of the type of commodity being purchased.

These purposes account for the growing use of the process capability concept.

Process Patterns. The concept of process capability can be better understood by an examination of the usual process patterns encountered. To make this examination, we can measure a sample, summarize the data in a histogram, and compare the result against the specification limits.

Typical histograms are shown in Figure 22.6. The examination has a three-part focus:

1. *Centering of the histogram:* This defines the aim of the process.
2. *Width of the histogram:* This defines the variability about the aim.
3. *Shape of the histogram:* For most characteristics, a normal or bell-shaped curve is expected. Any significant deviation from the normal pattern has a cause that, once determined, can shed much light on the variability in the process. For example, histograms with two or more peaks reveal that multiple "populations" have been mixed together, e.g., different suppliers of material or services.

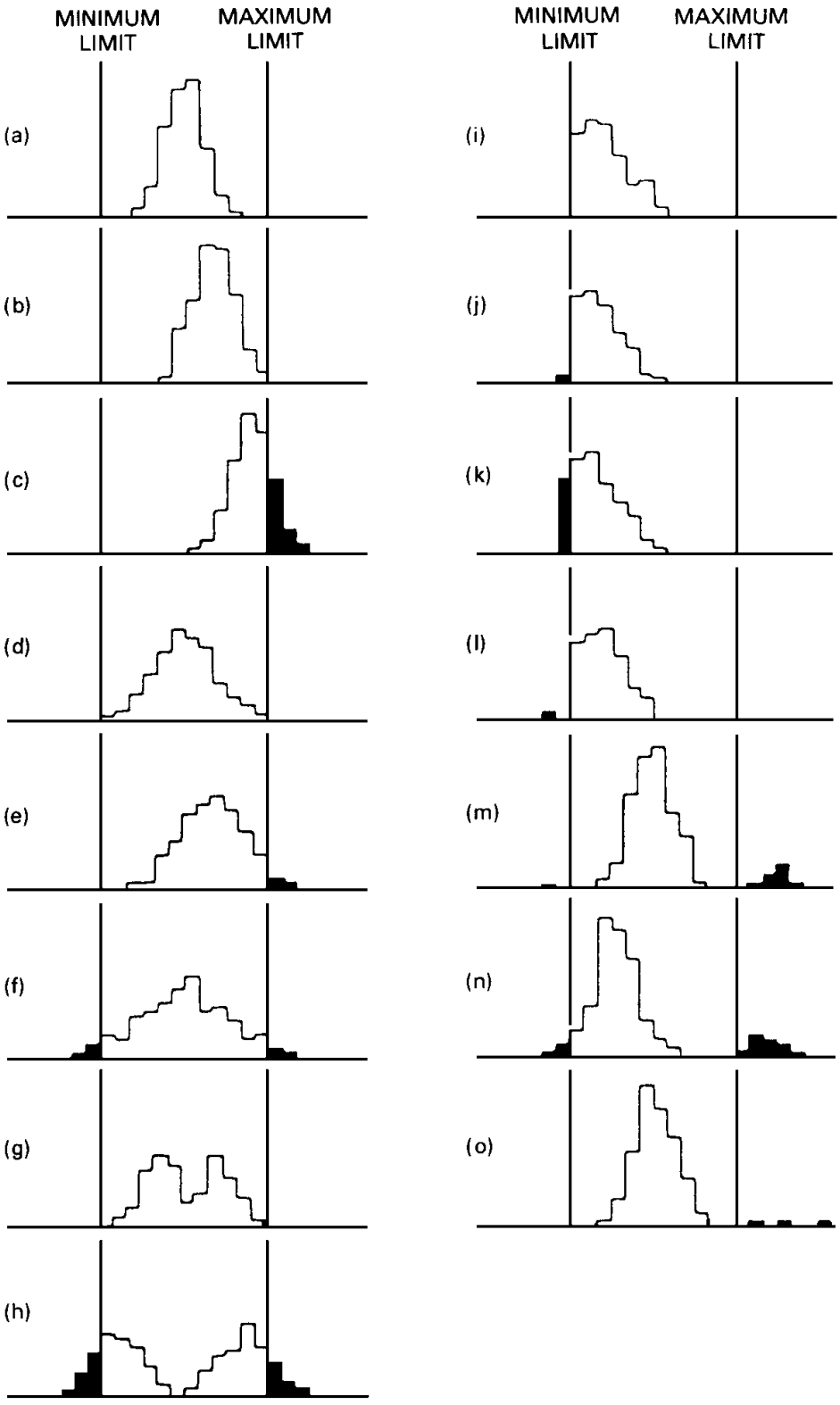

FIGURE 22.6 Histogram distribution patterns.

Histograms and chronological plots of process data indicate several reasons why some processes are not capable of holding specification limits. These are

1. *The inherent variability of the process is too large for the proposed specification limits:* Assuming that the process is in statistical control, the only courses of action are to revise the process, expand the limits, or live with a certain level of defectives.
2. *The process is misdirected:* Here the planner must provide the work force with the means to evaluate the extent of misdirection and to make compensating adjustments in the process.
3. *The measurement process itself is inadequate.*
4. *There is process drift:* Here the need is to quantify the amount of drift in a given period of time and to provide means for resetting the process to compensate for this drift.
5. *There are cyclic changes in the process:* We must identify the underlying cause and either remove it or reduce the effect on the process.
6. *The process is erratic:* Sudden changes can take place in processes. As the capability studies quantify the size of these changes and help to discover the reasons for them, appropriate planning action can be taken:
   - ***a.*** Temporary phenomena (e.g., cold machine coming up to operating temperature) can be dealt with by scheduling warming periods plus checks at the predicted time of stability.
   - ***b.*** More enduring phenomena (e.g., change due to new material supply) can be dealt with by specifying reverification at the time of introducing such change.

Note that the ability of the process to produce quality products consists of two different abilities:

1. The ability to achieve the desired average value (often called the *target* or *nominal specification*). This ability is evaluated by comparing the actual average with the target.
2. The ability to reproduce results consistently. This ability is evaluated by quantifying the width of the histogram (e.g., in terms of 6σ; see below). This "process capability" is compared with the specification in order to judge the adequacy of the process.

Process Mixture. A common obstacle to using the inherent capability of a process is that for reasons of productivity, product data from several processes are combined. Examples of this are widespread: multicavity plastic molding, multiple-unit film deposition for electronic components, and multiple-head filling of containers. What these processes have in common is a multiplicity of "machines" mounted on a single frame. The multiple character of these producing sources superimposes a stream-to-stream variation that materially affects the ability of the process to meet the specifications.

In such cases, any conventional sampling of product ends up with data that are a composite of two different sources of variation:

1. The stream-to-stream variation, traceable to differences in the mold cavities, spindles, heads, and so on.
2. The within-stream variation, which characterizes a single "pure" process.

To quantify the stream-to-stream variation requires that the product from different streams (e.g., cavities, spindles, molds, or heads) be segregated. Once segregated, the data for each stream can be treated in the conventional manner. Tarver (1984) presents procedures for process capability studies of multiple-stream processes.

An example of such mixture of data from a service industry is presented in Figure 22.7. Data were plotted to analyze turnover time in rooms in a laboratory at Brigham and Women's Hospital (Laffel and Plsek 1989). *Turnover time* was defined as the time between the moment all catheters and sheaths are removed from one patient and the time local anesthetic is injected into the next patient. Simply collecting data yielded some surprises: The mean time was 78 minutes (45 minutes had been the usual estimate), and the variation ranged from 20 to 150 minutes. In one part of the analysis, data were stratified by room, and histograms on turnover time were plotted by room (see Figure 22.7). Note what we learn when the total data are stratified by room: Room 1 had a shorter mean time and much less variation than

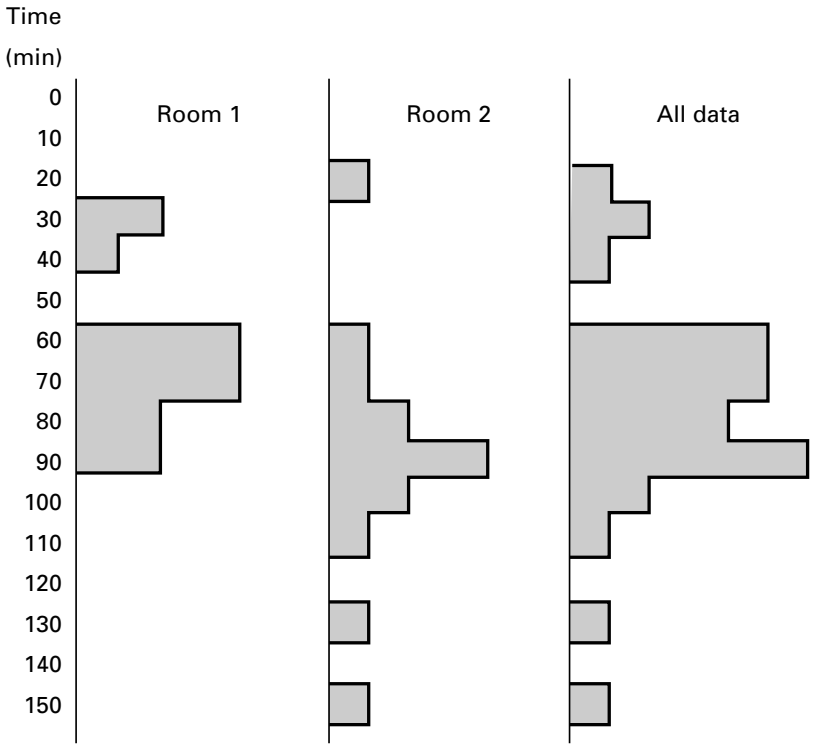

FIGURE 22.7 Room turnover times. (*Laffel and Plsek 1989.*)

room 2. Further analysis showed that when a nurse called for the next patient before the preceding case was completed, turnover time was relatively short. No one had been aware, until the data were recorded and the analysis made, that the timing of the call was a critical determinant of turnover time.

Standardized Formula. The most widely adopted formula for process capabilities is

$$\text{Process capability} = 6\sigma$$

where σ is the standard deviation of the process under a state of statistical control, i.e., under no drift and no sudden changes.

If the process is centered at the nominal specification and follows a normal probability distribution, 99.73 percent of production will fall within $\pm 3\sigma$ of the nominal specification.

Some industrial processes do operate under a state of statistical control. For such processes, the computed process capability of 6σ can be compared directly with specification tolerances, and judgments of adequacy can be made. The majority of industrial processes, however, do exhibit drift and do exhibit sudden changes. These departures from the ideal are a fact of life, and the practitioner must deal with them.

Nevertheless, there is great value in standardizing on a formula for process capability based on a state of statistical control. Under this state, the product variations are the result of numerous small variables (rather than being the effect of a single large variable) and hence have the character of random variation. It is most helpful for planners to have such limits in quantified form.

The standardized formula (process capability $= 6\sigma$) assumes a normal probability distribution. This is often the case, but it is not universally true. For example, dimensions that are close to a physical limit, such as the amount "out of round" (where a value of zero is desired), tend to show "skewed" distributions. In such cases, $\pm 3\sigma$ does not include 99.73 percent of the population. Whether the distribution is normal or not, it is useful to analyze capability graphically as a way to gain understanding of the distribution that is difficult to achieve with numerical analysis alone. (See Frequency Distribution and Histogram, below.)

Relation to Product Specification. A major reason for quantifying process capability (i.e., process variation) is to be able to compute the ability of the process to hold product specifications. For processes that are in a state of statistical control (see below), a comparison of 6σ to the specification limits permits ready calculation of percentage defective by conventional statistical theory. See Section 44, under Continuous Probability Distributions. The comparison of process capability with specification limits leads to some broad plans of action (see Table 22.3).

Capability Index. In most processes, not only are there departures from a state of statistical control but the process is not necessarily being operated to secure optimal yields; e.g., the average of the process is not centered between the upper and lower tolerance limits. To allow for these realities, planners try to select processes with the 6σ process capability well within the specification range. The two factors are expressed in a *capability index* C_p*:*

$$C_p = \frac{\text{specification range}}{\text{process capability}} = \frac{\text{USL} - \text{LSL}}{6\sigma}$$

where USL is the upper specification limit, and LSL is the lower specification limit

Figure 22.8 shows four of many possible relations between process variability and specification limits and the likely courses of action for each. Note that in all these cases the average of the process is at the midpoint between the specification limits.

Table 22.4 shows selected values of C_p and the corresponding level of defects assuming that the process average is midway between the specification limits. A process that is just meeting specification limits (specification range$=\pm 3\sigma$) has a C_p of 1.0. The criticality of many applications and the reality that the process average will not remain at the midpoint of the specification range suggest that C_p should be a least 1.33. Note that the C_p index measures whether the process variability can fit within the specification range. It does not indicate if the process is actually running within the specification, because the index does not include a measure of the process average (this is addressed below under Process Performance Measurement).

Three capability indices commonly in use are shown in Table 22.5. Of these, the simplest is C_p. The higher the value of any of these indices, the lower will be the amount of product that is outside specification limits.

Pignatiello and Ramberg (1993) provide an excellent discussion of various capability indices. Bothe (1997) provides a comprehensive reference book that includes extensive discussion of mathematical aspects. These references explain how to calculate confidence bounds for various process

TABLE 22.3 Action to Be Taken

	Product meets specifications		Product does not meet specifications	
	Process variation small relative to specifications	Process variation large relative to specifications	Process variation small relative to specifications	Process variation large relative to specifications
Process is in control	Consider cost reduction through less precise process; consider value to designer of tighter specifications.	Closely monitor process setting.	Process is "misdirected" to wrong average. Generally easy to correct permanently.	Process may be misdirected and also too scattered. Correct misdirection. Consider economics of more precise process versus wider specifications versus sorting the product.
Process is out of control	Process is erratic and unpredictable. Investigate causes of lack of control. Decision to correct based on economics of corrective action.		Process is misdirected or erratic or both. Correct misdirection. Discover cause for lack of control. Consider economics of more precise process versus wider specifications versus sorting the product.	

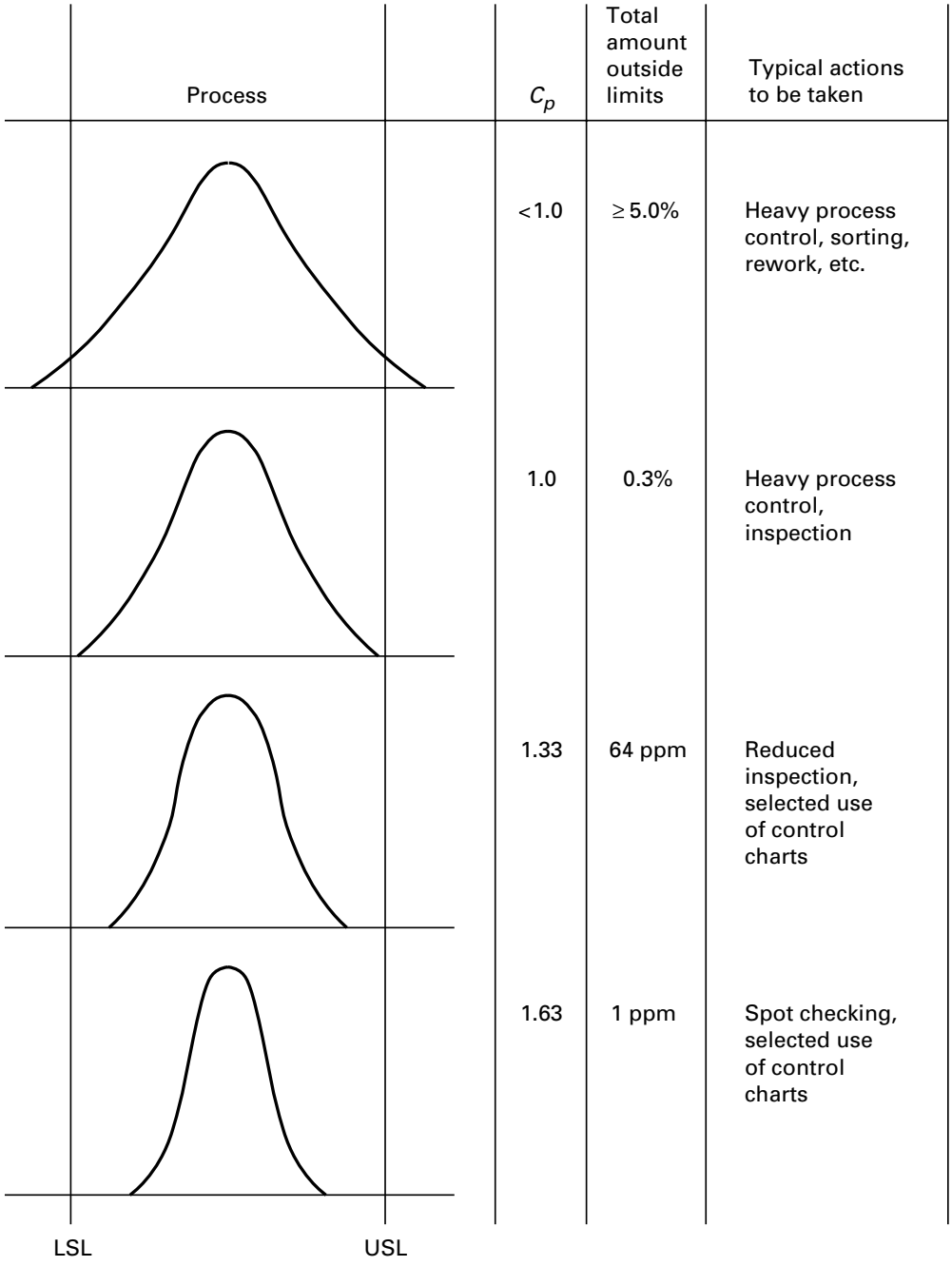

FIGURE 22.8 Four examples of process variability.

capability indices. Herman (1989) cites important precautions in using capability indices in the process industries—variability among lots and measurement variability are relevant issues.

Capability and Performance Studies. Two types of process studies can be identified:

1. Process capability studies that estimate the inherent or potential process capability, i.e., what the process can do under certain conditions. This type of study is discussed below.
2. Process performance studies that measure the present performance of the process, i.e., what the process *is* doing. This type of study is discussed later in this section under Process Performance Measurement.

TABLE 22.4 Process Capability Index C_p and Product Outside Specification Limits

Process capability index C_p	Total product outside two-sided specification limits*
0.5	13.36%
0.67	4.55%
1.00	0.3%
1.33	64 ppm
1.63	1 ppm
2.00	0

*Assuming the process is centered midway between the specification limits.

TABLE 22.5 Process Capability and Process Performance Indices

Process capability	Process performance
$C_p = \dfrac{\text{USL} - \text{LSL}}{6\sigma}$	$P_p = \hat{C}_p = \dfrac{\text{USL} - \text{LSL}}{6s}$
$C_{pk} = \min\left(\dfrac{\text{USL} - \mu}{3\sigma}, \dfrac{\mu - \text{LSL}}{3\sigma}\right)$	$P_p = \hat{C}_{pk} = \min\left\lvert\dfrac{\text{USL} - \bar{X}}{3s}, \dfrac{\bar{X} - \text{LSL}}{3s}\right\rvert$
$C_{pm} = \dfrac{\text{USL} - \text{LSL}}{6\sqrt{\sigma^2 + (\mu - T)^2}}$	$P_p = \hat{C}_{pm} = \dfrac{\text{USL} - \text{LSL}}{6\sqrt{s^2 + (\bar{X} - T)^2}}$

PROCESS CAPABILITY MEASUREMENT

Measuring the inherent or potential process capability requires that the process be stable. Stability is evaluated by a control chart.

The Control Chart. A *control chart* is a graphic comparison of process performance data to statistical control limits, not specification limits. The performance data consist of groups of measurements (*rational subgroups*) selected in regular sequence of production while preserving the order. The statistical control limits help to evaluate capability by first evaluating whether the process is operating at its minimum inherent variation.

Process variations are traceable to two kinds of causes: (1) random, i.e., due solely to "common" or chance causes, and (2) assignable, i.e., due to findable "special" causes. Ideally, only random causes should be present in a process because this represents the minimum possible amount of variation with the given set of process conditions. A process that is operating without assignable causes of variation is said to be in a *state of statistical control.* A control chart analysis should be made and assignable causes eliminated from the process prior to calculating 6σ as a measure of process capability. When this is done, 6σ then represents the inherent process capability. If 6σ is calculated without first making a control chart analysis, the calculated value of 6σ probably will be inflated. Many control chart analyses reveal the presence of assignable causes even though production people profess that the process is operating with the minimum possible variation. A description of control chart methodology, including formulas and procedures, is given in Section 45, Statistical Process Control.

Determination of Process Capability from a Control Chart Analysis. If, and only if, a process is in statistical control, the following relationship holds:

$$\text{Estimate of } \sigma = \frac{\bar{R}}{d_2}$$

Table A in Appendix II provides values of d_2. Knowing the standard deviation, process capability limits can be set at $\pm 3s$ and this used as an estimate of $\pm 3\sigma$. (This calculation converts $\bar{R}$ to a standard deviation of *individual* values. Control limits represent 3 standard deviations of sample *averages.*)

The Assumption of Statistical Control and Its Effect on Process Capability. If a process is out of control and the causes cannot be eliminated economically, the standard deviation and process capability limits nevertheless can be computed (with the out-of-control points included). These limits will be inflated because the process will not be operating at its best. In addition, the instability of the process means that the prediction is approximate.

It is important to distinguish between a process in a state of statistical control and a process that is meeting specifications. A state of statistical control does *not* necessarily mean that the product from the process conforms to specifications. Statistical control limits on sample averages *cannot* be compared directly with specification limits because the specification limits refer to individual units. For some processes that are not in control, the specifications are being met, and no action is required; other processes are in control, but the specifications are not being met and action is needed. In summary, we need processes that are both stable (in statistical control) and capable (meet product specifications).

The increasing use of capability indices has brought with it the inevitable failure to understand and verify some important assumptions that are essential for statistical validity of the results. Four key assumptions are

1. *Process stability:* This means a state of statistical control with no drift or oscillation (see above).
2. *Normality of the characteristic being measured:* This is needed to draw statistical inferences about the population.
3. *Representativeness of samples:* This includes random sampling.
4. *Independence of the measurements:* This means that consecutive measurements cannot be correlated.

In practice, these assumptions are often not verified. Examination likely would reveal that one or more of the assumptions is not realistic. These assumptions are not theoretical refinements—they are important conditions for properly applying capability indices. Before applying capability indices, the reader is urged to read the paper by Pignatiello and Ramberg (1993). Also, the October 1992 issue of the *Journal of Quality Technology* is devoted to statistical issues concerning capability indices. McCoy (1991) summarizes the situation well—how effective the indices are depends on how they are used and understanding the risks involved. These risks can be minimized by statistically and visually comparing the indices with the full data versus specifications as depicted in a histogram.

PROCESS PERFORMANCE MEASUREMENT

If a process is in statistical control, then the measure of process performance results also in determining process capability. Several of the techniques described below for determining process performance use the same calculations as techniques described earlier for process capability (the difference involves the assumption of statistical control, as explained below). Mentch (1980) provides a further breakdown of process analysis into four categories and presents methods and examples for each.

Measuring Present Process Performance. Specific tools for this type of study include process performance indices, the frequency distribution and histograms, probability paper, plot of individual measurements, and attributes data analysis. It is highly preferable to use variables rather than attributes data, i.e., numerical measurements rather than accept-reject information.

Process Performance Indices. Table 22.5 presents process performance indices P corresponding to the process capability indices C_p discussed earlier. For example, Kane (1986) discusses the use of a *performance index* C_{pk} that reflects the current process mean's proximity to either the upper specification limit USL or lower specification limit LSL. C_{pk} is estimated by

$$C_{pk} = \min\left(\frac{\overline{X} - \text{LSL}}{3s}, \frac{\text{USL} - \overline{X}}{3s}\right)$$

For Kane's example where

$$\text{USL} = 20 \qquad \overline{X} = 16$$

$$\text{LSL} = 8 \qquad s = 2$$

the standard capability ratio is estimated as

$$C_p = \frac{\text{USL} - \text{LSL}}{6\sigma} = \frac{20 - 8}{12} = 1.0$$

which implies that if the process were centered between the specification limits (at 14), then only a small proportion (about 0.27 percent) of product would be defective.

However, when we calculate C_{pk}, we obtain

$$C_{pk} = \min\left(\frac{16 - 8}{6}, \frac{20 - 16}{6}\right) = 0.67$$

which alerts us that the process mean is *currently* nearer the USL. (Note that if the process were centered at 14, the value of C_{pk} would be 1.0.) An acceptable process will require reducing the standard deviation and/or centering the mean.

Interpretation of C_{pk}. In using C_{pk} to evaluate a process, we must recognize that C_{pk} is an abbreviation of two parameters—the average and the standard deviation. Such an abbreviation can inadvertently mask important detail on these parameters; e.g., three extremely different processes can all have the same C_{pk} [for elaboration, see Juran and Gryna (1993, p. 402)].

Increasing the value of C_{pk} may require a change in the process average, the process standard deviation, or both. For some processes, it may be easier to increase the value of C_{pk} by changing the average value (perhaps through a simple adjustment of the process aim) than to reduce the standard deviation (by investigating the many causes of variability). The histogram of the process always should be reviewed to highlight both the average and the spread of the process.

Calculating and interpreting these performance indices do not require the assumptions of statistical control or normality of the distribution. Capability indices are useful in estimating future performance (based on certain assumptions); performance indices are useful as measures of past performance. In both cases, plotting data over time helps to identify trends and evaluate the success of improvement efforts.

Frequency Distribution and Histogram. In this type of study, a sample of about 50 consecutive units is taken, during which time no adjustments are made on the machines or tools. The units are all measured, the data are tallied in frequency distribution form, and the standard deviation s is calculated and used as an estimate of σ. The characteristics are assumed to follow a normal probability distribution where $\pm 3\sigma$ standard deviations include 99.73 percent of the population. Process performance is then defined as $\pm 3\sigma$ or 6σ. For example, analysis of 60 measurements yielded

$$\overline{X} = 9.6 \qquad s = 2.5$$

Computer programs are available to calculate the average and standard deviation, develop and plot the histogram, and make various checks on the assumption of a normal probability distribution.

The process capability is calculated as ±3(2.5), or ±7.5, or a total of 15.0.

Normal probability paper (see Section 44, under The Normal Distribution) can be used to graphically determine process performance. Process data are plotted on the probability paper, and the mean value and 3 standard deviation values are then estimated graphically. In some normal probability paper, the upper and lower horizontal grid lines represent ±3σ, respectively. Weibull probability paper is available to handle nonnormal distributions.

An extensive discussion of determining process capability using probability paper is given by Lehrman (1991). The paper presents the detailed steps in making the plot, a discussion of normal and skewed distributions, and confidence limits on the capability index.

Plots of Individual Measurements. A simple plot of individual measurements, in order of production, can be surprisingly revealing.

> In a classic study of a machine process, watch parts were measured for each of five quality characteristics. The resulting measurements were plotted in chronological order on a chart that also showed the five sets of specification limits. The study demonstrated that the process was capable of meeting the specification limits. The study also showed that the poor performance (12 percent nonconforming product) was due to the inadequacy of the instruments provided to the work force. Provision of adequate instruments reduced the defect level to 2 percent and made possible a sharp reduction in the amount of gauging done by inspectors (consulting experience of J. M. Juran).

Limitations of Histograms and Probability Paper Analyses. These methods of evaluating process performance do not evaluate the inherent capability of the process because they are usually performed without first evaluating the process for statistical control. The data may include measurements from several populations. There may be time-to-time changes such as solutions becoming dilute or tools becoming worn. Such process conditions result in observed dispersions that are wider than the inherent capability of the process. To evaluate the inherent capability requires use of a control chart (see above under Process Capability Measurement).

Six-Sigma Concept of Process Capability. For some processes, shifts in the process average are so common that such shifts should be recognized in setting acceptable values of C_p. In some industries, shifts in the process average of ±1.5 standard deviations (of individual values) are not unusual. To allow for such shifts, high values of C_p are needed. For example, if specification limits are at ±6σ (not ±3σ), and if the mean shifts ±1.5σ, then only 3.4 ppm will be beyond specification limits. The Motorola Company's "six-sigma" approach recognizes the likelihood of these shifts in the process average and makes use of a variety of quality engineering techniques to change the product, the process, or both in order to achieve a C_p of at least 2.0. Craig (1993) describes a seven-step approach applied to electronics manufacturing.

Attributes Data Analysis. The methods discussed earlier assume that numerical measurements are available from the process. This is the preferable type of data for a capability study. Sometimes, however, the only data available are in attribute form, i.e., the number defective and the number acceptable. Attributes data require large sample sizes and should be used only where variable measurement is impractical.

To illustrate, I will analyze data from a process for preparing insurance policies. Policy writers fill in blank policy forms with data from various inputs. The forms then go to a checker, who reviews them for errors. For a specified time period, the checker reported 80 errors from 6 policy writers and covering 29 types of errors (Table 22.6). Using errors as the unit of measure, the process performance can be calculated as 80/6, or 13.3 per writer. Note that none of the writers was close to the average.

The current *performance* of the process can be described as 13.3 errors per writer, but analysis revealed that this is not the *capability* of the process:

TABLE 22.6 Matrix of Errors by Insurance Policy Writers

	Policy writers						
Error type	A	B	C	D	E	F	Total
1	0	0	1	0	2	1	4
2	1	0	0	0	1	0	2
3	0	16	1	0	2	0	19
4	0	0	0	0	1	0	1
5	2	1	3	1	4	2	13
6	0	0	0	0	3	0	3
28							
29							
Totals	6	20	8	3	36	7	80

- For writer B, 16 of the 20 errors were due to a misunderstanding of a procedure. When this was clarified, error type 3 for writer B did not recur.
- In contrast, writer E made 36 errors in essentially all 29 categories. The writer was reassigned to other work.
- Error type 5 caused a problem for all the writers. Analysis revealed a difference in interpretation of the work instruction between the writers and the checker. When this was cleared up, error type 5 disappeared.

The process capability can now be calculated by excluding the preceding abnormal performances: type 3 errors by worker B, type 5 errors, and errors of worker E. The error data for the remaining 5 writers becomes 4, 3, 5, 2, and 5, with an average of 3.8 errors per writer. This process capability estimate of 3.8 compares with the original process performance estimate of 13.3.

Note that this example calculates process capability in terms of errors or mistakes rather than variability of a process parameter. Hinckley and Barkan (1995) point out that in many assembly processes, nonconforming product can be caused by excessive variability on one or more parameters or by mistakes (e.g., missing parts, wrong parts, or other processing errors). Mistakes are not included in a process capability calculation based on variability. For some processes, particularly complex processes, mistakes can be a major cause of failing to meet customer quality goals. The actions required to reduce mistakes are different from those required to reduce variability on a parameter.

OTHER ASPECTS OF PROCESS CAPABILITY

These aspects include complex processes, service industries, quality improvement, and planning for a study.

Process Capability in Service Industries. The concept of process capability analysis grew up in the manufacturing industries. This concept focuses on evaluating process variability (6 standard deviations) as a measure of process capability. The concept, however, can apply to *any* process, including nonmanufacturing processes in the manufacturing industries and the spectrum of processes in the service industries. Little has been published on the application of process capability other than its application to manufacturing processes.

For certain parameters in service processes, process capability can be measured using 6σ and various capability indices. For example, in a loan association, the cycle time to complete the loan-approval process is critical and could be analyzed. Time data are readily available in quantitative form for calculating 6σ.

Other service processes may not have variables data available. For example, a firm provides a service of guaranteeing checks written by customers at retail establishments. The decision whether to guarantee is based on a process that employs an on-line evaluation of six factors. A percentage of checks guaranteed by the firm have insufficient funds, and the customer must be pursued for payment. The percentage of checks that default ("bounce") could be viewed as a measure of process capability. This approach uses discrete (attributes) data rather than the classic approach of calculating 6σ from variables data. The example given earlier on insurance policy writing illustrates the use of attributes data to calculate process capability for a service industry process.

With the emphasis on processes in quality management, evaluating the capability of processes requires not only evaluating capability based on variability (e.g., 6σ) but also a broader view. Juran (1992, pp. 240–256) describes the issues involved in developing a broader framework.

Process Capability and Quality Improvement. Capability indices serve a role in quantifying the ability of a process to meet customer quality goals. The emphasis, however, should be on improving processes and not just determining a capability index for a product characteristic. Achieving customer quality goals (particularly for quality levels of 1 to 10 ppm) means meeting requirements on all variables and attributes characteristics. On variables characteristics, decreasing the amount of variability (even when specification limits are being met) has many advantages. Juran and Gryna (1993) discuss six of these advantages. Achieving decreased variability requires the use of basic and advanced improvement techniques. Sections 3, 4, and 47 cover many of these techniques. The Taguchi approach uses experimental design to determine the optimal values of process variables that will minimize the variation in a process while keeping a mean on target. Shina (1991) describes an application to a wave soldering process. The results were measured in terms of weekly solder defects in parts per million. Results, before and after the Taguchi application, were

	Mean	Standard deviation
Before	808.50	213.80
After	98.50	55.30

Because of this reduction in defects, follow-on projects such as computer control of the process and acquisition of additional process equipment were curtailed. The Taguchi approach is discussed in Section 47, under Orthogonal Arrays and Taguchi Off-Line Quality Control.

Planning for the Process Capability Study. A capability study is made for different reasons, e.g., to respond to a customer request for a capability index number or to evaluate and improve product quality. Prior to data collection, clarify the purposes of making the study and the steps taken to ensure that the purpose is achieved.

In some cases, the capability study will focus on determining a histogram and capability index for a relatively simple process. Here, the planning should ensure that process conditions (e.g., feeds, speeds, temperature, and pressure) are completely defined and recorded. All other inputs clearly must be representative, i.e., specific equipment, material, and of course, personnel.

For more complex processes or where defect levels of 1 to 10 ppm are desired, the following steps are recommended:

1. Develop a process description including inputs, process steps, and output quality characteristics. This can range from simply identifying the equipment to developing a mathematical equation showing the effect of each process variable on the quality characteristics.
2. Define the process conditions for each process variable. In a simple case, this means stating the settings for temperature and pressure. For some processes, however, it means determining the optimal value or aim for each process variable. The statistical design of experiments provides the methodology (see Section 47, Design and Analysis of Experiments). Also, determine the operating

ranges of the process variables around the optimum because this will affect the variability of the product results.

3. Make sure that each quality characteristic has at least one process variable that can be used to adjust it.
4. Decide if measurement error is significant. This can be determined from a separate error of measurement study (see Section 23, under Error of Measurement). In some cases, the error of measurement can be evaluated as part of the overall study.
5. Decide if the capability study will focus on variability only (6σ) or whether it also will include mistakes or errors that cause quality problems.
6. Plan for the use of control charts to evaluate stability of the process.
7. Prepare a data collection plan that documents results on quality characteristics along with the process conditions (e.g., values of all process variables) and preserves information on the order of measurements so that trends can be evaluated.
8. Plan what methods will be used to analyze data from the study to ensure, before starting the study, that all necessary data for the analysis will be available. The analyses will include not only process capability calculations on variability but also analysis of attribute data on mistakes and analysis of data from statistically designed experiments built into the study.
9. Be prepared to spend time investigating interim results before process capability calculations can be made. These investigations can include analysis of optimal values and ranges of process variables, out-of-control points on control charts, or other unusual results. The investigations can lead to the ultimate objective, i.e., improvement of the process.

Note that these steps focus on improvement rather than just on determination of a capability index.

In a classic paper, Bemesderfer (1979) describes an eight-point program for evaluating new processes prior to production. Middleton (1992) presents a detailed example of a broad process capability study that incorporates a capability index, attributes measurement, and experimental design. Keenan (1995) discusses making a process capability study during product development, prior to regular production startup. Bothe (1992) describes an approach for making a capability study for an entire product by first determining the probability of each product characteristic being within specifications, calculating the combined probability of all characteristics being within specifications, and then expressing this combined probability as a C_{pk} value.

ERROR-PROOFING THE PROCESS

An important element of manufacturing planning is the concept of designing the process to be error-free through error-proofing. Where this type of design is economic, it can

Prevent defects or nonconformities that fallible human beings would otherwise make through inadvertence

Make effective a knack that would otherwise require retraining many workers

Prevent defects or nonconformities resulting from carelessness, indifference, and similar reasons

Bypass complex analysis for causes by finding a solution even though the cause of defects remains a mystery

Methods of Error-Proofing. Some of the more usual forms are summarized below.

Fail-Safe Devices. These consist of

1. *Interlocking sequences:* For example, to ensure that operation A is performed, the subsequent operation B locates from a hole that only operation A creates.

2. *Alarms and cutoffs:* These are used to signal depletion of material supply, broken threads, or other abnormalities. The alarms are also fail safe; i.e., they are silent only if all is well. If there is doubt, they sound anyhow.
3. *All-clear signal:* These are designed to signal only if all remedial steps have been taken.
4. *Foolproof fixtures:* These serve not only as fixtures but also as instruments to check the quality of work from preceding operations.
5. *Limiting mechanisms:* For example, a slipping-type torque wrench to prevent overtightening.

Magnification of Senses. Examples are

1. Locating indexes and fixtures to outperform human muscle in precision of position.
2. Optical magnification to improve visibility.
3. Remote-control viewing (closed-circuit television) to permit viewing of the process despite distance, heat, fumes, etc.
4. Multiple signals to improve likelihood of recognition and response, e.g., simultaneously ringing of bells and flashing of lights; audiovisual systems
5. Use of pictures in place of numbers (e.g., cards on the hood of a car undergoing assembly, to show pictorially the equipment needed for that car)

Redundancy. This consists of extra work performed purely as a quality safeguard. Examples are

1. *Multiple-identity codings:* These are intended to prevent product mixups, e.g., color codes or other recognition schemes on drug labels, tool steel, aluminum sheet, etc.
2. *Redundant actions and approvals:* For example, the drug industry requires that formulation of recipes be prepared and approved by two registered pharmacists working independently.
3. *Audit review and checking procedures:* These are widely used to ensure that the plans are being followed.
4. *Design for verification:* The product may include specially designed provision for verification (holes for viewing, coupons for test, etc.). It also includes the rapidly growing use of nuclear tracers.
5. *Multiple test stations:* For example, a can-filling line may provide checks for empty cans through height gauges, weighing scales, and air jets (for blowing empties off the conveyer).

Countdowns. These are arranged by structuring sensing and information procedures to parallel the operating procedures so that the operational steps are checked against the sensing and informational needs. A dramatic example is the elaborate countdown for the launching of a space vehicle. Surgical operations require countdowns, accounting for all materials and tools used (e.g., sponges, surgical instruments, etc.). A useful principle is to use an active rather than passive form of countdown. For example, a welder counts all welds *aloud* in progressing from spot to spot. When the count reaches 17, the last weld has been made—just as called for by the specification.

Special Checking and Control Devices. Examples from the service sector include

1. *Automatic dispensing devices:* Examples are drink-filling and other portion-control devices in the fast-food sector.
2. *Software to detect incorrect information or data:* This includes "spell check" in word processing and software to detect errors in data such as extreme charges on an invoice or too many digits in a data field.
3. *Software to detect missing information or data.*
4. *Hand-held devices to check or perform calculations,* e.g., on meter readings or rental car charges.
5. *Automatic recording of information:* This includes the use of bar codes at the checkout counter of a supermarket and the scoping of a package with a wand to track the location of a package at each transfer during a delivery process.

6. *Automatic timing devices:* Examples are those used for controlling cooking in fast-food operations.

Binroth (1992) presents research on three categories of errors in automotive manufacturing, i.e., missing components, incorrect processing, and wrong components.

Error-Proofing Principles. A useful principle in error-proofing is that of providing feedback to the worker; i.e., *the performance of the work conveys a message to the worker.* For example, a worker at a control panel pushes a switch and receives three feedbacks: the *feel* of the shape of the switch handle, the *sound* of an audible click signaling that the switch went all the way, and the *sight* of a visual illumination of a specific color and shape.

In a classic study, Nakajo and Kume (1985) discuss five principles of error-proofing developed from an analysis of about 1000 examples collected mainly from assembly lines. The principles are elimination, replacement, facilitation, detection, and mitigation (see Table 22.7).

OTHER ELEMENTS OF EQUIPMENT AND WORK METHODS PLANNING

Planning for equipment goes beyond making a process capability study. Other factors include providing for process adjustments and for preventive maintenance.

Providing for Adjustments to Processes. Many processes require periodic adjustments. Manufacturing planners should (1) identify the process variables that must be monitored for possible adjustment, (2) provide rules for determining when an adjustment is necessary, (3) provide instructions for determining the amount of adjustment, and (4) provide a convenient physical means for making the adjustment.

Each product characteristic should have a process variable that can be used to adjust it. As corollaries to this principle, Bemesderfer (1979) proposes

1. A single process variable should correspond to a single characteristic.

2. The degree of adjustment required during the process for a given change in the characteristic should be constant.

3. The range of possible adjustments must be consistent with the range of application need.

4. The setting accuracy must be consistent with the product tolerance requirements.

5. The controlling accuracy, once the process is set, must be consistent with the product tolerance requirements.

TABLE 22.7 Summary of Error-Proofing Principles

Principle	Objective	Example
Elimination	Eliminate the possibility of error	Redesign the process or product so that the task is no longer necessary
Replacement	Substitute a more reliable process for the worker	Use robotics (e.g., in welding or painting)
Facilitation	Make the work easier to perform	Color code parts
Detection	Detect the error before further processing	Develop computer software which notifies the worker when a wrong type of keyboard entry is made (e.g., alpha versus numeric)
Mitigation	Minimize the effect of the error	Utilize fuses for overloaded circuits

To the degree that these aims cannot be achieved, the process will be difficult for a worker to control.

Preventive Maintenance. Maintenance of equipment is generally recognized as essential, but pressures for production can result in delaying the scheduled preventive maintenance. Sometimes the delay is indefinite, the equipment breaks down, and the maintenance becomes corrective instead of preventive.

The planning should determine how often preventive maintenance is necessary, what form it should take, and how processes should be audited to ensure that preventive maintenance schedules are followed.

In the event of objections to the proposed plan for preventive maintenance on the grounds of high cost, data on the cost of poor quality from the process can help to justify the maintenance plan.

The concept of *total productive maintenance* (TPM) aims to use equipment at its maximum effectiveness by eliminating waste and losses caused by equipment malfunctions. Shenoy (1994) identifies six major process losses in a paper mill and relates them to three measures of equipment effectiveness. The concept is shown in Figure 22.9.

This model provides a means of quantifying productivity and quality.

To quantify availability:

- Available hours: 4272 hours
- Downtime due to equipment failures, setups, and adjustment: 560 hours
- Availability = (4272−560)/4272 = 0.869

To quantify performance efficiency:

- Theoretical cycle time: 0.4 hours/ton
- Production amount: 7773 tons
- Operating time: 3712.5 hours
- Performance efficiency = (0.4 × 7773)/3712.5 = 0.837

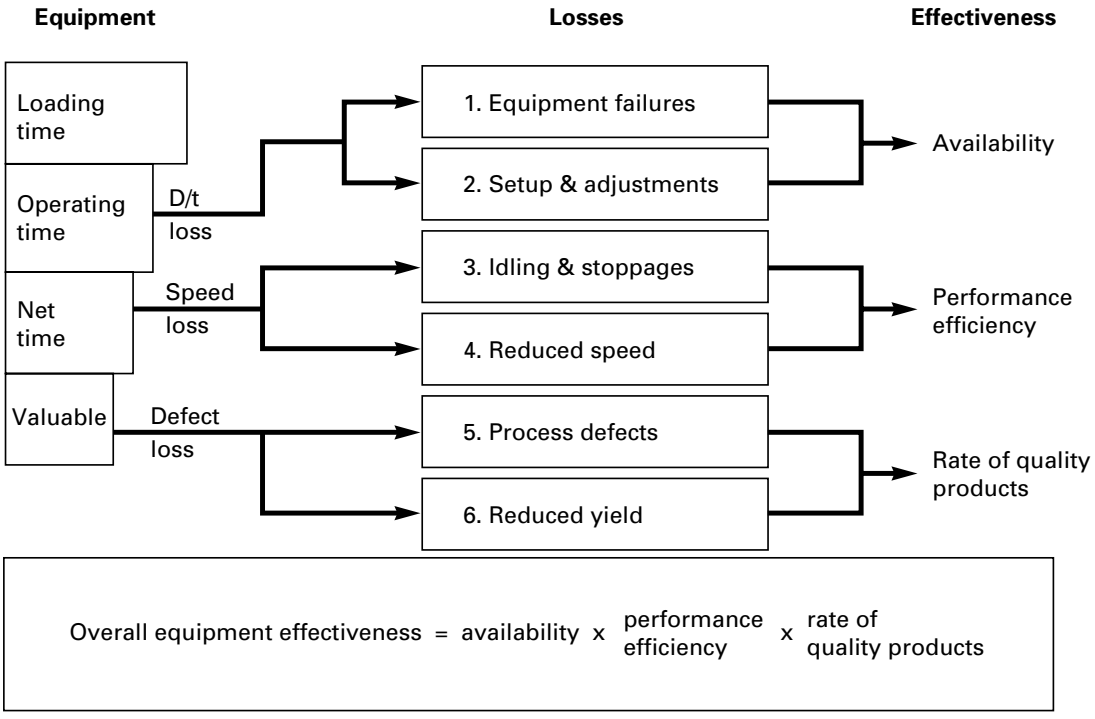

FIGURE 22.9 Six big losses and equipment effectiveness. (*Shenoy 1994.*)

To quantify the defect loss:

- Salable product: 7621 tons
- Rate of quality product: 7621/7773 = 0.98

The overall effectiveness is

$$0.869 \times 0.837 \times 0.98 \times 100 = 71.2\%$$

Note that downtime losses and cycle time (speed) losses were the major contributing factors to the low effectiveness of 71.2 percent. Particularly in backroom operations of service industries, computer downtime is emerging as a problem for operations.

OVERALL REVIEW OF MANUFACTURING PLANNING

Review of the proposed process can be accomplished most effectively through preproduction trials and runs. Techniques such as failure mode, effect, and criticality analysis can provide an even earlier warning before any product is made. Checklists for review of proposed processes also can be useful. These approaches are discussed below.

Preproduction Trials. Because the manufacturing plan starts as a mental concept, it will be "scaled up" many orders of magnitude if it goes into large-scale production. There is great risk in going directly into production from the conceptual plan primarily because of the risk of quality failures. To reduce this risk, companies make use of trial production lots (called *pilot plant production, preproduction,* etc.) to discover deficiencies in the planning and to remedy them before going into full-scale production. In some industries this concept is formalized into regular phases of scaling up.

The scaling up of production is actually a continuation of the scaling up that takes place from product design concept to prototype or model construction and test. The adequacy of the full-scale manufacturing plan cannot be judged from the record of models made in the model shop. In the model shop the basic purpose is to prove engineering feasibility; in the production shop the purpose is to meet standards of quality, cost, and delivery. The model shop machinery, tools, personnel, supervision, motivation, etc. are all different from the corresponding situations in the production shop.

Tool Tryout. At the workstation level, as new tools are completed, they are subjected to a tryout procedure that, in most companies, is highly formalized. The tryout consists of producing enough product from the new tool to demonstrate that it can meet quality standards under shop conditions.

These formalized tryouts conclude with the execution of a formal document backed up by supporting data, which always include the quality data. The release of the tool for full-scale production is contingent on the approval of this tryout document.

Limited Trial Lots. Beyond the tryouts at individual workstations, there is a need for collective tryouts. These require trial production lots, which must be scheduled for the prime purpose of proving in the manufacturing process. The trial lot is usually made in the regular production shop and provides an extensive preview of the problems that will be encountered in large-scale production. In the process industries, the equivalent intermediate scaling up is the *pilot plant.* It is widely used to provide the essential information (on quality, costs, productivity, etc.) needed to determine whether and how to go into full-scale production.

Software Verification. Software used with a process requires a tryout just like new tools—with the same degree of formality and approval process.

Experimental Lots. The trial lot concept provides opportunities for planners to test out alternatives, and they often combine the concept of experimentation with that of proving in the nonexperimental portion of the trial.

Attainment of good process yields is one of the most important purposes of experimental lots. These experiments can make use of all the techniques discussed in Section 47, Design and Analysis of Experiments, and in the various statistical sections.

Preproduction Runs. Ideally, product lots should be put through the entire system, with the deficiencies found and corrected before going into full-scale production. In practice, companies usually make some compromises with this ideal approach. The preproduction may be merely the first of the regular production, but with special provision for prompt feedback and correction of errors as found. Alternatively, the preproduction may be limited to those features of product and process design which are so new that prior experience cannot reliably provide a basis for good risk taking. While some companies do adhere to a strict rule of proving in the product and process through preproduction lots, the more usual approach is one of flexibility, in which the use of preproduction lots depends on

1. The extent to which the product embodies new or untested quality features
2. The extent to which the design of the manufacturing process embodies new or untried machines, tools, etc.
3. The amount and value of product which will be out in the field before there is conclusive evidence of the extent of process, product, and use difficulties

These trials sometimes include "production validation tests" to ensure that the full-scale process can meet the design intent. Figure 22.10 shows an example from Ford Motor Company.

Failure Mode, Effect, and Criticality Analysis for Processes A failure mode, effect, and criticality analysis is useful in analyzing the proposed design of a product (see Sections 3 and 48). The same technique can dissect the potential failure modes and their effects on a proposed process. Ishiyama (1977) discusses the application of the failure mode and effects analysis technique to both product design and manufacturing processes in the automobile industry.

The fault-tree analysis technique is also useful in analyzing a design (see Sections 3 and 48). Proposed manufacturing processes can be analyzed with this same technique. Raheja (1982) discusses this approach. Fault-tree analysis can help to identify areas of a process that require error-proofing.

A supplier of telecommunications services was about to implement a complex process to deliver a new service to customers (Plsek 1989). A team from field operations was asked to evaluate the process prior to implementation. The team constructed a flow chart and an FMEA (Figure 22.11). The FMEA was used to set priorities for addressing potential failure modes. Three factors were considered in setting priorities: probability of occurrence, impact on end customers, and impact on internal costs. Each factor was scored using a scale of 1 to 5 ("very low" to "very high").

Then

$$\text{Priority score} = \text{probability of occurrence} \times (\text{customer impact} + \text{cost impact})$$

Priority scores could range from 2 to 50. Failure modes that were highly likely to occur and whose occurrence would seriously affect *both* the customer and internal cost received the highest priority scores. Using the FMEA, the team was able to identify dozens of potential failure modes that had not been addressed adequately in the process. Eight of these were critical and could have resulted in major customer dissatisfaction or high costs.

Using this type of analysis, we probably will not identify and prevent *all* potential failure modes, but we will identify and prevent *some* serious failures that traditional process design techniques might overlook.

The fault-tree analysis technique is also useful in analyzing a design because it traces *all possible combinations of causes that could lead to a particular failure.* Proposed manufacturing processes can be analyzed with this same technique. Raheja (1982) discusses this approach. Fault-tree analysis can help to identify areas of a process that require error-proofing.

PRODUCTION VALIDATION PLAN AND REPORT #3 | 1.14-21812-A | PAGE 1 OF 3

SYSTEM 1.00 Body | ASSEMBLY Door Latch-Diab. | PROGRAM | DES. ENGR. S. Martin

SUBSYSTEM 1.14 Locks Handles & Mechs. | COMP N/A | DES LEVEL AA | CONC'R W.R.

TEST NAME SOURCE	ACCEPTANCE CRITERIA	TEST RESULTS	DES.	S/SIZE		REL. ACCEP. CRIT.		TIMING		REMARKS
				REQ.	TEST	REQ.	ACTUAL	SCH.	ACTUAL	
Life Cycle ES-Diab-652181 AB	35,000 cycles minimum at 650# rebound and 250#	21 completed 120,000 cycles	AA	21	21	$P_{.90}$ = .90	$P_{.90}$ = .90	7-15	7-20	
Static Strength FMVSS (ES)	Prim. Sec. longitude 3000 2250 transverse 4000 2700	-3σ greater than min. strength req'd (see Problem Plots)	AA	60	60	-3 σ> req't.	-3 σ> req't.	7-24	7-20	
Corrosion Resistance (ES) 48-hour salt spray	Operating efforts must not increase 25% over drawing specifications	+ 3σ less than max. effort allowed (see Problem Plots)	AA	40	40	+ 3σ< req't.	+ 3σ< req't.	7-30	8-15	

FIGURE 22.10 Production validation report. (*Ford Motor Company.*)

Process Step	Potential Failure Modes	Probability of Occurrence	Impact-On:		Priority	Effect
			Customer	Cost		
	Presubscription order too early	4	5	5	40	Can't use 1+ 10-digit dialing
	Presubscription order too late	4	5	5	40	Billing errors
	Incorrect information about exchange access end office	1	1	2	3	Equipment ordered in wrong office; delay of service

FIGURE 22.11 Process FMEA for telecommunications service. (*Stampen and Stampen 1995.*)

The ultimate review of plans for manufacturing or service operations consists of an actual test. This may consist of a small-scale "pilot test" under laboratory conditions, a modular test of a portion of a process, a computer simulation, a "dry run" of the process using regular operating personnel, or a full trial of the process under typical process conditions and including acceptance or rejection of the process output.

Evaluation of Processes. Processes should be evaluated for four parameters: effectiveness (of output), efficiency, adaptability, and cycle time. One approach for evaluating a process is the rating method developed by IBM in connection with its business process management activities. The method defines five levels of process maturity. The highest level, level 1, designates a business process that operates at maximum effectiveness and efficiency and serves as a benchmark or leader; the lowest level, level 5, suggests a process that is ineffective, may have major deficiencies, and the process management approach has not been instituted. Melan (1993) defines the specific criteria associated with each level. Criteria include both organizational matters (e.g., a process owner) and technical matters (e.g., measurements for effectiveness and efficiency).

Black (1993) describes a program for certification of a manufacturing process at Caterpillar, Inc. The requirements include a process that is significant, the product must meet specifications, all customers must be satisfied, and there must be evidence of continuous improvement. Recertification occurs annually.

A 12-step procedure for certification includes identify critical product characteristics, determine if the characteristics are in control, determine process capability, identify critical process parameters and their limits, determine if process parameters are in control and within limits, and develop an action plan to control process parameters. The procedure is at a sufficiently detailed level to achieve process control. As an example, for a foundry process making an engine block, limits on the temperature of the molten metal might be set at 2650 and 2675°F.

This internal certification procedure is particularly helpful when product is transferred to another "profit center." Under the profit center concept, a division chooses its suppliers, and they may be internal or external to Caterpillar. For example, the foundry profit center delivers an engine block to the engine assembly profit center. If the foundry engine block process is certified as meeting product requirements, the assembly division accepts the block without extensive incoming inspection. Thus the certification procedure reduces costs and maintains quality, thus helping the foundry profit center to retain the assembly division as an internal customer.

Evaluation and Reduction of Process Cycle Time. Competitive pressures to reduce cycle time are now a galvanizing force to diagnose processes for improvement. Juran (1992) explains how a flow diagram can reveal

The number of functions that are affected

The extent to which the same macroprocess is used for the vital few customers and the useful many

The existence of redoing of prior work

The extent and location of bottlenecks such as numerous needs for signatures

Additional analysis is made of the vital few individual steps (microprocesses). Here the analysis focuses on

Is there a customer for the work done in this step?

Can this step be performed after serving the customer rather than before?

What can be done to reduce the time to perform this step?

Numerous ways have been found to shorten the cycle time for macroprocesses. These include

1. Provide a simplified process for the useful many applications.
2. Reduce the number of steps and handoffs.
3. Eliminate wasteful "loops."
4. Reduce changeover time.
5. Change from consecutive to concurrent processing.

These and other remedies, of course, can benefit from changes in technology. In any case, they have resulted in some stunning reductions in cycle time.

PLANNING PROCESS CONTROLS

The process specification, procedures, and instruction sheets prepared by the planners are the software of manufacturing planning. Their purpose is to inform the production people how to set up, run, and regulate the processes so that the result will be good product. Conversely, the production people should follow these plans. Otherwise, good product might not be the result.

Many companies institute process controls to provide assurance that the plans will in fact be followed. There are several kinds of these controls, and they are established by some combination of manufacturing engineers, quality engineers, production supervisors, and workers. The precise combination varies widely from company to company.

Process control is based on the feedback loop as discussed in Section 3, under Design Feedback Loop. The steps for planning manufacturing process controls follow closely the universal approach for use of the feedback loop.

Control Criteria. While execution of the control plan is typically delegated to the work force, it is common to impose criteria to be met before the process is allowed to run. These criteria are imposed in three main areas:

1. *Setup criteria:* For some processes the start of production must await meeting setup criteria (e.g., five pieces in a row must test "good"). In critical cases this form of early warning assurance may require that a supervisor or inspector independently approve the setup.
2. *Running criteria:* For many processes there is a need to check the running periodically to decide whether the process should continue to run or should stop for readjustment. The criteria here relate to such things as frequency of check, size of sample, manner of sample selection, tests to be made, tolerances to be met.

3. *Equipment maintenance criteria:* In some processes, the equipment itself must be closely controlled if quality is to be maintained. This type of control is preventive in nature and is quite different in concept from repair of equipment breakdowns. This preventive form of equipment maintenance includes a carefully drawn set of criteria that define the essential performance characteristics of the equipment. Then, on a scheduled basis (strictly adhered to), the equipment is checked against these criteria. In the United States this aspect of equipment maintenance is not well developed, and there is need to take positive steps to strengthen it.

Relation to Product Controls. Process controls are sometimes confused with product controls, but there is a clear difference. Process controls are associated with the decision: Should the process run or stop? Product controls are associated with the decision: Does the product conform to specification? Usually both these decisions require input derived from sampling and measuring the product. (It is seldom feasible to measure the process directly.) However, the method of selecting the samples is often different. Production usually makes the "process run or stop" decision and tends to sample in ways which tell the most about the process. Inspection usually (in the United States) makes the "product conformance" decision and tends to sample in ways that tell the most about the product.

This difference in sampling can easily result in different conclusions on the "same" product. Production commonly does its sampling on a scheduled basis and at a time when the product is still traceable to specific streams of the process. Inspection often does its sampling on a random basis and at a time when traceability has begun to blur.

Despite the different purposes being served, it is feasible for the two departments to do joint planning. Usually they are able to establish their respective controls so that both purposes are well served and the respective data reinforce each other.

Control Systems and the Concept of Dominance. Specific systems for controlling characteristics can be related to the underlying factors that dominate a process. The main categories of dominance include those discussed below.

1. *Setup-dominant:* Such processes have high reproducibility and stability for the entire length of the batch to be made. Hence the control system emphasizes verification of the setup before production proceeds. Examples of such processes are drilling, labeling, heat sealing, printing, and presswork.
2. *Time-dominant:* Such a process is subject to progressive change with time (wear of tools, depletion of reagent, machine heating up). The associated control system will feature a schedule of process checks with feedback to enable the worker to make compensatory changes. Screw machining, volume filling, wood carding, and papermaking are examples of time-dominant processes.
3. *Component-dominant:* Here the quality of the input materials and components is the most influential. The control system is strongly oriented toward supplier relations along with incoming inspection and sorting of inferior lots. Many assembly operations and food formulation processes are component-dominant.
4. *Worker-dominant:* For such processes quality depends mainly on the skill and knack possessed by the production worker. The control system emphasizes such features as training courses and certification for workers, error-proofing, and worker and quality rating. Workers are dominant in processes such as welding, painting, and order picking.
5. *Information-dominant:* These are usually processes in which the job information undergoes frequent change. Hence the control system places emphasis on the accuracy and up-to-dateness of the information provided to the worker (and everyone else). Examples include order editing and "travelers" used in job shops.

The different types of dominance differ also in the tools used for process control. Table 22.8 lists the forms of process dominance along with the usual tools used for process control. Additional discussion of control tools as related to process dominance is included in Section 45.

Evaluation of Proposed Control Tools. Proposed control tools need to be evaluated for both deficiencies and excesses. One health care manufacturer uses "process failure analysis" to analyze proposed control tools. A flowchart is first prepared to identify the elements of the manufacturing system and the output. Possible failure mechanisms are listed and the control system is analyzed in terms of

1. *The failure:* probability of occurrence, criticality, effects, etc.
2. *The measurement:* method, frequency, documentation, etc.
3. *The standard of comparison:* selection, limits, etc.
4. *The feedback:* method, content, speed

The proposed control for each failure mechanism is analyzed and classified as deficient, appropriate, or excessive.

PLANNING FOR EVALUATION OF PRODUCT

The planning must recognize the need for formal evaluation of product to determine its suitability for the marketplace. Three activities are involved:

1. Measuring the product for conformance to specifications
2. Taking action on the nonconforming product
3. Communicating information on the disposition of nonconforming product

These activities are discussed in Section 23 under Inspection and Test. However, these activities impinge on the manufacturing planning process. For example, several alternatives are possible for determining conformance, i.e., to have it done by production workers, by an independent inspection force, or by a combination of both. Second, the disposition of nonconforming product involves participation by production personnel, in such forms as segregation of product in the shop, and documentation. Finally, the communication of the decisions should include feedback to Production.

TABLE 22.8 Control Tools for Forms of Process Dominanace

Setup-dominant	Time-dominant	Component-dominant	Worker-dominant	Information-dominant
Inspection of process conditions	Periodic inspection	Supplier rating	Acceptance inspection	Computer-generated information
First piece inspection	$\bar{X}$ chart	Incoming inspection	*p* chart	"Active" checking of documentation
Lot plot	Median chart	Prior operation control	*c* chart	Barcodes and electronic entry
Precontrol	$\bar{X}$ and *R* chart	Acceptance inspection	Operating scoring	Process audits
Narrow limit gauging	Precontrol	Mockup evaluation	Recertification of workers	
Attribute visual inspection	Narrow-limit gauging		Process audits	
	p chart			
	Process variables check			
	Automatic recording			
	Process audits			

AUTOMATED MANUFACTURING

In many manufacturing facilities, the computer is leading the march to automation. Several terms are important:

Computer-integrated manufacturing (CIM): This is the process of applying the computer in a planned fashion from design through manufacturing and shipping of the product. CIM has a broad scope.

Computer-aided manufacturing (CAM): This is the process in which the computer is used to plan and control the work of specific equipment.

Computer-aided design (CAD): This is the process by which the computer assists in the creation or modification of a design.

A basic reference for these areas is provided by Chang, Wysk, and Wang (1991).

Benefits to Product Quality. Automation may provide as large an increase in factory productivity as did the introduction of electric power. Product quality will benefit in several ways:

1. Automation can eliminate some of the monotonous or fatiguing tasks that cause errors by human beings. For example, when a manual seam welding operation was turned over to a robot, the scrap rate plunged from 15 percent to zero (Kegg 1985).
2. Process variation can be reduced by the automatic monitoring and continuous adjustment of process variables.
3. An important source of process troubles can be reduced, i.e., the number of machine setups.
4. Machines not only can measure product automatically but also can record, summarize, and display the data for line production operators and staff personnel. Feedback to the worker can be immediate, thus providing an early warning of impending troubles.
5. With cellular manufacture (see below), tracing a part to its origin is simplified, and this facilitates accountability for quality.
6. With CAD, the quality engineer can provide inputs early in the design stage. When a design is placed in the computer, the quality engineer can review that design over and over again and keep abreast of design changes.

Achieving these benefits requires a spectrum of concepts and techniques. Three of these are discussed below: the key functions of CIM, group technology, and flexible manufacturing systems.

With the emergence of an electronic information network provided by the Internet, a group of companies can operate as one virtual factory. This enables companies to exchange and act on information concerning inventory levels, delivery schedules, supplier lists, product specifications, and test data. It also means that CAD/CAM information and other manufacturing process information can be exchanged, data can be transferred to machines in a supplier's plant, and supplier software can be used to analyze producibility and to begin actual manufacturing.

Key Functions of Computer-Integrated Manufacturing. To integrate the computer from design through shipping involves a network of functions and associated computer systems. Willis and Sullivan (1984) describe this in terms of eight functions: design and drafting (CAD/CAM), production scheduling and control, process automation, process control, material handling and storage, maintenance scheduling and control, distribution management, and finance and accounting. Such a CIM system rests on a foundation of databases covering both manufacturing data and product data.

Lee (1995) discusses manufacturing initiatives in the perspective of global manufacturing competitiveness. CIM must integrate engineering and production with suppliers and customers globally

to interactively design, plan, and process the manufacturing activities. A globalized CIM system includes the following technologies:

1. *Concurrent product design:* Real-time design tools that will support innovation in a remote site to eliminate the time barriers to rapid transition of designs to production.
2. *Manufacturing planning:* Tools for quick selection of resources and optimal process steps.
3. *Virtual manufacturing:* A set of computer modeling and simulation tools to evaluate and predict the performance of products and processes, eliminating production delays and ensuring first-pass success.
4. *Remote performance monitoring, control, and diagnostics:* Sensing and control tools for monitoring the machines and equipment remotely to control the behavior of the manufacturing process.
5. *Knowledge learning and acquisition:* Intelligent tools for the acquisition and organization of process data to share with other manufacturing sites. The system allows global access to process data.
6. *Communications and integration:* Multimedia information environment for information processing and transferring among geographically dispersed participants.
7. *Natural language translation:* Automated translation of text between different languages.

Lee also describes research in progress to further develop these technologies.

Many manufacturing processes include automatic, self-calibrating systems with real-time closed-loop control. These processes achieve target values for product characteristics while minimizing variation around the target values.

Group Technology. *Group technology* is the process of examining all items manufactured by a company to identify those with sufficient similarity that a common design or manufacturing plan can be used. The aim is to reduce the number of new designs or new manufacturing plans. In addition to the savings in resources, group technology can improve both the quality of design and the quality of conformance by using proven designs and manufacturing plans. In many companies, only 20 percent of the parts initially thought to require new design actually need it; of the remaining new parts, 40 percent could be built from an existing design, and the other 40 percent could be created by modifying an existing design.

Flexible Manufacturing System. A *flexible manufacturing system* (FMS) is a group of several computer-controlled machine tools, linked by a materials handling system and a computer, to accommodate varying production requirements. The system can be reprogrammed to accommodate design changes or new parts. This system is in contrast to a fixed automation system, in which machinery, materials handling equipment, and controllers are organized and programmed for production of a single part or limited range of parts.

Quality Planning for Automated Processes. Planning for automated processes requires special precautions:

1. Changes in the product design may be necessary to facilitate automated manufacture. For example, robots have difficulty picking up a randomly oriented part in a bin, but a redesign of the part may solve the problem.
2. Automated manufacturing equipment is complex and has the reliability and maintainability problems of most complex products. Design planning and evaluation tools (see Section 19, Research and Development) should be a part of the design process for automated equipment.
3. All software must be thoroughly tested (see Section 20, Software Development).
4. Knowledge of process capability, precise setup of equipment, and preventive maintenance are essential.

5. When feasible, on-line automatic inspection should be integrated with the operation. With manual operation of a process, the worker can observe a defect and take action. Automated processes can have mechanical, programming, or other problems that can create a disaster if not detected early.
6. Special provisions are necessary for measurement. These include the need for rugged gauges, cleaning of the measuring surfaces, reliability of gauges, and adherence to calibration schedules.
7. Some personnel will have greater responsibility under automated manufacture, particularly when computers are made available to workers for data entry and process control. All of this requires training.

The potential benefits of the automated factory will require significant time and resources for planning. However, automation will never be total. For example, there will never be robot plumbers in the factory. Therefore, in addition to ensuring that operating personnel have the new technical skills required of automated equipment, we also must give thought to the personnel requirements of the more conventional processes and plan for recruiting, training, and retaining people for these processes too.

PLANNING FOR SELECTION, TRAINING, AND RETENTION OF PERSONNEL

The principles of selection, training, and retention of personnel are known but are not always practiced with sufficient intensity in many functions, including operations. However, this is changing as organizations increasingly spend time and resources on these personnel matters to help achieve quality goals. First, we will consider the selection of personnel.

Selection of Personnel. Norrell, a human resource company, provides client companies with traditional temporary help, managed staffing, and outsourcing services. A survey of over 1000 clients clarified the client definition of *quality* as excellence of personnel for a number of criteria. These criteria are shown in Table 22.9 for clerical and technical-industrial positions. These criteria are used in the selection and training of personnel assigned to the client companies. In another example based on a survey of five service organizations and nine manufacturers, Jeffrey (1995) identified 15 competencies that these organizations and their customers viewed as important in customer service activities by front-line employees. Many of these competencies apply to both front-line personnel and backoffice personnel.

To help in personnel selection, one human resource firm is developing a series of 50 to 100 questions to pose to prospective employees who would be assigned to client companies. The firm has data on client satisfaction with individual employees (from marketing research studies). Employees who are rated superior by clients answer certain questions differently than other employees who are not

TABLE 22.9 Criteria for Excellence

Clerical	Technical-Industrial
Punctuality	Being on time
Productivity	Showing up every day
Job skills	Having the right skills
Attitude	Keeping busy
Attire	Following safety procedures
Communication skills	Being productive
Employee preparation	Following safety procedures
Quick response by branch	Working together
	Norrell office responsiveness

superior. (Other questions result in the same response from most employees.) Responses to these "differentiating questions" will help to select new employees.

McDonald's Corporation uses an innovative job interview process for new "crew members." The interviewer asks "targeted questions" that probe the degree of customer satisfaction orientation of the applicant, teamwork orientation, work standards, and job fit. Applicants are asked to respond in terms of their own work experience. In addition, "targeted situations" are presented, and applicants are asked what action they would personally take in the situation. These situations cover interactions both with customers and with other team members.

Personality is one important attribute for many (but not all) positions in the operations function. This is increasingly the case as organizing by teams becomes more prevalent. One chemical manufacturer even places job applicants in a team problem-solving situation as part of the selection process.

One tool for evaluating personality types is the Myers-Briggs Type Indicator. This personality test describes 16 personality types that are based on four preference scales: extrovert or introvert, sensing or intuition, thinking or feeling, and judgment or perception. Thus one personality type is an extrovert, sensing, thinking, judgment person. Analyzing responses to test questions from prospective or current employees helps to determine the personality types of individuals. Organizations need many personality types, and the Myers-Briggs approach describes the contributions to the organization of each of the 16 types. By understanding the types and making job assignments accordingly, an organization can take advantage of all personality types to achieve high performance in the workplace. McDermott (1994) explains the 16 types and how the tool can help in recruiting new personnel and assigning current personnel.

Next we will consider some training aspects with respect to quality. It should be emphasized, however, that even well-planned training cannot make up for the lack of personal characteristics of people that are essential for certain positions. Thus intensive efforts in the selection process are justified.

Training. The general subject of training for quality is treated in Section 16, Training for Quality. The training required for operations personnel depends on the responsibilities assigned. Major areas of training are

1. *Job skills:* This is the minimal training. Such training must include provisions for updating, as knowledge on special knacks or other process information becomes available. Critical skills such as welding should have formal skills testing to certify that personnel can apply their training to make product that meets specifications. Passing these tests becomes a requirement for this job. Instances of falsification of tests have occurred, and steps must be taken to ensure valid results.
2. *Problem-solving tools:* Depending on the responsibilities assigned to operations, training in problem solving may be needed. A notable example is the training provided to quality circles (data collection, cause-and-effect diagrams, Pareto analysis, histograms and other graphic techniques, etc.).
3. *Process control tools:* Increasingly, production workers are receiving training in statistical control charts and other analysis techniques for routine control of a process.
4. *Importance of meeting specifications:* It is useful periodically to reinforce the importance of meeting all specifications. In one chemical company, visits are made by workers to customer sites. Immediately after each visit, the workers hold a "reflections meeting" to discuss their observations and to decide how to get the message to the rest of the work force.
5. *Basic skills:* To function effectively in a world of increasing technology and complex information, operations personnel must have basic skills in communication and mathematics. Communication skills include reading, writing, speaking, and listening; mathematical skills include arithmetic and recording and graphing of data. The 1993 National Adult Literacy Survey revealed that 47 percent of American adults have such poor literacy skills that they are unable to perform tasks that are more difficult than filling out a bank deposit slip or finding an intersection on a street map. Do not be surprised if you discover that some personnel do not understand that $8\frac{3}{4}$ is the same as 8.75. We cannot assume that all personnel possess the basic skills required of specific positions. For a discussion of how basic skills can have an impact on quality, see Perkins (1994).

One organization sets aside 5 percent of working time for training, and when the training is completed, personnel receive a 5 percent bonus. This applies at all levels in the organization.

To ensure that training efforts meet the job needs of those being trained, it is useful to formalize the setting of priorities for the training. One approach is illustrated in Figure 22.12. The position is coordinating marketing and human resource activities in a department at a community bank. To relate job abilities to training priorities, the department manager and the employee jointly create the matrix in Figure 22.12. A scale of 1 to 10 is used, with 10 being the most important. The "Employee now" column shows the current proficiency of the employee in each ability; the "Plan for improvement" column shows the goal of an agreed-on plan to enhance the ability; the "Index of improvement" column is the difference between the previous two columns; the "Priority weight" column is the product of the "Relative importance" and "Index of improvement" columns. In the last column, the raw priority scores are converted to percentages for easier comparison. This approach for setting training priorities represents two steps of an eight-step process called *training function deployment,* analogous to quality function deployment. For elaboration, see Stampen and Stampen (1995).

A national chain of restaurants provides four levels of training for new employees. A formal test (written plus a "practicum") is required at each level. Employees decide when they are ready for the test. As a level is achieved, the employee receives a pay increase and other benefits.

Solectron, a winner of the Malcolm Baldrige National Quality Award, has a work force of about 3000 employees representing 20 nationalities and 40 languages. For a description of the company's training approach and results in skills improvement for quality, communication skills, managerial leadership, and lead worker interpersonal training, see Yee and Musselwhite (1993).

Some organizations, such as IBM, are extending formal certification of skills to various levels of management. This means that even experienced managers receive training in new managerial skills and then pass a certification examination. Such certification is entered in a database of skills used to select managers for new positions.

Retention. Investing increased resources in selection and training leads to stronger efforts to retain these skilled employees. Compensation, of course, is an essential contributor to employee retention. Other factors, however, are also essential, including

1. Career planning and development
2. Designing jobs for self-control (see below)
3. Providing sufficient empowerment and other means for personnel to excel
4. Removing the sources of job stress and burnout
5. Providing continuous coaching for personnel
6. Providing for participation in departmental planning
7. Providing the opportunity to interact with customers (both external and internal)
8. Providing a variety of forms of reward and recognition

Retaining superior operations personnel, particularly in the fast-paced operations environment, is clearly important to achieve quality goals. It means hire the best people, give them the tools they need, train them, and reward them in tangible and intangible ways.

ORGANIZATIONAL FORMS ON THE OPERATIONS FLOOR

Many firms organize around functional departments having a well-defined management hierarchy. This applies both to the major functions (e.g., Operations, Marketing, Product Development) and also to sections within a functional department such as Operations.

Step 1	Step 2					
Identify Abilities	**Establish Training Priorities**					
	RELATIVE IMPORTANCE	EMPLOYEE NOW	PLAN FOR IMPROVEMENT	INDEX OF IMPROVEMENT (PLAN - NOW)	PRIORITY WGHT. (Importance Index)	PRIORITY WGHT. AS A PERCENTAGE
Coordinate Educational Offerings	9	9	9	0	0	0%
Develop Presentation Materials	6	8	9	1	6	3%
Employee Benefit Tracking	6	1	7	6	36	19%
Team Participation & Support	7	4	6	2	14	7%
Future H.R. Projects	8	2	7	5	40	21%
Payroll Back-up	9	1	7	6	54	29%
Design & Layout of Communications	5	3	5	2	10	5%
Facilitate Marketing Efforts	10	6	8	2	20	11%
Dvlp rltnshp w/ printers, ad agent, hotels	8	7	8	1	8	4%

FIGURE 22.12 Training priorities. (*Stampen and Stampen 1995.*)

Organizing by function has certain advantages—clear responsibilities, efficiency of activities within a function, and so on. But this organizational form also creates "walls" between the departments. These walls—sometimes visible, sometimes invisible—often cause serious communication barriers. The outcome can be efficient operations *within* each department but with a less-than-optimal result delivered to external (and internal) customers.

Clearly, the participation of the work force in planning and improvement has become a way of life. It seems likely that self-managing teams will replace the Taylor system (see Section 15, under Empowerment and Commitment: Self-Regulating Team).

The "organization of the future" will be influenced by the interaction of two systems that are present in all organizations: the technical system (equipment, procedures, etc.) and the social system (people, roles, etc.)—thus the name *sociotechnical systems* (STSs).

Much of the research on sociotechnical systems has concentrated on designing new ways of organizing work, particularly at the work force level. For example, supervisors are emerging as "coaches"; they teach and empower rather than assign and direct. Operators are becoming "technicians"; they perform a multiskilled job with broad decision making rather than a narrow job with limited decision making. Team concepts play an important role in these new approaches. Some organizations now report that within a given year, 40 percent of their people participate on a team; some organizations have a goal of 80 percent. Permanent teams (e.g., process team, self-managing team) are responsible for all output parameters, including quality; ad hoc teams (e.g., a quality project team) are typically responsible for improvement in quality. A summary of the most common types of quality teams is given in Table 22.10.

The literature on organizational forms in operations and other functions is extensive and increases continuously. For a discussion of research conducted on teams, see Katzenbach and Smith (1993). Mann (1994) explains how managers in process-oriented operations will need to develop skills as coaches, developers, and "boundary managers."

CONCEPT OF CONTROLLABILITY; SELF-CONTROL

When work is organized in a way that enables a person to have full mastery over the attainment of planned results, that person is said to be in a state of *self-control* and therefore can 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 clerk processing checks. The concept also applies to work teams.

To achieve self-control, people must be provided with a means for

1. Knowing what they are supposed to do, e.g., the product specification or the work procedure.
2. Knowing what they are actually doing, e.g., instruments to measure process variables or the amount of output conforming to quality requirements.
3. Regulating the process, e.g., the authority and ability to regulate the work process.

TABLE 22.10 Summary of Types of Quality Teams

	Quality project team	Quality circle	Business process quality team	Self-managing team
Purpose	Solve cross-functional quality problems	Solve problems within a department	Plan, control, and improve the quality of a key cross-functional process	Plan, execute, and control work to achieve a defined output
Membership	Combination of managers, professionals, and work force from multiple departments	Primarily work force from one department	Primarily managers and professionals from multiple departments	Primarily work force from one work area
Basis of and size of membership	Mandatory; 4–8 members	Voluntary 6–12 members	Mandatory; 4–6 members	Mandatory; all members in the work area (6–18)
Continuity	Team disbands after project is completed	Team remains intact, project after project	Permanent	Permanent
Other names	Quality improvement team	Employee involvement group	Business process management team; process team	Self-supervising team; semiautonomous team

The three basic criteria for self-control make possible a separation of defects into categories of "controllability," of which the most important are

1. *Worker-controllable:* A defect or nonconformity is worker-controllable if all three criteria for self-control have been met.
2. *Management-controllable:* A defect or nonconformity is management-controllable if one or more of the criteria for self-control have not been met.

The theory behind these categories is that only the management can provide the means for meeting the criteria for self-control. Hence any failure to meet these criteria is a failure of management, and the resulting defects are therefore beyond the control of the workers. This theory is not 100 percent sound. Workers commonly have the duty to call management's attention to deficiencies in the system of control, and sometimes they do not do so. (Sometimes they do, and it is management who fails to act.) However, the theory is much more right than wrong.

Whether the defects or nonconformities in a plant are mainly management-controllable or worker-controllable is a fact of the highest order of importance. To reduce the former requires a program in which the main contributions must come from the managers, supervisors, and technical specialists. To reduce the latter requires a different kind of program in which much of the contribution comes from the workers. The great difference between these two kinds of programs suggests that managers should quantify their knowledge of the state of controllability before embarking on major programs.

An example of controllability study is given in Table 22.11. A diagnostic team was set up to study scrap and rework reports in six machine shop departments for 17 working days. The defect cause was entered on each report by a quality engineer who was assigned to collect the data. When the cause was not apparent, the team reviewed the defect and, when necessary, contacted other specialists (who had been alerted by management about the priority of the project) to identify the cause. The purpose of the study was to resolve a lack of agreement on the causes of chronically high scrap and rework. It did the job. The study was decisive in obtaining agreement on the focus of the improvement program. In less than 1 year over $2 million was saved, and important strides were made in reducing production backlogs.

Controllability also can be evaluated by posing specific questions for each of the three criteria of self-control. (typical questions that can be posed are presented below.) Although this approach does not yield a quantitative evaluation of management-controllable and worker-controllable defects, it does show whether the defects are primarily management-controllable or worker-controllable.

TABLE 22.11 Controllability Study in a Machine Shop, %

Management-controllable	
Inadequate training	15
Machine inadequate	8
Machine maintenance	8
Other process problems	8
Materials handling	7
Tool, fixture, gauge (TFG) maintenance	6
TFG inadequate	5
Wrong material	3
Operation run out of sequence	3
Miscellaneous	5
Total	68
Worker-controllable	
Failure to check work	11
Improperly operated	11
Other (e.g., piece mislocated)	10
Total	32

In my experience, defects are about 80 percent management-controllable. This figure does not vary much from industry to industry but varies greatly among processes. Other investigators, in Japan, Sweden, the Netherlands, and Czechoslovakia, have reach similar conclusions.

While the available quantitative studies make clear that defects are mainly management-controllable, many industrial managers do not know this or are unable to accept the data. Their long-standing beliefs are that most defects are the result of worker carelessness, indifference, and even sabotage. Such managers are easily persuaded to embark on worker-motivation schemes which, under the usual state of facts, aim at a small minority of the problems and hence are doomed to achieve minor results at best. The issue is not whether quality problems *in industry* are management-controllable. The need is to determine the answer *in a given plant.* This cannot be answered authoritatively by opinion but requires solid facts, preferably through a controllability study of actual defects, as in Table 22.11.

The concept of self-control draws attention to the importance of manufacturing planning. Manufacturing planning for quality is the means of *prevention* of both management- and worker-controllable defects on the manufacturing floor.

Collins and Collins (1993) provide six examples from the manufacturing and service sectors illustrating problems that were originally blamed on people but which really were management-controllable (often called *systems-controllable*). A similar situation is found in the service sector. Berry, Parasuramen, and Zeithmal (1994) identified 10 lessons learned in improving service quality. Three of these are service design ("The real culprit is poor service system design"), employee research (Ask employees why service problems occur and what they need to do their jobs), and servant leadership (Managers must serve by coaching, teaching, and listening to employees). Note that these three lessons are directly related to the concept of self-control.

Often in practice the 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); and people do not know how to correct a process (the third criterion).

The section on operations focuses on the factory floor and backroom operations in service firms. The concept of self-control, however, also applies to operations activities that involve extensive front-line customer contact.

The freedom provided to individuals working in a state of self-control inspires initiative, creativity, and a sense of well-being, all leading to self-development of the individual. Designing—and maintaining—work activities to meet the three criteria of self-control is a prerequisite to motivating personnel to achieve quality goals. Only management can create and maintain the conditions for self-control. If jobs are designed for self-control, management might hear a chorus of appreciation from the work force—followed by a smash hit of success on quality. Self-control is related to the broader concept of democracy in the workplace [see Rubinstein (1993) for elaboration)]. The three criteria for self-control are discussed below.

KNOWLEDGE OF "SUPPOSED TO DO"

This knowledge commonly consists of the following:

1. The product standard, which may be a written specification, a product sample, or other definition of the end result to be attained.
2. The process standard, which may be a written process specification, written process instructions, an oral instruction, or other definition of "means to an end"
3. A definition of responsibility, i.e., what decisions to make and what actions to take (discussed earlier in this section)

Product Specifications. The ideal source of knowledge is the use required by the user. In most situations this is translated into a product specification. In developing these product specifications, some essential precautions must be observed.

Provide Unequivocal Information. Two obstacles to proper knowledge can exist:

1. The specification may be vague. For example, when fiberglass tanks are transported in vehicles, the surface of the supporting cradles should be smooth. It was recognized that weld spatter would be deposited on the cradle surface, so an operation was specified to scrape the surface "smooth." However, there was no definition of "how smooth," and many rejections resulted.
2. There may be conflicting specifications. The supervisor's "black book" has had a long, durable career. Changes in specifications may fail to be communicated, especially when there is a constant parade of changes. In one instance, an inspector rejected product that lacked an angle cut needed for clearance in assembly. It was discovered that the inspector was using drawing revision D, the production floor had used revision B, and the design office had issued revision E just 3 days before.

Provide Information on Seriousness. All specifications contain multiple characteristics, and these are not equally important. When workers are informed of the vital few characteristics, their emphasis is better placed.

Explain the "Why." Explanation of the purposes served by the product and by the specification enlarges the knowledge of "supposed to do" and provides motivation through the resulting feeling of participation.

For example, a specification on weight called for a nominal value of 40.0 g with a tolerance of ±0.5 g. Although the total tolerance of 1.0 was being met, most of the tolerance range was being used up, and this created some problems later in assembly. A process capability study showed that the process capability was 0.10 g—far better than the tolerance of 1.0 g. But why was most of the tolerance range being used? Discussion revealed that (1) workers had not been told of the impact of inconsistent weights on later assembly, and (2) workers had not been instructed on centering the process to the nominal specification value.

Provide Standards. In those cases where the specification cannot be quantitative, physical or photographic standards should be provided. There is an extensive array of needs here, especially on widely prevailing characteristics such as product appearance. (For years, enormous numbers of electrical connections were soldered in the absence of clear standards for an acceptable soldered connection.) If these standards are not provided by the managers and engineers, then, by default, the standards will be set by the inspectors and workers.

Process Specifications. Work methods and process conditions (e.g., temperature, pressure, time cycles) must be unequivocally clear. A steel manufacturer uses a highly structured system of identifying key process variables, defining process control standards, communicating the information to the work force, monitoring performance, and performing diagnosis when problems arise. The process specification is a collection of process control standard procedures. A procedure is developed for controlling each of the key process variables (variables that must be controlled in order to meet specification limits on the product). The procedure answers the following questions:

1. What are the process standards?
2. Why is control needed?
3. Who is responsible for control?
4. How is measurement made?
5. When is measurement made?
6. How are routine data reported?
7. Who is responsible for data reporting?
8. How is audit conducted?

9. Who is responsible for audit?
10. What is done with product that is out of compliance?
11. Who developed the standard?

Often, detailed process instructions are not known until workers have experience with the process. Updating of process instructions based on job experience can be conveniently accomplished by posting a cause-and-effect diagram (see Section 5, under Formulation of Theories, Arrangement of Theories) in the Operations Department and inviting employees to attach index cards to the diagram. Each card recommends additional process instructions based on recent experience.

The Primester Division of Eastman Chemical immediately communicates changes in product and process specifications electronically to operations, and the software includes checks for understanding, assimilation, and retention of the changes.

Ford and Leader (1989) explain experiences in integrating group dynamics, communication skills, conflict management, and other "human dynamics" issues in a statistical process control activity. Newberg and Nielsen (1990) explain an approach to "operator control" in which operators participate to remove barriers (to operator control), develop process controls, and receive specific job training for a process producing soup. This participation includes operator use of flow diagrams to establish "critical control points" for the process.

Checklist for Manufacturing. The preceding discussion covers the first criterion of self-control; people must have the means for knowing what they are supposed to do. To evaluate adherence to this criterion, a checklist of questions can be created, including the following:

1. Are there written product specifications, process specifications, and work instructions? If written in more than one place, do they all agree? Are they legible? Are they conveniently accessible to the worker?
2. Does the specification define the relative importance of different quality characteristics? Are advisory tolerances on a process distinguished from mandatory tolerances on a product? If control charts or other control techniques are to be used, is it clear how these relate to product specifications?
3. Are standards for visual defects displayed in the work area?
4. Are the written specifications given to the worker the same as the criteria used by inspectors? Are deviations from the specification often allowed?
5. Does the worker know how the product is used?
6. Has the worker been adequately trained to understand the specification and perform the steps needed to meet the specification? Has the worker been evaluated by test or other means to see if he or she is qualified?
7. Does the worker know the effect on future operations and product performance if the specification is not met?
8. Does the worker receive specification changes automatically and promptly?
9. Does the worker know what to do with defective raw material and defective finished product?
10. Have the responsibilities in terms of decisions and actions been clearly defined?

(A checklist for self-control as applied to manufacturing operations was originally presented by L. A. Seder in the second edition of this handbook.)

The manufacturing sector has a long history of documenting quality and other requirements in the form of product and process specifications, work procedures, and other forms of written information. In the service sector, the formalization of quality requirements and associated documentation is now evolving. Highly detailed product specifications and process specifications are not yet common documents in service firms. Nevertheless, providing personnel in the service sector with the knowledge of what they are supposed to do is essential for self-control.

A framework starts with identifying control subjects. Control subjects are the features (or characteristics) that must be addressed to meet customer needs. Control subjects are a mixture of

Features of the product: Some control is carried out by evaluating features of the work product itself (e.g., the time to process an application or the completeness of a report). In manufacturing, these features are described in a product specification.

Features of the process: Much control consists of evaluating those features of the work process which directly affect the product features and therefore customer needs (e.g., the availability of equipment, the staffing levels for a service desk, the frequency of "out of stock" conditions, etc.). In manufacturing, a "process specification" describes these features. Such a specification is translated into procedures for use by operations personnel. Gass (1994) explains an approach for preparing and implementing procedures that encourages the use of the procedures on the operations floor. For service processes, Pyzdek (1994) describes a framework of service systems engineering.

Side effects: Some features that do not affect the work product directly but which may create troublesome side effects (e.g., irritations to employees, offense to the neighborhood, or threats to the environment) also can be control subjects.

Examples of control subjects and their relation to products and processes are shown in Table 22.12. To choose control subjects requires these steps: identify the major work process, identify the process objective, describe the work process, identify customers of the process, discover customer needs, and finally, select the control subjects. For elaboration, see Section 3, under Step 6: Develop Process Controls.

For self-control, these control subjects should be quantified and measured using appropriate units of measure and sensors. This quantification involves two kinds of indicators that must be made explicit for those running the process:

1. *Performance indicators:* These measure the output of the process and its conformance to customer needs as defined by the unit of measure for the control subject.
2. *Process indicators:* These measure activities or variation within the process that affect the performance indicators.

For clarity to personnel running a process, these indicators should have target values and maximum and minimum limits, where appropriate.

TABLE 22.12 Control Subjects

Major work product	Major work process	Control subjects
Photo developing	Film processing	Maintenance of chemicals Accuracy of placement of film on spool
Medical insurance	Claim processing	Accuracy of claim form Completeness of supporting documentation
Printing	Billing process	Accuracy of invoices Maintenance of customer information
Over-the-counter cold medications	Packaging of bottles	Safety seals Number of tablets per bottle
Catering services	Food preparation	Freshness of ingredients Oven temperature
Industrial tubing	Manufacture of tubing	Speed of intrusion machine Heat of machine
24-Hour banking services	Maintenance of ATM machines	Availability of cash Number of service people available

Source: Juran Institute (1995, pp. 1–45).

Checklist for Services. Based on research (Shirley and Gryna 1998) with personnel in backroom operations of the financial services industry, the following questions can help to evaluate if personnel "know what they are supposed to do":

Work Procedures

1. Are job descriptions published, available, and up to date?
2. Do personnel know who their customers are? Have they ever met them?
3. Do personnel who perform the job have any impact on the formulation of the job procedure?
4. Are job techniques and terminologies consistent with the background and training of personnel?
5. Are there guides and aids (e.g., computer prompts) that lead personnel to the next step in a job?
6. Are there provisions to audit procedures periodically and make changes? Are changes communicated to all affected personnel?
7. Are there provisions for deviations from "home office" directives to meet local conditions?
8. Are procedures "reader friendly"?
9. Does supervision have a thorough knowledge of the operations to provide assistance when problems arise?
10. Do procedures given to personnel fully apply to the job they do in practice?
11. Have personnel responsibilities been clearly defined in terms of decisions and actions?
12. Do personnel know what happens to their output in the next stage of operations and understand the consequences of not doing the job correctly?
13. If appropriate, is job rotation used?

Performance Standards

14. Are formal job standards on quality and quantity needed? If "yes," do they exist. Are they in written form?
15. Have personnel been told about the relative priority of quality versus quantity of output? Do personnel really understand the explanation?
16. Are job standards reviewed and changed when more tasks are added to a job?
17. Do personnel feel accountable for their output, or do they believe that shortcomings are not under their control?
18. Does information from a supervisor about how to do a job always agree with information received from a higher level manager?

Training

19. Are personnel given an overview of the entire organization?
20. Is there regularly scheduled training to provide personnel with current information on customer needs and new technology?
21. Do personnel and their managers provide input to their training needs?
22. Does training include the "why," not just the "what"?
23. Does the design of the training program consider the background of those to be trained?
24. Do the people doing the training provide enough detail? Do they know how to do the job?
25. Where appropriate, are personnel who are new to a job provided with mentors?

KNOWLEDGE OF "IS DOING"

This is the second criterion for self-control. For self-control, people must have the means of knowing whether their performance conforms to standard. This conformance applies to

1. The product in the form of specifications on product characteristics
2. The process in the form of specifications on process variables

The knowledge is secured from three primary sources: measurements inherent in the process, measurements by production workers, and measurements by inspectors.

Measurement Inherent in the Process. Many processes are engineered to include much instrumentation. The resulting information provides a feedback to enable the workers to close the loop. Even where the feedback is into an automated system, the data are usually available to human workers acting as monitors.

Measurements by Workers Where the worker is to use the instruments, it is necessary to provide training in how to measure, what sampling criteria to use, how to record, how to chart, and what kinds of corrective action to take. The difficulty of motivating the workers to follow these instructions is so widespread a problem that many companies go to great lengths to minimize the need for worker action by providing instruments that require little or no human effort to measure, record, and control.

When these instruments are provided to workers, it is also necessary to ensure that these instruments are compatible with those used by inspectors and in other operations later in the progression of events.

On one construction project, the "form setters" were provided with carpenter levels and rulers to set the height of forms prior to the pouring of concrete. The inspectors were provided with a complex optical instrument. The differences in measurement led to many disputes.

Control of the process is strengthened if the worker is provided with the type of gauge that provides numerical measurements on a characteristic rather than providing accept-reject information.

A problem arises when the measurement necessary to control a process must be made in a laboratory off the production floor. The time required to send a sample to the laboratory, to have the analysis made, and to have the data relayed back to production can result in a delay to proper control of a process. One solution is the development of auxiliary measuring devices that can be used on the production floor by the worker and thereby provide immediate feedback. An example comes from a process used to control the concentration of chloride in a corn product derivative. Traditionally, the raw material undergoes centrifuging, a sample of the product is sent to a laboratory for analysis, the test results are forwarded to Production, and any necessary changes are then made in the centrifugal loads. (Chloride level, for the most part, is dependent on the load size of crystallized liquor being spun in the centrifugals.) Under the new setup, the worker takes a spot sample at the surge bin and analyzes the product for parts per million chloride on an ion analyzer and thereby directly regulates the process. Total time between processing a batch and obtaining a measurement plunges from 90 to 20 minutes. As a result, the amount of inferior product due to delayed process adjustment is greatly reduced.

Parker (1981) describes how the use of on-line gauges overcame problems in obtaining adequate sampling of product at a paper mill.

Measurements by Inspectors. When an Inspection Department makes measurements that are to serve as a basis for action by Operations, the feedback usually goes to both workers and supervisors.

Criteria for Good Feedback to Workers. The needs of production workers (as distinguished from supervisors or technical specialists) require that the data feedback read at a glance deals only with the few important defects, deals only with worker-controllable defects, provides prompt information about symptom and cause, and provides enough information to guide corrective actions. Criteria of good feedback are

1. *Read at a glance:* The pace of events on the factory floor is swift. Workers should be able to review the feedback in stride.

Where the worker needs information about process performance over time, charts can provide an excellent form of feedback, provided they are designed to be consistent with the assigned responsibility of the worker (Table 22.13). It is useful to use visual displays to highlight recurrent problems. A problem described as "outer hopper switch installed backwards" displayed on a wall chart in large block letters has much more impact than the same message buried away as a marginal note in a work folder. Carlisle (1981) describes the effectiveness of such a system.

2. *Deal only with the few important defects:* Overwhelming workers with data on all defects will result in diverting attention from the vital few.

3. *Deal only with worker-controllable defects:* Any other course provides a basis for argument which will be unfruitful.

4. *Provide prompt information about symptom and cause:* Timeliness is a basic test of good feedback the closer the system is to "real time" signaling, the better.

5. *Provide enough information to guide corrective action:* The signal should be in terms that make it easy to decide on remedial action.

Software helps to collect, analyze, and display process data on a real-time basis. The control chart in Figure 22.13 shows an example of operator feedback in printed wiring assembly manufacture at Group Technologies. The unit of measure is defects per million opportunities (DPMO); the "Alarm line" is the computed average DPMO. Depending on the color of this line, the operator receives guidance on controlling the process. If the color is black, the process is acceptable, and the operator maintains the process under current conditions; a yellow color alerts the operator to exercise caution; a red color directs the operator to stop the process and seek help from a supervisor or a "reaction team." Limits for each of the zones are set by the process engineer based on customer specifications.

TABLE 22.13 Worker Responsibility versus Chart Design

Responsibility of the worker is to	Chart should be designed to show
1. Make individual units of product meet a product specification	The measurements of individual units of product compared to product specification limits
2. Hold process conditions to the requirements of a process specification	The measurements of the process conditions compared with the process specification limits
3. Hold averages and ranges to specified statistical control limits	The averages and ranges compared to the statistical control limits
4. Hold percent nonconforming below some prescribed level	Actual percent nonconforming compared to the limiting level

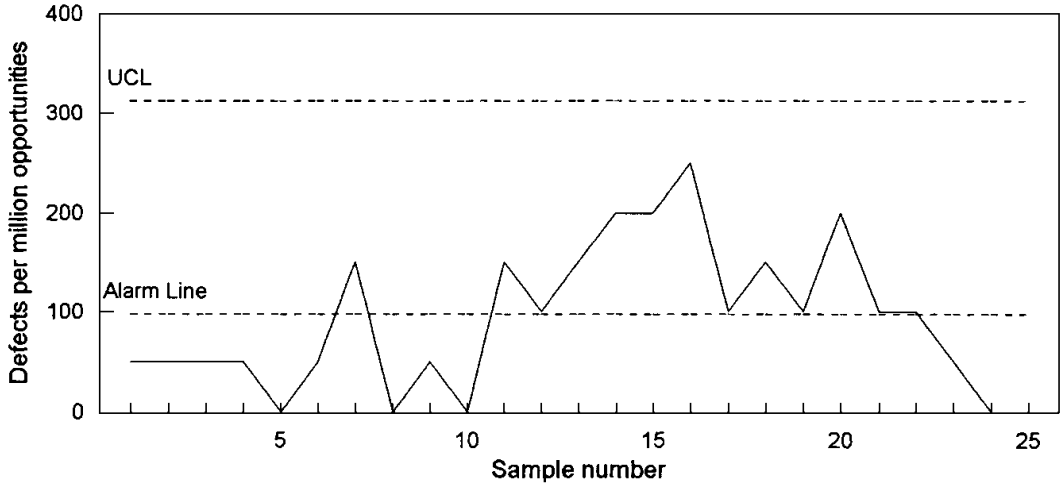

FIGURE 22.13 Operator feedback chart. (*Group Technologies Corporation internal document.*)

The control chart is just one of the many tools of statistical process control (SPC). SPC provides an arsenal of tools that operations people need to understand and apply. For elaboration, see Section 45, Statistical Process Control.

Feedback Related to Worker Action. The worker needs to know what kind of process change to make to respond to a product deviation. Sources of this knowledge are

1. The process specification
2. Cut-and-try experience by the worker
3. The fact that the units of measure for product and process are identical

Lacking all these, the workers can only cut and try further or stop the process and sound the alarm.

Sometimes it is feasible for the data feedback to be supplemented with other graphic information that enables process personnel to decide on and take appropriate action on the process. Foster and Zirk (1992) explain how complex research and development information can be converted into "multiple curve plots" for use by process workers. An illustration is given in Figure 22.14. In a hydrocarbon cracking process, two of the operator-controlled variables are fuel capacity and burner air opening (BAO). The graphs serve as operating guides for workers to adjust the two variables.

Feedback to Supervisors. Beyond the need for feedback at the workstations, there is need to provide supervisors with short-term summaries. These take several forms.

Matrix Summary. A common form of matrix is workers versus defects; i.e., the vertical columns are headed by worker names and the horizontal rows by the names of defect types. The matrix makes clear which defect types predominate, which workers have the most defects, and what the interaction is. Other matrices include machine number versus defect type, defect type versus calendar week, and so on.

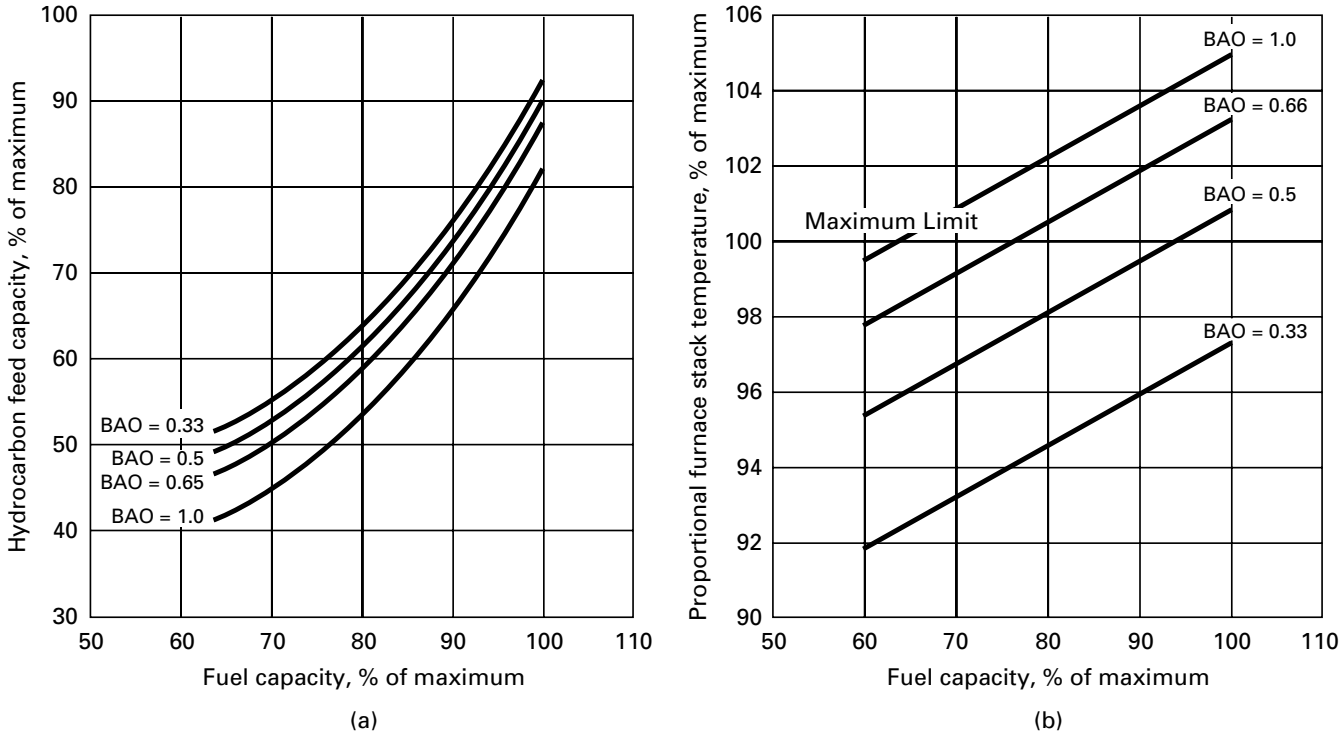

FIGURE 22.14 (*a*) Hydrocarbon feed capacity. (*b*) Proportional furnace stack temperature. [Parameter: burner air opening, area fraction; fixed condition: furnace draft = 0.065 inches H_2O.] (*Foster and Zirk 1992.*)

When the summary is published, it is usual to circle the matrix cells to highlight the vital few situations that call for attention. An elaboration of the matrix is to split the cell diagonally, permitting the entry of two numbers, e.g., number defective and number produced.

Pareto Analysis. Some companies prefer to minimize the detail and provide information on the total defects for the day plus a list of the top three (or so) defects encountered and how many of each. Increasingly, supervisors can monitor processes by reviewing summarized and detailed process data on a personal computer (PC) in their office. One manufacturer even makes data available on a PC at the homes of people who are "on call" to assist on process problems.

Special Graphing of Multiple Parameters. Traditionally, individual parameters are tracked in a process. The single-measure approach can lead to focusing on the numbers and not on the practices that drive desired performance. Madigan (1993) describes a chart that provides a "holistic approach to understanding operations." First, measures are identified that describe factors that are critical to the success of the operation. For example, in a building services operation, the measures relate to training, cleaning area, safety, wages, and absentee rate. Data are gathered from four plants. For each measure, the plant with the best result serves as a benchmark. The *measures matrix chart* consists of concentric circles that plot the data from all five measures and provide a profile of the average values and a profile of each plant. The approach is used in both service and manufacturing applications at Eastman Kodak. For further explanation, see Madigan (1993).

Automated Quality Information. Production volume and complexity are important factors in determining the role of the computer. However, the role can be important even in relatively simple processes. For example, in a fast-food franchise, the elapsed time in filling a customer order is visibly shown (the goal is 45 seconds); the number of calls waiting to be answered in an insurance service center is clearly displayed. Section 10, Computer Applications in Quality Systems, explains the role of computers in analyzing and reporting data during production and other phases of the product life cycle.

Checklist for Manufacturing A checklist to evaluate the second criterion of self-control includes questions such as

1. Are gauges provided to the worker? Do they provide numerical measurements rather than sort good from bad? Are they precise enough? Are they regularly checked for accuracy?
2. Is the worker told how often to sample work? Is sufficient time allowed?
3. Is the worker told how to evaluate measurements to decide when to adjust the process and when to leave it alone?
4. Is there a check to see that the worker does follow instructions on sampling work and making process adjustments?
5. Are inspection results provided to the worker, and are these results reviewed by the supervisor with the worker?

Examples of the second criterion of self-control also can be found in the service sector. These focus on identification and measurement of service indicators. A credit card provider has identified 18 key processes covering all activities: 2 business processes, 6 support processes, 10 product and service production and delivery processes. Two examples of production processes are credit screening and payment processing. For the total of 18 processes, over 100 internal and supplier process measures were defined. (In addition, external customer satisfaction research is conducted.) Daily and monthly performance results are available through video monitors and are also posted. Each morning, the head of operations meets with senior managers to discuss the latest results, identify problems, and propose solutions. Employees can access a summary of this meeting via telephone or electronic mail.

To emphasize the importance of quality, the measurement system is linked to compensation by a daily bonus system that provides up to 12 percent of base salary for nonmanagers and 8 to 12 percent for managers. For elaboration, see Davis et al. (1995).

Hestand (1991) explains how a bank uses a "report card" to measure the services provided to internal customers. Performance on specific quality measures is rated from A (excellent) to F (fails to meet requirements). At each participating branch, ratings are provided by a branch manager (BR MAN), an operations manager (OP MAN), and a customer service representative (CSR). A sample of the results for two measurements is presented in Table 22.14. Thus, for the accuracy of proof item encoding measurement, the total frequency of grades reported ranged from 2 A's, to 38 B's, to 0 F's. (The letter grades are also expressed in numerical form.) Further detail is automatically provided on D and F grades along with a procedure on follow-up toreport action taken.

One fast-food firm creates teams of "crew members" (workers at one location) who are trained to manage the site without a full-time manager (Harvard Business School 1994). Not only does this mean installing on-line technology such as the time to prepare an order, but it also means providing crew members with the same operating and financial information provided to a restaurant general manager to run the site. At these "team-managed units," the crew members make decisions on such matters as ordering food. Thus knowledge that long separated "brain workers" from "hand workers" now resides in a computer on the operations floor.

Lochner (1995) explains the use of a balanced set of measures in health care activities and makes the distinction between process measures (room occupancy rate) versus results measures (waiting time at admissions). Latzko (1993) explains the use of quality measurements to identify key potential "quality deviations" in a retail lending function at a bank. Early (1989) provides guidance on developing quality measures in the service sector.

Checklist for Services. A checklist developed from discussions with personnel in backroom operations in financial service is provided below (Shirley and Gryna 1998):

Review of Work

1. Are personnel provided with the time and instructions for making self-review of their work?
2. Can errors be detected easily?
3. Are independent checks on quality needed? Are they performed? Are these checks performed by peer personnel or others?

TABLE 22.14 Examples of Quality Measurements from Internal Customers: Proof Department

72. Promptness of responses to special requests								
	A	B	C	D	F	N/A	?	
Total	7	26	30	5	0	22	3	2.51
BR MAN	1	7	10	2	0	11	0	2.35
OP MAN	3	9	12	1	0	6	0	2.56
CSR	3	10	8	2	0	5	3	2.61
73. Accuracy of proof item encoding for transactions received by branch								
	A	B	C	D	F	N/A	?	
Total	2	38	23	3	0	26	0	2.59
BR MAN	1	10	6	1	0	13	0	2.61
OP MAN	1	20	9	0	0	1	0	2.73
CSR	0	8	8	2	0	12	0	2.33

Source: Hestand (1991).

4. Is a review of work performed at various checkpoints in a process, not just when work is completed? Is the sample size sufficient?
5. Is there an independent audit of an entire process to ensure that individual work assignments are integrated to achieve process objectives?
6. Where appropriate, are detailed logs kept on customer contracts?

Feedback

7. Do upper management and supervision both provide the same message and actions on the importance of quality versus quantity?
8. If needed, do standards exist on making corrections to output?
9. Where appropriate, is feedback provided to both individuals and a group of personnel? Is time provided for discussion with the supervisor, and does the discussion occur?
10. Is feedback provided to those who need it? Is it timely? Is it personnel specific?
11. Does feedback provide the level of detail needed particularly to correct problem areas? Have personnel been asked what detail is needed in the feedback?
12. Is feedback provided from customers (external or internal) to show the importance of the output and its quality?
13. Does feedback include information on both quality and quantity?
14. Is positive in addition to negative (corrective) feedback provided?
15. Is negative (corrective) feedback given in private?
16. Do personnel receive a detailed report of errors by specific type of error?
17. Where appropriate, are reports prepared describing trends in quality (in terms of specific errors)? Is this done for individual personnel and for an entire process performed by a group of people?
18. Are there certain types of errors that are tracked with feedback from external customers? Could some of these be tracked with an internal early indicator?

ABILITY TO REGULATE

This is the third criterion for self-control. Regulating the process must always include both the authority to regulate and the ability to regulate. Regulation depends on a number of conditions, including

1. *The process must be capable of meeting the specifications:* (See above under Process Capability.)

2. *The process must be responsive to regulating mechanisms in a predictable cause-and-effect relationship (this is essential to minimize variation):* In a process for making polyethylene film, the workers were required to meet multiple product parameters. The equipment had various regulating devices, each of which could vary performance with respect to one or more parameters. The workers, however, could not "dial in" a predetermined list of settings that would meet all parameters. Instead, it was necessary to cut and try in order to meet all parameters simultaneously. During the period of cut and try, the machine produced nonconforming product to an extent that interfered with meeting standards for productivity and delivery. The workers were unable to predict how long the cut-and-try process would go on before full conformance was achieved. Consequently, it became the practice to stop cut and try after a reasonable amount of time and to let the process run, whether in conformance or not.

Skrabec (1991) describes how a cause-and-effect diagram can be combined with a process flow diagram to relate key input variables to key output variables. The result provides a guide for making process changes.

3. *The worker must be trained in how to use the regulating mechanisms and procedures:* This training should cover the entire spectrum of action: under what conditions to act, what kind and extent of changes to make, how to use the regulating devices, and why these changes need to be done.

Of three qualified workers on a food process, only one operated the process every week and became proficient. The other two workers were used when the primary worker was on vacation or was ill, and thus they never became proficient. Continuous training of the relief people was considered uneconomical, and agreements with the union prohibited their use except under the situations cited. This problem is management-controllable; i.e., additional training or a change in union agreements is necessary.

4. *The act of adjustment should not be personally distasteful to the worker, e.g., should not require undue physical exertion:* In a plant making glass bottles, one adjustment mechanism was located next to a furnace area. During the summer months, this area was so hot that workers tended to keep out as much as possible.

When the regulation consists of varying the human component of the operation, the question of process capability arises in a new form: Does the worker have the capability to regulate? This important question is discussed in Section 5, under Technique Errors, which includes some examples of discovering worker "knack."

5. *The process must be maintained sufficiently to retain its inherent capability:* Without adequate maintenance, equipment breaks down and requires frequent adjustments—often with an increase in both defects and variability around a nominal value. Clearly, such maintenance must be both preventive and corrective. The importance of maintenance has given rise to the concept of total productive maintenance (TPM). Under this approach, teams are formed to identify, analyze, and solve maintenance problems for the purpose of maximizing the uptime of process equipment. These teams consist of production line workers, maintenance personnel, process engineers, and others as needed. Problems are kept narrow in scope to encourage a steady stream of small improvements. Examples of improvement include a reduction in the number of tools lost and simplification of process adjustments.

Process Control Tools. The tools selected are often related to one of five forms of dominance in a process: setup, time, component, worker, and information. For a listing of specific process control tools related to each form, see above under Planning Process Controls.

Checklist for Manufacturing. A checklist to evaluate the third criterion of self-control typically includes such questions as the following:

1. Has the quality capability of the process been measured to include both inherent variability and variability due to time? Is the capability periodically checked?
2. Has the worker been told how often to reset the process or how to evaluate measurements to decide when the process should be reset?
3. Is there a process adjustment that the worker can make to eliminate defects? Under what conditions should the worker adjust the process? When should the worker shut down the machine and seek more help? Whose help?
4. Have the worker actions that cause defects, and the necessary preventive action, been given to the worker, preferably in the written form?
5. Is there an adequate preventive maintenance program on the process?
6. Is there a hidden knack possessed by some workers that needs to be discovered and transmitted to all workers?

Following a brief discussion of empowerment, a similar checklist will be provided for the service sector.

Empowerment. In providing sufficient authority for process regulation, the concept of empowerment plays an important part. *Empowerment* is the process of delegating decision-making authority to lower levels within the organization. Particularly dramatic is empowerment of the work force. But empowerment goes far beyond delegating authority and providing additional training. It means encouraging people to take the initiative and broaden their scope; it also means being supportive if they make mistakes.

As employees become more empowered in their work, the feeling of ownership and responsibility becomes more meaningful. Further, the act of empowering employees provides evidence of management's trust. Additional evidence is furnished when management shares confidential business information with employees. For many organizations, such steps are clearly a change in the culture.

The concept of empowerment applies both to individuals and to groups of workers. Self-managed teams (see Section 15, under Empowerment and Commitment: Self-Regulating Team) provide an illustration of empowerment for groups of workers. With empowerment comes the need to redefine the basic roles of upper management, middle management, and the work force. One model at a bank looks like this:

> *Upper managers* act as shapers and coaches. As shapers, they create, communicate, and support the organization's mission. As coaches, they help when asked but avoid entering into the day-to-day problems of middle management.
>
> *Middle managers* not only run their areas of responsibility but also work as a group to integrate all parts of the organization. In addition, they support the work force by eliminating obstacles to progress.
>
> The *workers* are the primary producers of the output for customers. Their closeness to and knowledge about their work means that they uses their empowerment to determine how the work can best be done.

Dramatic illustrations of empowerment of the work force from authorizing a worker to stop the production line to authorizing clerks to make check-cashing decisions span all industries. Shay et al. (1991) trace the history, approach, and results of empowerment at an unusual firm—a century-old manufacturing plant with seven unions. The new system uses self-managing teams with new roles for supervisors, operators, and inspectors. Hayes (1994) shows how an employee questionnaire can be developed to learn the extent of empowerment within a firm. Simons (1995) explains how in an environment of empowering personnel, a firm may be exposed to some business risks that can be minimized by following four approaches, which he describes.

Checklist for Services. A checklist for the third criterion, developed from discussions with personnel in backroom operations of financial service, is provided below (Shirley and Gryna 1998).

Job Design

1. Is the process (including procedures, equipment, software, etc.) given to personnel capable of meeting standards on quality and quantity of output? Has this capability been verified by trial under normal operating conditions?
2. Has the design of the job made use of the principles of error-proofing?
3. Does the job design minimize monotonous or unpleasant tasks?
4. Have provisions been made in the job design to anticipate and minimize errors due to normal interruptions in the work cycle?
5. Can special checks be created (e.g., balancing of accounts) to detect errors?
6. Can steps be incorporated in data entry processes to reject incorrect entries?
7. Does the job design include provisions for action when wrong information is submitted or information is missing as an input to a job?
8. Is paperwork periodically examined and obsolete records destroyed to simplify working conditions?

9. When volume of work changes significantly, are there provisions for adjusting individual responsibilities or adding resources?
10. Are there external factors (e.g., no account number on a check, cash received instead of a check, etc.) that hinder the ability to perform a task?
11. Are some personnel cross-trained for different tasks to provide an adequate supply of experienced personnel for filling in when needed?
12. If appropriate, is a "productive hour" scheduled each day in which phone calls and other interruptions are not allowed, thus providing time to be away from the work location to attend to other tasks?
13. Has equipment, including any software, been designed to be compatible with the abilities and limitations of personnel?
14. Is there an adequate preventive maintenance program for computers and other equipment used by personnel?
15. Is there a hidden knack possessed by some personnel that needs to be discovered and explained to all personnel?
16. For a job requiring special skills, have personnel been selected to ensure the best match of personnel skills and job requirements?

Changes in Job Design

17. Are proposed changes limited by technology (e.g., address fields on forms)?
18. Can personnel institute changes in a job when they show that the change will provide benefits? Are personnel encouraged to suggest changes?
19. What levels of approval by management are required for proposed changes to be instituted? Could certain types of changes be identified as not needing any level of management approval?
20. Do management actions confirm that they are open to recommendations from all personnel?

Handling Problems

21. Have personnel been provided with the time and training to identify problems, analyze problems, and develop solutions? Does this include diagnostic training to look for patterns of errors and determine sources and causes?
22. Are personnel permitted to exceed permitted process limits (e.g., maximum time on a customer phone call) if they believe it is necessary?
23. When personnel encounter an obstacle on a job, do they know where to seek assistance? Is the assistance conveniently available?

Use of Checklists on Self-Control. The checklists presented have several applications in operations:

1. *The design of new jobs and redesign of old jobs to assist in the prevention of errors and to place personnel in a state of self-control:* The checklist can serve as a tool to evaluate all quality-related aspects of the job, e.g., clarity of formal requirements and job instructions, adequacy of feedback to control the job, capability of the process itself, and the means of regulating the process. When a re-engineering effort is in progress, the design of specific jobs within a process using self-control criteria ensures that the job requirements and the needs of personnel are in harmony.
2. *Analysis and diagnosis of current jobs that have quality problems:* The search for root causes of current quality problems can be difficult and time-consuming. The checklist can help identify potential causes by providing an exhaustive list of candidate areas.
3. *Use by supervisors to discuss jobs with personnel:* In reviewing both general job performance and current job problems, the checklist can focus on specific aspects of the job—some of which

are under control of the person and some of which are not—and help the supervisor to function as a coach. Similarly, the checklist can be beneficial to self-managing teams.

4. *Getting prepared for auditors on financial transactions:* Auditors check output and procedures in many financial areas, e.g., moving money from one account to another. The checklist can help to prepare for the auditing process.
5. *Help to focus on a broad improvement strategy:* Use of the checklists for reviewing current jobs may reveal that many job designs have basic weaknesses such as lack of clarity in quality requirements or job instructions, timely and relevant feedback on output, or capability of the process itself. Why not ask personnel to review the checklist and then prioritize the specific problem areas?
6. *Use in training classes in quality:* The concept of self-control helps to plan new jobs and to analyze quality problems on current jobs. Exercises on the three elements of self-control can be made part of a training class. Checklists developed by the participants or the checklists in this section can serve as a basis for discussion by the participants.

You might wish to refine the checklists or develop your own to meet the needs of your organization. This could be done by circulating the checklist internally and asking for additions to the list, identification of critical items, or any input that would make the list more useful. Additional ideas also could be generated by using the list for an exercise and discussion in a training class on quality.

TROUBLESHOOTING

Chronic versus Sporadic Troubles. Quality troubles exist in two different forms: chronic and sporadic. *Chronic* troubles go on and on because no way has ever been found to eliminate them. For example, a process has for years operated at 10 percent nonconforming. No one has succeeded in reducing this level, so we learn to live with it.

Sporadic troubles are the result of some sudden adverse change. For example, a process that is usually at 10 percent nonconforming suddenly goes to 25 percent. Such a change sets off a number of alarm signals that demand prompt action to restore the status quo (to go back to the usual 10 percent). *Troubleshooting* (also called *firefighting*) is the process of dealing with the sporadic and restoring quality to the original level. Section 5, The Quality Improvement Process, discusses a structured approach for dealing with chronic problems; Section 4, The Quality Control Process, presents a structured approach for sporadic problems.

For organizations that do not have a formal effort to reduce chronic and sporadic problems, operations managers often spend 30 percent of their time on troubleshooting; for the supervisors reporting to these managers, the time consumed frequently exceeds 60 percent.

Responsibility for Troubleshooting. While Operations Department responsibility for troubleshooting is fairly clear, the ability to carry out this responsibility varies. The main variables are the *complexity* of the adverse change and the *extent* to which operations personnel are trained in the tools of diagnosis.

A complex adverse change can require an extent of data collection and analysis that goes beyond the training and experience of operations personnel. This same complexity also can require extensive time for data collection and analysis—time that is not available to Operations Department supervisors.

In such complex cases, a team approach may be needed. The team is usually drawn from the following:

Operations personnel to supply theories and authorize data collection

Technicians to carry out data collection

Diagnosticians to design the data plan and to analyze the subsequent data

"Outsiders" as the needs arise

The responsibility for creating such a team rests with the Operations Department.

The trend is to train operations personnel to become self-sufficient in troubleshooting. If nonsupervisors are trained to do troubleshooting within their own work areas, the supervisors will have more time to participate on the cross-functional project teams that typically are needed for chronic troubles. The training needed is common to that needed by operations personnel for dealing with quality problems generally. The problem-solving training provided to quality teams is useful (see Section 5, under The Diagnostic Journey). At each step of the journey, the tools and techniques mentioned are candidates for training topics.

SELF-INSPECTION

Once goods or services have been produced, there arises the question: Do they conform to specification? In manufacturing industries, the activity to determine conformance is called *inspection* or *test* (see Section 23, Inspection and Test). In the service sector, typical terms used are *checking, examination, review,* and *reconciliation.*

In the manufacturing sector in the United States, the responsibility for making the conformance decision often rests with full-time inspectors in an independent Inspection Department but this is changing fast to in-process inspection by the worker with an audit inspection by an independent inspector. In the service sector, output is checked by the person creating the output, and typically no independent check occurs. Often the only independent check is by the customer (internal or external).

Under the concept of self-inspection, the worker who made the product also measures the product and decides whether it conforms to specifications. (Special or complex tests are performed by a separate department.)

Note that the worker is *not* given the responsibility for determining the disposition of any nonconforming product. Also, self-inspection does *not* involve transfer of full-time inspectors to the Production Department. It involves abolishing the jobs of full-time inspectors and having the inspection done on a part-time basis by the production workers. Provision is made for an audit (see below under Audit of Decisions).

Self-inspection has decided advantages over the traditional delegation of inspection to a separate department:

1. Production workers are made to feel more responsible for the quality of their work.
2. Feedback on performance is immediate, thereby facilitating process adjustments. Traditional inspection also has the psychological disadvantage of using an "outsider" to report the defects to a worker.
3. The costs of a separate Inspection Department can be reduced.
4. The job enlargement that takes place by adding inspection to the production activity of the worker helps to reduce the monotony and boredom that are inherent in many jobs.
5. Elimination of a specific station for inspecting all products reduces the total manufacturing cycle time.

The current emphasis on downsizing in organizations, coupled with the benefits of self-inspection, has resulted in pressures to reduce the size of inspection departments in manufacturing. Sometimes the reduction in independent inspection activities has been premature.

Criteria for Self-Inspection. Before self-inspection can be adopted, some essential criteria must be met:

1. Quality is the number 1 priority within an organization. If this is not clear, the worker may succumb to schedule and cost pressures and classify as acceptable products that should be rejected.
2. There is mutual confidence between managers and workers. Managers must have sufficient confidence in the work force to be willing to entrust to them the responsibility of deciding whether the product conforms to specification. In turn, workers must have enough confidence in management to be willing to accept this responsibility.
3. The criteria for self-control are met. Failure to eliminate the management-controllable causes of defects suggests that management does not view quality as a high priority, and this may bias the workers during inspections.
4. Workers are trained to understand the specifications and perform the inspection. In some companies, "certification" (for making product conformance decisions) is issued only to those workers who demonstrate their competence.
5. Specifications are unequivocally clear.
6. Workers understand the use that will be made of the products (internally and externally) in order to grasp the importance of a conformance decision.
7. The process permits assignment of clear responsibility for decision making.

Several references provide elaboration on these criteria: Ziegler (1995) discusses six elements common to successful self-inspection; Whittingham (1987) explains some implementation details, including use of a "work conditions questionnaire" (to evaluate the criteria of self-control) and the importance of feedback to workers.

Sequence for Instituting the Self-Inspection Concept. The many benefits of self-inspection suggest that steps be taken to successfully apply it broadly. However, the criteria listed above are not easy to meet. In practice, it is unlikely that the criteria could be met for all products, all operations, and all personnel. It is best to apply the concept only to products and processes that are stabilized and meet product specifications and to personnel who have demonstrated their competence.

This competence can be verified by a trial period during which workers make conformance decisions while duplicate decision making is done by inspectors. The purpose of this duplication is to discover, through data, which workers consistently make good product-conformance decisions.

Audit of Decisions. During the trial period, the inspection is conducted for two purposes:

1. Product approval, lot by lot
2. Comparison of inspector results with worker results

As the comparison establishes validity of the worker's decisions, the duplicate inspections are reduced in frequency until their prime purpose is to determine whether the worker continues to make good decisions (hence the name *audit of decisions*). At this stage, any knowledge of the product is incidental. If an audit reveals that wrong decisions were made by the workers, then the product evaluated since the last audit is suspect and must be investigated.

Results of Self-Inspection. In a coning operation of textile yarn, the traditional method of inspection often resulted in finished cones sitting for several days in the inspection department, thereby delaying any feedback to production. Under self-inspection, the worker received immediate feedback and could more promptly get machines repaired and setups improved. Overall, the program reduced nonconformities from 8 to 3 percent. An audit inspection of the products that were classified by the workers as "good" showed that virtually all of them were classified correctly. In this company, workers also can classify product as "doubtful." In one analysis, worker inspections classified 3 percent of the product as doubtful, after which an independent inspector reviewed the doubtful product and classified two-thirds of it as acceptable and one-third as nonconforming.

A pharmaceutical manufacturer employed a variety of tests and inspections before a capsule product was released for sale. These checks included chemical tests, weight checks, and visual inspections of the capsules. A 100 percent visual inspection traditionally had been conducted by an Inspection Department. Defects ranged from "critical" (e.g., an empty capsule) to "minor" (e.g., faulty print). This inspection was time-consuming and frequently caused delays in production flow. A trial experiment of self-inspection by machine operators was instituted. Operators performed a visual inspection on a sample of 500 capsules. If the sample was acceptable, the operator shipped the full container to the warehouse; if the sample was not acceptable, the full container was sent to the Inspection Department for 100 percent inspection. During the experiment, both the samples and the full containers were sent to the Inspection Department for 100 percent inspection with reinspection of the sample recorded separately. The experiment reached two conclusions: (1) the sample inspection by the operators gave consistent results with the sample inspection by the inspectors, and (2) the sample of 500 gave consistent results with the results of 100 percent inspection.

The experiment convinced all parties to switch to the sample inspection by operators. Under the new system, good product was released to the warehouse sooner, and marginal product received a highly focused 100 percent inspection. In addition, the level of defects *decreased*. The improved quality level was attributed to the stronger sense of responsibility by operators (they themselves decided if product was ready for sale) and the immediate feedback received by operators from self-inspection. However, there was another benefit—the inspection force was reduced by 50 people and these 50 people, were shifted to other types of work, including experimentation and analysis activities on the various types of defects. Inspectors became analysts.

Schilling (1994) provides a sobering explanation of the importance of inspection and its relationship to acceptance sampling, acceptance control, and process control.

In the service sector, relatively little use is made of full-time independent personnel who check work output. Workers check their own work, with perhaps a sampling check by a supervisor. Thus an operations supervisor in a bank money transfer department spends about 1.5 hours a day in 10-minute segments going from clerk to clerk and examining the last piece of work completed, and a housekeeping supervisor in a hotel samples a number of rooms to verify the quality of the work performed by the maids.

The lack of extensive checking and inspection activity in the service sector certainly does not mean that all output conforms to service requirements or goals. Particularly in backroom activities, service processes have many rework loops. One example of extensive rework is the department of 32 people in a regional office of a utility. The sole purpose of this department is to detect errors in internal billing charges received from other units of the company. The budget of this department can easily be justified by the savings achieved in detecting the errors. Two obvious questions are (1) Was there any form of inspection by those who generated the charges? and (2) Are there any plans to prevent these errors?

AUDIT OF OPERATIONS QUALITY

A *quality audit* is an independent evaluation of various aspects of quality performance for the purpose of providing information to those in need of assurance with respect to that performance. Application to manufacturing has been extensive and includes both audit of activities (systems audits) and audit of product (product audit). For products (e.g., medical, financial) that are subject to government regulations, audits are often concerned with compliance to these regulations.

Systems Audit. Systems audits (sometimes called *process audits*) can be conducted for any activity that affects the final quality of goods or services. The audit is usually made of a specific activity against a specific document, such as process operating instructions, employee training manuals, certification of personnel for critical operations, and quality provisions in purchasing docu-

ments. The checklists presented earlier in this section for the three criteria of self-control can suggest useful specific subjects for audits. Priority is assigned to subjects that affect customer satisfaction. Adherence to existing procedures is often emphasized, but systems audits often uncover situations of inadequate or nonexistent procedures.

Peña (1990) explains an audit approach for processes. Two types of audits are employed: engineering and monitor. The *engineering process audit* is conducted by a quality assurance engineer and entails an intense review of all process steps, including equipment parameters, handling techniques, and statistical process control. Table 22.15 shows the audit checklist. The *monitor process audit* is conducted by a certified auditor; it covers a broad range of issues, e.g., whether specifications are correct and whether logs are filled in and maintained. Discrepancies (critical, major, or minor) are documented and corrective action is required in writing. Critical defects must be corrected immediately; majors and minors must be resolved within 5 working days.

McDonald's Corporation conducts a system evaluation of restaurants using visits (announced and unannounced) by a trained consultant. The evaluation includes quality, service, cleanliness, and sanitation. Highly detailed audit items include numerical standards on food-processing variables. Key questions for the overall systems evaluation cover training, ordering, scheduling, production control, equipment, and leadership. An overall grade (A, B, C, or F) encompasses operational standards and customer expectations.

A major airline employs audits to evaluate service in three areas: airport arrival and departure, aircraft interior and exterior, and airport facilities. Forty-seven specific activities are audited periodically, and then performance measurements are made and compared with numerical goals. Two examples on the aircraft are the condition (appearance) of carpets inside the planes and the adhesion of paint on the planes.

Dedhia (1985) describes an audit system for an electronics manufacturer. The audit consists of 14 subsystems each having an audit checklist. Routine audits are performed by quality audit personnel on a scheduled basis. For selected activities, annual audits are conducted by a team from

TABLE 22.15 Audit Checklist

1. Is the specification accessible to production staff?
2. Is the current revision on file?
3. Is the copy on file in good condition with all pages accounted for?
4. If referenced documents are posted on equipment, do they match the specification?
5. If the log sheet is referenced in specifications, is a sample included in the specification?
6. Is the operator completing the log sheet according to specifications?
7. Are lots with out-of-specification readings authorized and taken care of in writing by the engineering department or the proper supervisor?
8. Are corrections to paperwork made according to specification?
9. Are equipment time settings according to specifications?
10. Are equipment temperature settings according to specification?
11. Is the calibration sticker on equipment current?
12. Do chemicals or gases listed in the specification match usage on line?
13. Do quantities listed in the specification match the line setup?
14. Are changes of chemicals or gases made according to specification?
15. Is the production operator certified? If not, is this person authorized by the supervisor?
16. Is the production operating procedure according to specification?
17. Is the operator performing the written cleaning procedure according to specification?
18. If safety requirements are listed in the specification, are they being followed?
19. If process control procedures are written in the specification, are the actions performed by process control verifiable?
20. If equipment maintenance procedures are written in the specification, are the actions performed verifiable? according to specification?

Source: Peña (1990).

Manufacturing, Quality Engineering, Test Engineering, Purchasing, and other departments. The system includes a numerical audit rating based on classifying each discrepancy as major or minor. A rating below 90 percent requires an immediate corrective action response. Craner (1994) explains how managers (and others) conduct audits at a medical device firm. Lane (1989) relates how a microelectronics firm reduced redundant inspection and shifted the resources to a defect-prevention effort that included audits of broad systems, individual process, and products.

Who Performs the Audits? There are several categories of personnel to whom systems audits may be delegated:

Production Management: In this situation, the middle or upper operations managers undertake the audit of execution versus plan. Because most production activities are highly visible, skilled observers can learn much from shop tours. Generally, operations managers possess these skills and, in addition, put a high value on direct observation.

Inspectors: Some inspections are conducted not to measure the product but to observe the process (see, for example, Section 23, under Patrol Inspection). Such observations are themselves a review of execution versus plan. It is often feasible to extend these patrol inspections to review other aspects of execution.

Independent auditors: For critical work, the auditing preferably should be done by those who are not a part of the Inspection Department. Usually such auditors review the practices of inspectors as well as production workers.

The independent audit tends to be more completely planned than an audit by operations management or by inspectors. In addition, the entire concept of the independent audit has the support of upper management, which receives the audit reports for review. For further discussion, see Section 11, under Quality System Certification/Registration.

A self-audit and an independent audit can be combined to provide a two-tier audit each with an audit plan, execution, and report. Advantages include using the expertise of the person responsible for the activity, ensuring objectivity with an independent auditor, and minimizing some of the human relationship issues. The aim of both the self-audit and the independent audit is to build an atmosphere of trust based on the reputation of the auditors, the approach used during the audit, and an emphasis on being helpful to the activity audited.

There are two trends in auditing worth noting. First, the scope of audits often goes beyond determining compliance with specific procedures and requirements to include broader issues such as the effectiveness, efficiency, and adaptability of processes (see Section 6, Process Management). Second, audits increasingly emphasize helping operational areas to meet customer expectations and needs. Myers and Heller (1995) provide an illustration of how the broader scope (modeled after the Baldrige Award) helps to align business processes with customer needs and also recognize employees' efforts. Audits having a broad companywide scope are often called *assessments.*

The audit of decisions discussed previously requires a regular examination (product audit) of product conformance along with the associated documentation. This cannot be done readily by the independent auditors who are on the scene so infrequently. Instead, it is assigned to a special category of auditor created at the time of delegating conformance decisions to production workers.

Product Audit. This form of audit provides information on the extent of product conformance to specification and fitness for use. For elaboration, see Section 11.

OVERALL QUALITY MEASUREMENT IN OPERATIONS

The management of key work processes must include provision for measurement. In developing units of measure, the reader should review the basics of quality measurement discussed in Section 9, Measurement, Information, and Decision Making.

Table 22.16 shows examples for manufacturing activities and for backroom operations in the service sector. Note that the measurements cover both output from operations and input to operations. Also note that the examples include early indicators, concurrent indicators, and lagging indicators of performance.

The units in Table 22.16 become candidates for data analysis using statistical techniques such as control charts. More important, the selection of the unit of measure and the periodic collection and reporting of data demonstrate to operating personnel that management regards quality as having priority importance. This helps to maintain a focus on improvement, which we will discuss below.

Many control subjects for quality measurement are forms of work output. In reviewing current units in use, a fruitful starting point is the measure of productivity. *Productivity* is usually defined as the amount of output related to input resources. Surprisingly, some organizations still mistakenly calculate only one measure of output—the total (acceptable *and* nonacceptable). Clearly, the pertinent output measure is that which is usable by customers, *acceptable output*).

MAINTAINING A FOCUS ON CONTINUOUS IMPROVEMENT

Historically, the operations function always has been involved in troubleshooting sporadic problems (see above under Troubleshooting). As chronic problems were identified, these were addressed using various approaches, such as quality improvement teams (see Section 5, The Quality Improvement Process). Often the remedies for improvement involve quality planning or replanning (see Section 3, The Quality Planning Process). These three types of actions are summarized in Table 22.17.

Global competitive pressures and other forces will result in an even stronger emphasis on improvement. Continuous improvement in the future will need to

1. Draw on many sources of information to identify improvement opportunities that go beyond nonconformance to specifications. These sources of information include studies on the cost of poor quality (see Section 8, Quality and Costs), market research on customer satisfaction and loyalty (see Section 18, Market Research and Marketing), assessments of quality culture (see Section 15, Human Resources and Quality), and broad assessments using, for example, Baldrige Award criteria (see Section 14, Total Quality Management).
2. Address process improvement in terms of effectiveness, efficiency, adaptability, and cycle time (see Section 6, Process Management).

TABLE 22.16 Examples of Quality Measurements in Operations

Quality of output from operations
Percentage of output meeting specifications at initial inspection (“first-time yield”)
Percentage of output meeting specifications at intermediate and final inspections
Amount of scrap, rework (quantity, cost, percentage, etc.)
Percentage of invoices returned due to errors
Average cycle time to fill customer orders for products or documentation
Warranty and adjustment costs due to errors in operations
Overall measure of quality (defects per million, weighted defects per unit, variability in units of standard deviation, etc.)
Quality of input to operations
Percentage of incoming material meeting specifications
Percentage of incoming data that is complete and error-free
Amount of downtime of manufacturing equipment, computer systems, and other support equipment
Percentage of critical operations with certified employees
Percentage of specifications or process instructions requiring changes after release

TABLE 22.17 Three Types of Action

Type of action to take	When to take action	Basic steps
Troubleshooting (part of quality control)	Performance indicator outside control limits Performance indicator in clear trend toward control limits Performance indicator normally meets target but does not now Process indicator outside target range or control limits Process indicator trend toward target or control limits	Identify problem Diagnose problem Take remedial action
Quality improvement	The control limits are so wide that it is possible for the process to be in control and still miss the targets Performance indicator frequently misses its target	Identify project Establish project Diagnose the cause Remedy the cause Hold the gains
Quality planning	Many performance indicators for this process miss their targets frequently Customers have significant needs that the work product does not meet	Establish project Identify customers Discover customer needs Develop product Develop process Design controls

Source: Adapted from Juran Institute (1995, pp. 5–7).

3. Pursue radical forms of improvement ("re-engineering") in addition to incremental forms (see Section 6, Process Management).
4. Effectively and quickly capture, share, and take action on experience-based information. A fast-food firm is creating an "intellectual network" of computer bulletin boards of information that include best practices information. Personnel will be able to use the system 24 hours a day, 7 days a week. Rethmeier (1995) explains how an alliance of 300 hospitals uses a "learning center" to create and transfer knowledge for continuous improvement. See also the *Harvard Business Review* (September–October 1994) for a special section on "regaining the lead in manufacturing." This section is based on a 4-year study of 20 development projects and identifies 7 elements of learning (core capabilities, guiding vision, organization and leadership, ownership and commitment, "pushing the envelope," prototypes, and integration).
5. Apply all the tools of improvement—technical and behavioral, simple and sophisticated. Increasingly, savings from improvement projects have "skimmed the cream off the top." The next round will require deeper analysis.

Many sections of this handbook present both methodologies and case examples on quality improvement; see particularly Section 5, The Quality Improvement Process, and Section 45, Statistical Process Control. The general literature is replete with examples from operations in virtually every industry. For examples in manufacturing see Kitamura et al. (1994) for a discussion of the Toyota production system; also, Hays and Gander (1993) explain how yield and turn-around time were improved on a printed circuit board production line. For examples in the service sector, see Aubrey and Gryna (1991) to learn about the experiences of over 1000 quality teams at a bank; also, Anderson et al. (1995) describe experiences (including advantages and disadvantages) in applying computer simulation to achieve improvement in claims processing and other activities in a health insurance firm.

QUALITY AND OPERATIONS CULTURE

For an organization to become superior in quality, it needs an unusual marriage:

1. Technologies to create products and processes that meet customer needs. Part of this is the design of individual jobs (that meet the criteria of self-control).
2. A culture throughout the organization that continually views quality as a primary goal. Quality culture is the pattern—the emotional scenery—of human habits, beliefs, and behavior concerning quality. Designing and maintaining jobs to meet the criteria of self-control are essential prerequisites to achieving a positive quality culture.

Some companies have a strong—but negative—quality ethic. Examples are legion: hide the nonconforming product, e.g., bury the rejected paint in the ground; and finesse the inspector, e.g., keep producing defective product and wait until an inspector discovers the situation. Such negative actions are often taken in order to achieve other objectives such as production quotas. To build a strong quality culture requires two steps: (1) collect information to determine the present quality culture and (2) take the steps necessary to change the culture.

Determining the Quality Culture. Learning about the present quality culture in a firm can be accomplished by a carefully planned attitude survey on quality for various levels of operations supervision and the work force. However, be prepared for some sobering results. For a general discussion of quality culture, see Section 15. For a discussion of the results of a survey (20 questions) given to both American and Russian factory workers, see Pooley and Welsh (1994). Yavas and Burrows (1994) used 33 questions to compare the attitudes of American and Asian manufacturing managers on quality. Tabladillo and Canfield (1994) describe a 25-question survey employed at a hospital. Turner and Zipursky (1995) describe a survey of 20 questions that measure "employee commitment." The analysis of the results made use of several tools, including cause-and-effect diagrams, analysis of means on performance versus importance of factors, regression analysis, interrelation digraph, and quality function deployment. The road to developing a positive quality culture is lengthy and difficult—though essential for survival. The general approach of Section 15 to organizing for quality, the manager's role, and so on is germane to quality culture.

Changing the Quality Culture. Developing a positive quality culture involves five key elements [for elaboration, see Juran and Gryna (1993, Chap. 8)]:

1. Create and maintain an awareness of quality. This means we must create and disseminate information on our current status of quality. The message must go to upper management, middle and lower management, and all other personnel—using languages that fit each territory.
2. Provide evidence of management leadership on quality. This is not only cheerleading but serving on a quality council, doing strategic planning for quality, providing resources for quality, and doing a host of other tasks to plan and deploy quality goals.
3. Provide for self-development and empowerment. This includes designing jobs for self-control, selection and training for jobs, organizing work using approaches for self-development such as self-managing teams, and encouraging personal commitment for quality.
4. Provide participation as a means of inspiring action. The forms of participation are almost endless: serve on a quality council, a quality circle, or an improvement team; be a process owner; take part in a product or process design review; or make presentations on quality.
5. Provide recognition and rewards. These expressions of esteem play an essential role in inspiring people on quality. Recognition takes the form of public acknowledgment for great performance on quality. Rewards are tangible benefits (salary increases, bonuses, promotions, etc.) for quality. Aside from these specifics, some countries that are moving toward democracy in the workplace

must address basic "quality of life" issues (e.g., clean bathrooms and other working conditions) before attempts at changing the quality culture will succeed.

Creating a positive culture is an important factor in building loyalty and retaining key personnel in operations. Reichheld (1993) explains the importance of loyal employees in achieving loyal customers.

ACKNOWLEDGMENTS

I extend my thanks to Charles Amaral and Jack Beatty of McDonald's Corporation, Erik Bredal and Kim O'Haver of Group Technologies Corporation, Derek S. Gryna of Mercantile/Bancorp, and Ron Rogge of J. S. Alberici Construction Company for their input and comments.

REFERENCES

American Management Association (1992). *Blueprints for Service Quality.* American Management Association, New York, pp. 51–64.

Anderson, DeAnn, Abetti, Frank, and Savage, Phillip (1995). "Process Improvement Utilizing Computer Simulation: Case Study." *ASQC Quality Congress Transactions 1995*. American Society for Quality Control, New York, pp. 713–724.

Aubrey, Charles A., II and Gryna, Derek S. (1991). "Revolution Through Effective Improvement Projects." *ASQC Quality Congress Transactions 1991*. American Society for Quality Control, Milwaukee, pp. 8–13.

Bemesderfer, John L. (1979). "Approving a Process for Production." *Journal of Quality Technology,* Vol. 11, No.1, pp. 1–12.

Berry, Leonard L., Parasuraman, A., and Zeithmal, Vllerie A. (1994). "Improving Service Quality in America: Lessons Learned." *Academy of Management Executive,* Vol. 8, No. 2, pp. 32–52.

Bettis, Richard, Bradley, Stephen P., and Hamel, Gary (1992). "Outsourcing and Industrial Decline." *Academy of Management Executive,* Vol. 6, No. 1, pp. 7–22.

Binroth, William. (1992). "Fail-Safe Manufacturing for Assembly Operations." *ASQC Quality Congress Transactions 1993*. American Society for Quality Control, Milwaukee, pp. 107–115.

Black, Sam P. (1993). "Internal Certification: The Key to Continuous Quality Success." *Quality Progress,* January, pp. 67–68.

Bothe, Davis R. (1997). *Measuring Process Capability. McGraw-Hill, New York.*.

Bothe, Davis R. (1992). "A Capability Study for an Entire Product." *ASQC Quality Congress Transactions 1992*. American Society for Quality Control, Milwaukee, pp. 172–178.

Business Week. (1996). "Has Outsourcing Gone Too Far?" *Business Week,* April, 1, pp. 26–28.

Carlisle, Rodney (1981). "Shirt-Sleeve Quality." *Quality,* March, pp. 48–49.

Carpenter, Ben H. (1982). "Control of Copper Ore Roasting Exit Gas Quality." *ASQC Quality Congress Transactions 1982*. American Society for Quality Control, Milwaukee, pp. 748–755.

Chang, Tien-Chien, Wysk, Richard A., and Wang, Hus-Pin (1991). *Computer-Aided Manufacturing.* Prentice-Hall, Englewood Cliffs, NJ.

Clark, J. M., and Milligan, G. W. (1994). "How Sweet it Is—Quality Management in a Honey House: The Stickey Quality Problems of Honey." *Quality Engineering,* Vol. 6, No. 3, pp. 379–400.

Collins, William H., and Collins, Carol B. (1993). "Differentiating System and Execution Problems." *Quality Progress,* February, pp. 59–62.

Cooper, Robin and Slagmulder, Regine (1997). *Target Costing and Value Engineering*. Productivity Press, Portland, OR and Institute of Management Accountants, Montvale, NJ.

Craig, Robert J. (1993). "Six Sigma Quality: The Key to Customer Satisfaction." *ASQC Quality Congress Transactions 1993*. American Society for Quality Control, Milwaukee, pp. 206–212.

Craner, Barrett C. (1994). "Managers' Audit System: Managers Just Do It." *ASQC Quality Congress Transactions 1994*. American Society for Quality Control, Milwaukee, pp. 920–928.

Davis, Robert, Rosegrant, Susan, and Watkins, Michael (1995). "Managing the Link Between Measurement and Compensation." *Quality Progress,* February, pp. 101–106.

Dedhia, Navin S. (1985). "Process Audit System Effectiveness." *European Organization for Quality Control Annual Conference.* EOQC, Berne, Switzerland, pp. 159–173.

Dodson, B. L. (1993). "Determining the Optimal Target Value for a Process with Upper and Lower Specification Limits." *Quality Engineering,* Vol. 5, No. 3, pp. 393–402.

Early, John F. (1989). "Strategies for Measurement of Service Quality." *ASQC Quality Congress Transactions 1989.* American Society for Quality Control, Milwaukee, pp. 2–9.

Ford, J. I. and Leader, C. R. (1989). "Integrating Human Dynamics and Statistical Process Control." *Quality Engineering,* Vol. 1, No. 2, pp. 179–189.

Foster, Robert D., and Zirk, Wayne E.(1992). "Getting Operators to Really Use SPC: MCPS Can Help." *ASQC Quality Congress Transactions 1992.* American Society for Quality Control, Milwaukee, pp. 201–207.

Gass, K. C. (1994). "How to Make Procedures Work." *Quality Engineering,* Vol.7, No. 2, pp. 337–343.

Godfrey, A. Blanton (1995). "Critical Issues in Service Quality Management." Address for the Fourth Annual Service Quality Conference of the American Society for Quality Control, Baltimore.

Goldman, Steven L., Nagel, Roger N., and Preiss, Kenneth (1995). *Agile Competitors and Virtual Organizations.* Van Nostrand Reinhold, New York.

Hart, Christopher W. L. (1995). "The Power of Internal Guarantees." *Harvard Business Review,* January-February, pp. 64–74.

Harvard Business School (1994). *Case 9-694-076, Taco Bell.* Boston.

Hayes, Bob E. (1994). "How to Measure Empowerment." *Quality Progress,* February, pp. 41–46.

Hays, Thomas J., and Gander, Mary J. (1993). "Total Quality Transformation on a PCB Manufacturing Line." *ASQC Quality Congress Transactions 1993.* American Society for Quality Control, Milwaukee, pp. 112–118.

Herman, John T. (1989). "Capability Index—Enough for Process Industries?" *ASQC Quality Congress Transactions 1989.* American Society for Quality Control, Milwaukee, pp. 670–675.

Hestand, Randy (1991). "Measuring the Level of Service Quality." *Quality Progress,* September, pp. 55–60.

Hinckley, C. Martin, and Barkan, Philip (1995). "The Role of Variation, Mistakes, and Complexity in Producing Nonconformities." *Journal of Quality Technology,* Vol. 27, No. 3, pp. 242–249.

Jeffrey, Jaclyn R. (1995). "Preparing the Front Line." *Quality Progress,* February, pp. 79–82.

Juran Institute, Inc. (1995). *Work Team Excellence.* Wilton, CT.

Juran, J. M. (1992). *Juran on Quality by Design.* Free Press, New York.

Juran, J. M., and Gryna, Frank M. (1993). *Quality Planning and Analysis,* 3d ed. McGraw-Hill, New York.

Kane, Victor E. (1986). "Process Capability Indices." *Journal of Quality Technology,* Vol. 18, No. 1, pp. 41–52.

Katzenbach, J. R., and Smith, D. K. (1993). *Wisdom of Teams: Creating the High Performance Organization.* Harvard Business School Press, Boston.

Kearney, Francis J. (1984). "Management of Product Quality without a Quality Department." *ASQC Quality Congress Transactions 1984.* American Society for Quality Control, Milwaukee, pp. 249–252.

Keenan, Thomas M. (1995). "A System for Measuring Short-Term Producibility." *ASQC Quality Congress Transactions 1995.* American Society for Quality Control, Milwaukee, pp. 50–56.

Kegg, Richard L. (1985). "Quality and Productivity in Manufacturing System." *Annals of the CIRD International Association for Production Research,* Vol. 34, No. 2, pp. 531–534.

Kitamura, Toshiyuki, Hiller, Dennis E., and Ingram, Larry J. (1994). "Lean Production System Implementation at Supplier Base." *Impro94 Conference Proceedings.* Juran Institute, Wilton, CT, pp. 4C-1–4C-23.

Laffel, Glenn, and Plsek, Paul E. (1989). "Preliminary Results from a Quality Improvement Demonstration Program at Brigham and Women's Hospital." *Impro89 Conference Proceedings,* Juran Institute, Wilton, CT, pp. 8A-21–8A-27.

Lane, Patricia A. (1989). "Continuous Improvement—AT&T QA Audits." *ASQC Quality Congress Transactions 1989.* American Society for Quality Control, Milwaukee, pp. 772–775.

Latzko, William J. (1993). "A Bank Quality Model." *ASQC Quality Congress Transactions 1993.* American Society for Quality Control, Milwaukee, pp. 38–44.

Lee, Jay (1995). "Perspective and Overview of Manufacturing Initiatives in the United States." *International Journal of Reliability, Quality and Safety Engineering,* Vol. 2, No. 3, pp. 227–233.

Lehrman, Karl Henry (1991). "Capability Analyses and Index Interval Estimates: Quantitative Characteristics (variables)." *Quality Engineering,* Vol. 4, No. 1, pp. 93–130.

Lochner, Robert H. (1995). "Developing a Balanced Set of Measures in Healthcare." *ASQC Quality Congress Transactions 1995*. American Society for Quality Control, Milwaukee, pp. 293–300.

Madigan, James M. (1993). "Measures Matrix Chart: A Holistic Approach to Understanding Operations." *Quality Management Journal,* Vol. 1, No. 1, pp. 77–86.

Mann, David W. (1994). "Re-engineering the Manager's Role." *ASQC Quality Congress Transactions 1994.* American Society for Quality Control, Milwaukee, pp. 155–159.

McCoy, Paul F. (1991). "Using Performance Indexes to Monitor Production Processes." *Quality Progress,* February, pp. 49–55.

McDermott, Robin (1994). "The Human Dynamics of Total Quality." *ASQC Quality Congress Transactions 1994*. American Society for Quality Control, Milwaukee, pp. 225–233.

Melan, Eugene H. (1993). *Process Management.* McGraw-Hill, New York.

Mentch, C. C. (1980). "Manufacturing Process Optimization Studies." *Journal of Quality Technology,* Vol. 12, No. 3, pp. 119–129.

Middleton, David H. (1992). "Accrediting a Machine for a Lifetime of Quality." *ASQC Quality Congress Transactions 1992*. American Society for Quality Control, Milwaukee, pp. 151–157.

Myers, Dale H., and Heller, Jeffrey (1995). "The Dual Role of AT&T's Self-assessment Process." *Quality Progress,* Vol. 28. No. 1, pp. 79–83.

Nakajo, Takeshi, and Kume, Hitoshi (1985). "The Principles of Foolproofing and Their Application in Manufacturing." *Reports of Statistical Application Research,* Vol. 32, No. 2, pp. 10–29.

Newberg, Craig K., and Nielsen, James R. (1990). "The Pathway to Operator Control." *ASQC Quality Congress Transactions 1990*. American Society for Quality Control, Milwaukee, pp. 723–728.

Parker, H. V. (1981). "A Paper Mill Solves a Quality Control Problem with Process Control Data." *Quality Progress.* March, pp. 18–22.

Peña, Ed (1990). "Motorola's Secret to Total Quality Control." *Quality Progress,* October, pp. 43–45.

Perkins, Nancy S. (1994). "Can TQM Be Derailed by an Enemy from Within?" *ASQC Quality Congress Transactions 1994*. American Society for Quality Control, Milwaukee, pp. 731–738.

Pignatiello, Joseph H., Jr., and Ramberg, John S. (1993). "Process Capability Indices: Just Say No." *ASQC Quality Congress Transactions 1993.* American Society for Quality Control, Milwaukee, pp. 92–104.

Plsek, Paul E. (1989). "FMEA for Process Quality Planning." *ASQC Quality Congress Transactions 1989.* American Society for Quality Control, Milwaukee, pp. 484–489.

Pooley, John, and Welsh, Dianne H. B. (1994). "A Comparison of Russian and American Factory Quality Practices." *Quality Management Journal,* Vol. 1, No. 2, pp. 57–70.

Pyzdek, Thomas (1994). "Toward Service Systems Engineering." *Quality Management Journal,* Vol. 1, No. 3, pp. 26–42.

Raheja, Dev (1982). "Fault Tree Analysis—How Are We Doing?" *ASQC Quality Congress Transactions 1982.* American Society for Quality Control, Milwaukee, pp. 355–359.

Reichheld, Frederick F. (1993). "Loyalty-Based Management." *Harvard Business Review,* March-April, pp. 64–73.

Rethmeier, Kenneth A. (1995). "Creating the Learning Organizations." *Impro95 Conference Proceedings.* Juran Institute, Wilton, CT, pp. 3C.1-1–3C.1-11.

Rubinstein, Sidney P. (1993). "Democracy and Quality as an Integrated System." *Quality Progress.* September, pp. 51–55.

Scharlacken, John W. (1992). "The Advantages of Manufacturing Technology Planning." *Quality Progress.* July, pp. 57–62.

Schilling, Edward G. (1994). "The Importance of Sampling in Inspection." *ASQC Quality Congress Transactions 1994*. American Society for Quality Control, Milwaukee, pp. 809–812.

Schonberger, Richard J. (1996). *World Class Manufacturing: The Next Decade.* Free Press, New York.

Shay, Michael E., White, G. Randy, and Blackman, Paul (1991). "Team Work and Empowerment at the A. O. Smith Corporation." *ASQC Quality Congress Transactions 1991*. American Society for Quality Control, Milwaukee, pp. 801–807.

Shenoy, Muralidhar (1994). "Machine Monitoring for Quality Assurance." *ASQC Quality Congress Transactions 1994*. American Society for Quality Control, Milwaukee, pp. 439–445.

Shina, S. G. (1991). "The Successful Use of the Taguchi Method to Increase Manufacturing Process Capability." *Quality Engineering,* Vol. 3, No. 3, pp. 333–350.

Shirley, Britt M., and Gryna, Frank M. (1998). "Work Design for Self-Control in Financial Services: *Quality Progress,* May, pp. 67–71.

Shostack, G. Lynn (1984). "Designing Services that Deliver." *Harvard Business Review,* January-February, pp. 133–139.

Siff, Walter C. (1984). "The Strategic Plan of Control a Tool for Participative Management." *ASQC Quality Congress Transactions 1984.* American Society for Quality Control, Milwaukee, pp. 384–390.

Simons, Robert (1995). "Control in an Age of Empowerment." *Harvard Business Review,* March-April, pp. 80–88.

Skrabec, Q. R., Jr. (1991). "Using the Ishikawa Process Classification Diagram for Improved Process Control." *Quality Engineering,* Vol. 3, No. 4, pp. 517–528.

Snee, Ronald D. (1993). "Creating Robust Work Processes." *Quality Progress,* February, pp. 37–41.

Somerton, Diana G., and Mlinar, Sharon E. (1996). "What's Key? Tool Approaches for Determining Key Characteristics." *ASQC Quality Congress Transactions 1996.* American Society for Quality Control, Milwaukee, pp. 364–369.

Stalk, George Jr., and Hout, Thomas M. (1990). *Competing Against Time.* Free Press, New York.

Stampen, John O., and Stampen, Jacob O. (1995). "Training Function Deployment: A New Approach for Designing and Evaluating Employee Development Programs." *ASQC Quality Congress Transactions 1995.* American Society for Quality Control, Milwaukee, pp. 933–946.

Tabladillo, Mark F., and Canfield, Susan (1994). "Creation of Management Performance Measures from Employee Surveys." *Quality Management Journal 1994,* Vol. 1, No. 4, pp. 52–56.

Tarver, Mae G. (1984). "Multistation Process Capability-Filling Equipment." *ASQC Quality Congress Transactions 1984.* American Society for Quality Control, Milwaukee, pp. 281–288.

Turner, Robert B., and Zipursky, Lorne S. (1995). "Quality Tools Help Improve Employee Commitment." *ASQC Quality Congress Transactions 1995.* American Society for Quality Control, Milwaukee, pp. 770–776.

Whittingham, P. R. B. (1987). "Operator Self-Inspection." *ASQC Quality Congress Transactions 1987.* American Society for Quality Control, Milwaukee, pp. 278–286.

Willis, Roger G., and Sullivan, Kevin H. (1984). "CIMS in Perspective=Costs, Benefits, Timing, Payback Periods Are Outlined." *Industrial Engineering,* Vol. 16, No. 2, pp. 23–26.

Yavas, Burhan Fatih, and Burrows, Thomas M. (1994). "A Comparative Study of Attitudes of U.S. and Asian Managers Toward Product Quality." *Quality Management Journal,* Vol. 2, No. 1, pp. 41–56.

Yee, William, and Musselwhite, Ed (1993). "Living TQM with Workforce 2000." *ASQC Quality Congress Transactions 1993.* American Society for Quality Control, Milwaukee, pp. 141–146.

Ziegler, August H. (1995). "Self-Inspection Implementation: Beyond the Rhetoric." *ASQC Quality Congress Transactions 1995.* American Society for Quality Control, Milwaukee, pp. 618–621.