

Note that the total yield from this process, after reworking, is 90 good parts per day.

An engineering study of this process reveals that excessive process variability is responsible for the extremely high fallout. A new statistical process-control procedure is implemented that reduces variability, and consequently the process fallout decreases from 25% to 5%. Of the 5% fallout produced, about 60% can be reworked, and 40% are scrapped. After the process-control program is implemented, the manufacturing cost per good part produced is

$$\text{Cost/good part} = \frac{\$20(100) + \$4(3)}{98} = \$20.53$$

Note that the installation of statistical process control and the reduction of variability that follows result in a 10.3% reduction in manufacturing costs. Furthermore, productivity is up by almost 10%; 98 good parts are produced each day as opposed to 90 good parts previously. This amounts to an increase in production capacity of almost 10%, without any additional investment in equipment, workforce, or overhead. Efforts to improve this process by other methods (such as Just-in-Time, lean manufacturing, etc.) are likely to be completely ineffective until the basic problem of excessive variability is solved.

1.4.3 Quality Costs

Financial controls are an important part of business management. These financial controls involve a comparison of actual and budgeted costs, along with analysis and action on the differences between actual and budget. It is customary to apply these financial controls on a department or functional level. For many years, there was no direct effort to measure or account for the costs of the quality function. However, many organizations now formally evaluate the cost associated with quality. There are several reasons why the cost of quality should be explicitly considered in an organization. These include the following:

1. The increase in the cost of quality because of the increase in the complexity of manufactured products associated with advances in technology
2. Increasing awareness of life-cycle costs, including maintenance, spare parts, and the cost of field failures
3. Quality engineers and managers can most effectively communicate quality issues in a way that management understands.

As a result, quality costs have emerged as a financial control tool for management and as an aid in identifying opportunities for reducing quality costs.

Generally speaking, quality costs are those categories of costs that are associated with producing, identifying, avoiding, or repairing products that do not meet requirements. Many manufacturing and service organizations use four categories of quality costs: prevention costs, appraisal costs, internal failure costs, and external failure costs. These cost categories are shown in Table 1.5. We now discuss these categories in more detail.

Prevention Costs. Prevention costs are those costs associated with efforts in design and manufacturing that are directed toward the prevention of nonconformance. Broadly speaking, prevention costs are all costs incurred in an effort to “make it right the first time.” The important subcategories of prevention costs follow.

Quality planning and engineering. Costs associated with the creation of the overall quality plan, the inspection plan, the reliability plan, the data system, and all specialized plans and activities of the quality-assurance function; the preparation of manuals and procedures used to communicate the quality plan; and the costs of auditing the system.

New products review. Costs of the preparation of bid proposals, the evaluation of new designs from a quality viewpoint, the preparation of tests and experimental programs to

■ TABLE 1.5

Quality Costs

Prevention Costs	Internal Failure Costs
Quality planning and engineering	Scrap
New products review	Rework
Product/process design	Retest
Process control	Failure analysis
Burn-in	Downtime
Training	Yield losses
Quality data acquisition and analysis	Downgrading (off-specing)
Appraisal Costs	External Failure Costs
Inspection and test of incoming material	Complaint adjustment
Product inspection and test	Returned product/material
Materials and services consumed	Warranty charges
Maintaining accuracy of test equipment	Liability costs
	Indirect costs

evaluate the performance of new products, and other quality activities during the development and preproduction stages of new products or designs.

Product/process design. Costs incurred during the design of the product or the selection of the production processes that are intended to improve the overall quality of the product. For example, an organization may decide to make a particular circuit component redundant because this will increase the reliability of the product by increasing the mean time between failures. Alternatively, it may decide to manufacture a component using process A rather than process B, because process A is capable of producing the product at tighter tolerances, which will result in fewer assembly and manufacturing problems. This may include a vendor's process, so the cost of dealing with other than the lowest bidder may also be a prevention cost.

Process control. The cost of process-control techniques, such as control charts, that monitor the manufacturing process in an effort to reduce variation and build quality into the product.

Burn-in. The cost of preshipment operation of the product to prevent early-life failures in the field.

Training. The cost of developing, preparing, implementing, operating, and maintaining formal training programs for quality.

Quality data acquisition and analysis. The cost of running the quality data system to acquire data on product and process performance; also the cost of analyzing these data to identify problems. It includes the work of summarizing and publishing quality information for management.

Appraisal Costs. Appraisal costs are those costs associated with measuring, evaluating, or auditing products, components, and purchased materials to ensure conformance to the standards that have been imposed. These costs are incurred to determine the condition of the product from a quality viewpoint and ensure that it conforms to specifications. The major subcategories follow.

Inspection and test of incoming material. Costs associated with the inspection and testing of all material. This subcategory includes receiving inspection and test; inspection, test, and evaluation at the vendor's facility; and a periodic audit of the quality-assurance system. This could also include intraplant vendors.

Product inspection and test. The cost of checking the conformance of the product throughout its various stages of manufacturing, including final acceptance testing, packing and shipping checks, and any test done at the customer's facilities prior to turning the product over to the customer. This also includes life testing, environmental testing, and reliability testing.

Materials and services consumed. The cost of material and products consumed in a destructive test or devalued by reliability tests.

Maintaining accuracy of test equipment. The cost of operating a system that keeps the measuring instruments and equipment in calibration.

Internal Failure Costs. Internal failure costs are incurred when products, components, materials, and services fail to meet quality requirements, and this failure is discovered prior to delivery of the product to the customer. These costs would disappear if there were no defects in the product. The major subcategories of internal failure costs follow.

Scrap. The net loss of labor, material, and overhead resulting from defective product that cannot economically be repaired or used.

Rework. The cost of correcting nonconforming units so that they meet specifications. In some manufacturing operations rework costs include additional operations or steps in the manufacturing process that are created to solve either chronic defects or sporadic defects.

Retest. The cost of reinspection and retesting of products that have undergone rework or other modifications.

Failure analysis. The cost incurred to determine the causes of product failures.

Downtime. The cost of idle production facilities that results from nonconformance to requirements. The production line may be down because of nonconforming raw materials supplied by a supplier, which went undiscovered in receiving inspection.

Yield losses. The cost of process yields that are lower than might be attainable by improved controls (for example, soft-drink containers that are overfilled because of excessive variability in the filling equipment).

Downgrading/off-specing. The price differential between the normal selling price and any selling price that might be obtained for a product that does not meet the customer's requirements. Downgrading is a common practice in the textile, apparel goods, and electronics industries. The problem with downgrading is that products sold do not recover the full contribution margin to profit and overhead as do products that conform to the usual specifications.

External Failure Costs. External failure costs occur when the product does not perform satisfactorily after it is delivered to the customer. These costs would also disappear if every unit of product conformed to requirements. Subcategories of external failure costs follow.

Complaint adjustment. All costs of investigation and adjustment of justified complaints attributable to the nonconforming product.

Returned product/material. All costs associated with receipt, handling, and replacement of the nonconforming product or material that is returned from the field.

Warranty charges. All costs involved in service to customers under warranty contracts.

Liability costs. Costs or awards incurred from product liability litigation.

Indirect costs. In addition to direct operating costs of external failures, there are a significant number of indirect costs. These are incurred because of customer dissatisfaction with the level of quality of the delivered product. Indirect costs may reflect the customer's attitude toward

the company. They include the costs of loss of business reputation, loss of future business, and loss of market share that inevitably results from delivering products and services that do not conform to the customer's expectations regarding fitness for use.

The Analysis and Use of Quality Costs. How large are quality costs? The answer, of course, depends on the type of organization and the success of their quality improvement effort. In some organizations quality costs are 4% or 5% of sales, whereas in others they can be as high as 35% or 40% of sales. Obviously, the cost of quality will be very different for a high-technology computer manufacturer than for a typical service industry, such as a department store or hotel chain. In most organizations, however, quality costs are higher than necessary, and management should make continuing efforts to appraise, analyze, and reduce these costs.

The usefulness of quality costs stems from the **leverage effect**; that is, dollars invested in prevention and appraisal have a payoff in reducing dollars incurred in internal and external failures that exceeds the original investment. For example, a dollar invested in prevention may return \$10 or \$100 (or more) in savings from reduced internal and external failures.

Quality-cost analyses have as their principal objective cost reduction through identification of improvement opportunities. This is often done with a **Pareto analysis**. The Pareto analysis consists of identifying quality costs by category, or by product, or by type of defect or nonconformity. For example, inspection of the quality-cost information in Table 1.6 concerning defects or nonconformities in the assembly of electronic components onto printed circuit boards reveals that insufficient solder is the highest quality cost incurred in this operation. Insufficient solder accounts for 42% of the total defects in this particular type of board and for almost 52% of the total scrap and rework costs. If the wave solder process can be improved, then there will be dramatic reductions in the cost of quality.

How much reduction in quality costs is possible? Although the cost of quality in many organizations can be significantly reduced, it is unrealistic to expect it can be reduced to zero. Before that level of performance is reached, the incremental costs of prevention and appraisal will rise more rapidly than the resulting cost reductions. However, paying attention to quality costs in conjunction with a focused effort on variability reduction has the capability of reducing quality costs by 50% or 60% provided that no organized effort has previously existed. This cost reduction also follows the Pareto principle; that is, most of the cost reductions will come from attacking the few problems that are responsible for the majority of quality costs.

In analyzing quality costs and in formulating plans for reducing the cost of quality, it is important to note the role of prevention and appraisal. Many organizations devote far too much effort to appraisal and not enough to prevention. This is an easy mistake for an organization to make, because appraisal costs are often budget line items in manufacturing. On the

■ **TABLE 1.6**
Monthly Quality-Costs Information for Assembly of Printed Circuit Boards

Type of Defect	Percent of Total Defects	Scrap and Rework Costs
Insufficient solder	42%	\$37,500.00 (52%)
Misaligned components	21	12,000.00
Defective components	15	8,000.00
Missing components	10	5,100.00
Cold solder joints	7	5,000.00
All other causes	5	4,600.00
Totals	100%	\$72,200.00

other hand, prevention costs may not be routinely budgeted items. It is not unusual to find in the early stages of a quality-cost program that appraisal costs are eight or ten times the magnitude of prevention costs. This is probably an unreasonable ratio, as dollars spent in prevention have a much greater payback than do dollars spent in appraisal.

Generating the quality-cost figures is not always easy, because most quality-cost categories are not a direct component in the accounting records of the organization. Consequently, it may be difficult to obtain extremely accurate information on the costs incurred with respect to the various categories. The organization's accounting system can provide information on those quality-cost categories that coincide with the usual business accounts, such as, for example, product testing and evaluation. In addition, many companies will have detailed information on various categories of failure cost. The information for cost categories for which exact accounting information is not available should be generated by using estimates, or, in some cases, by creating special monitoring and surveillance procedures to accumulate those costs over the study period.

The reporting of quality costs is usually done on a basis that permits straightforward evaluation by management. Managers want quality costs expressed in an index that compares quality cost with the opportunity for quality cost. Consequently, the usual method of reporting quality costs is in the form of a ratio, where the numerator is quality-cost dollars and the denominator is some measure of activity, such as (1) hours of direct production labor, (2) dollars of direct production labor, (3) dollars of processing costs, (4) dollars of manufacturing cost, (5) dollars of sales, or (6) units of product.

Upper management may want a standard against which to compare the current quality-cost figures. It is difficult to obtain absolute standards and almost as difficult to obtain quality-cost levels of other companies in the same industry. Therefore, the usual approach is to compare current performance with past performance so that, in effect, quality-cost programs report variances from past performance. These trend analyses are primarily a device for detecting departures from standard and for bringing them to the attention of the appropriate managers. They are not necessarily in and of themselves a device for ensuring quality improvements.

This brings us to an interesting observation: Some quality-cost collection and analysis efforts fail. That is, a number of companies have started quality-cost analysis activities, used them for some time, and then abandoned the programs as ineffective. There are several reasons why this occurs. Chief among these is failure to use quality-cost information as a mechanism for generating improvement opportunities. If we use quality cost information as a scorekeeping tool only, and do not make conscious efforts to identify problem areas and develop improved operating procedures and processes, then the programs will not be totally successful.

Another reason why quality-cost collection and analysis doesn't lead to useful results is that managers become preoccupied with perfection in the cost figures. Overemphasis in treating quality costs as part of the accounting systems rather than as a management control tool is a serious mistake. This approach greatly increases the amount of time required to develop the cost data, analyze them, and identify opportunities for quality improvements. As the time required to generate and analyze the data increases, management becomes more impatient and less convinced of the effectiveness of the activity. Any program that appears to management as going nowhere is likely to be abandoned.

A final reason for the failure of a quality-cost program is that management often underestimates the depth and extent of the commitment to prevention that must be made. The author has had numerous opportunities to examine quality cost data in many companies. In companies without effective quality improvement programs, the dollars allocated to prevention rarely exceed 1% to 2% of revenue. This must be increased to a threshold of about 5% to 6% of revenue, and these additional prevention dollars must be spent largely on the technical methods of quality improvement, and not on establishing programs such as TQM, Zero Defects, or other

similar activities. If management is persistent in this effort, then the cost of quality will decrease substantially. These cost savings will typically begin to occur in one to two years, although it could be longer in some companies.

1.4.4 Legal Aspects of Quality

Consumerism and product liability are important reasons why quality assurance is an important business strategy. Consumerism is in part due to the seemingly large number of failures in the field of consumer products and the perception that service quality is declining. Highly visible field failures often prompt the questions of whether today's products are as good as their predecessors and whether manufacturers are really interested in quality. The answer to both of these questions is yes. Manufacturers are always vitally concerned about field failures because of heavy external failure costs and the related threat to their competitive position. Consequently, most producers have made product improvements directed toward reducing field failures. For example, solid-state and integrated-circuit technology has greatly reduced the failure of electronic equipment that once depended on the electron tube. Virtually every product line of today is superior to that of yesterday.

Consumer dissatisfaction and the general feeling that today's products are inferior to their predecessors arise from other phenomena. One of these is the explosion in the number of products. For example, a 1% field-failure rate for a consumer appliance with a production volume of 50,000 units per year means 500 field failures. However, if the production rate is 500,000 units per year and the field-failure rate remains the same, then 5,000 units will fail in the field. This is equivalent, in the total number of dissatisfied customers, to a 10% failure rate at the lower production level. Increasing production volume increases the **liability exposure** of the manufacturer. Even in situations in which the failure rate declines, if the production volume increases more rapidly than the decrease in failure rate, the total number of customers who experience failures will still increase.

A second aspect of the problem is that consumer tolerance for minor defects and aesthetic problems has decreased considerably, so that blemishes, surface-finish defects, noises, and appearance problems that were once tolerated now attract attention and result in adverse consumer reaction. Finally, the competitiveness of the marketplace forces many manufacturers to introduce new designs before they are fully evaluated and tested in order to remain competitive. These "early releases" of unproved designs are a major reason for new product quality failures. Eventually, these design problems are corrected, but the high failure rate connected with new products often supports the belief that today's quality is inferior to that of yesterday.

Product liability is a major social, market, and economic force. The legal obligation of manufacturers and sellers to compensate for injury or damage caused by defective products is not a recent phenomenon. The concept of product liability has been in existence for many years, but its emphasis has changed recently. The first major product liability case occurred in 1916 and was tried before the New York Court of Appeals. The court held that an automobile manufacturer had a product liability obligation to a car buyer, even though the sales contract was between the buyer and a third party—namely, a car dealer. The direction of the law has always been that manufacturers or sellers are likely to incur a liability when they have been unreasonably careless or negligent in what they have designed, or produced, or how they have produced it. In recent years, the courts have placed a more stringent rule in effect called **strict liability**. Two principles are characteristic of strict liability. The first is a strong responsibility for both manufacturer and merchandiser, requiring immediate responsiveness to unsatisfactory quality through product service, repair, or replacement of defective product. This extends into the period of actual use by the consumer. By producing a product, the manufacturer and seller must accept responsibility for the ultimate use of that product—not only for its performance, but also for its environmental effects, the safety aspects of its use, and so forth.