

► Learning Objectives

1. Explain the four cost categories in a costs-of-quality program
2. Develop nonfinancial measures and methods to improve quality
3. Combine financial and nonfinancial measures to make decisions and evaluate quality performance
4. Describe customer-response time and explain why delays happen and their costs
5. Explain how to manage bottlenecks

To satisfy ever-increasing customer expectations, managers need to find cost-effective ways to continuously improve the quality of their products and services and shorten response times.

This requires trading off the costs of achieving these improvements and the benefits from higher performance on these dimensions. When companies do not meet customer expectations, the losses can be substantial, as the following article about Toyota Motor Corporation shows.

Toyota Plans Changes After Millions of Defective Cars Are Recalled¹

Toyota Motor Corporation, the Japanese automaker, built its reputation on manufacturing reliable cars. In 2002, Toyota executives set an ambitious goal to gain 15% of the global auto industry by 2010, meaning it would surpass General Motors as the world's largest carmaker. In the subsequent years, Toyota grew sales by 50% and managed to win bragging rights as the world's biggest car company. But the company's focus on rapid growth appears to have come at a cost to its reputation for quality.

Between November 2009 and January 2010, Toyota was forced to recall 9 million vehicles worldwide because gas pedals began to stick and were causing unwanted acceleration on eight Toyota models. After months of disagreements with government safety officials, the company ultimately recalled 12 models and suspended the production and sales of eight new Toyota and Lexus models, including its popular Camry and Corolla sedans. While most cars were quickly returned to the sales floor, some industry analysts estimated that the loss of revenue to Toyota could have been as much as \$500 million each week.

Beyond lost revenue, Toyota's once-vaunted image took a serious hit. As the crisis unfolded, Toyota was slow to take responsibility for manufacturing problems. The company then faced the long and difficult task of restoring its credibility and assuring

¹ Sources: Kaufman, Wendy. 2010. Can Toyota recover its reputation for quality? Morning Edition, National Public Radio, February 9. <http://www.npr.org/templates/story/story.php?storyId=123519027&cps=rs>; Linebaugh, Kate and Norihiko Shirouzu. 2010. Toyota heir faces crisis at the wheel. *Wall Street Journal*, January 27. <http://online.wsj.com/article/SB10001424052748704094304575029493222357402.html>; Maynard, Micheline and Hiroko Tabuchi. 2010. Rapid growth has its perils, Toyota learns. *New York Times*, January 27. <http://www.nytimes.com/2010/01/28/business/28toyota.html>; Kageyama, Yuri. 2010. Toyota holds quality meeting to help repair reputation; promises quicker complaint response. *Associated Press*, March 29. <http://abcnews.go.com/International/wireStory?id=10238266>

owners and new-car shoppers that it had fixed the problems.

It established a quality committee led by Akio Toyoda, the company's chief executive; announced plans to add a brake override system to all new models; added four new quality training facilities; and promised faster decisions on future recall situations. "Listening to consumer voices is most important in regaining credibility from our customers," Mr. Toyoda said.

The Toyota example vividly illustrates the importance of quality. But improving quality is hard work. This chapter describes how a balanced scorecard approach helps managers and management accountants improve quality, customer-response time, and throughput.

This chapter covers three topics. The first topic addresses quality as a competitive tool, looking at quality from the financial perspective, the customer perspective, the internal business process perspective, and the learning-and-growth perspective before discussing the evaluation of quality performance. The second topic addresses time as a competitive tool and focuses on customer response time, on-time performance, time drivers, and the cost of time. The third topic looks closely at the theory of constraints and throughput-margin analysis, covering the management of bottlenecks and nonfinancial measures of time. The presentation is modular so you can omit a topic or explore it in any order.

Quality as a Competitive Tool

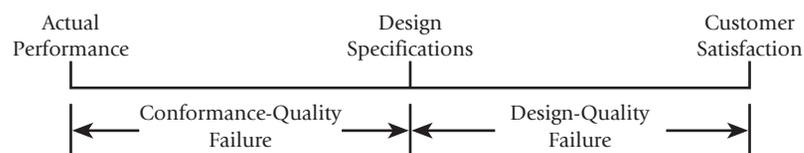
The American Society for Quality defines **quality** as the total features and characteristics of a product or a service made or performed according to specifications to satisfy customers at the time of purchase and during use. Many companies throughout the world—like Cisco Systems and Motorola in the United States and Canada, British Telecom in the United Kingdom, Fujitsu and Honda in Japan, Crysler in Mexico, and Samsung in South Korea—emphasize quality as an important strategic initiative. These companies have found that focusing on the quality of a product or service generally builds expertise in producing it, lowers the costs of providing it, creates higher satisfaction for customers using it, and generates higher future revenues for the company selling it. Several high-profile awards, such as the Malcolm Baldrige National Quality Award in the United States, the Deming Prize in Japan, and the Premio Nacional de Calidad in Mexico, are given to companies that have produced high-quality products and services.



International quality standards have also emerged. ISO 9000, developed by the International Organization for Standardization, is a set of five international standards for quality management adopted by more than 85 countries. ISO 9000 enables companies to effectively document and certify the elements of their production processes that lead to quality. To ensure that their suppliers deliver high-quality products at competitive costs, companies such as DuPont and General Electric require their suppliers to obtain ISO 9000 certification. Documenting evidence of quality through ISO 9000 has become a necessary condition for competing in the global marketplace.

As corporations' responsibilities toward the environment grow, managers are applying the quality management and measurement practices discussed in this chapter to find cost-effective ways to reduce the environmental and economic costs of air pollution, wastewater, oil spills, and hazardous waste disposal. An environmental management standard, ISO 14000, encourages organizations to pursue environmental goals vigorously by developing (1) environmental management systems to reduce environmental costs and (2) environmental auditing and performance-evaluation systems to review and provide feedback on environmental goals. Nowhere has the issue of quality and the environment come together in a bigger way than at the British Petroleum (BP) Deepwater Horizon oil rig in the Gulf of Mexico. An explosion on the oil-drilling platform in April of 2010 resulted in millions of gallons of oil spilling out in the Gulf, causing environmental damage over thousands of square miles and resulting in billions of dollars of clean up costs for BP.

We focus on two basic aspects of quality: design quality and conformance quality. **Design quality** refers to how closely the characteristics of a product or service meet the needs and wants of customers. **Conformance quality** is the performance of a product or service relative to its design and product specifications. Apple Inc. has built a reputation for design quality by developing many innovative products such as the iPod, iPhone, and iPad that have uniquely met customers' music, telephone, entertainment, and business needs. Apple's products have also had excellent conformance quality; the products did what they were supposed to do. In the case of the iPhone 4, however, many customers complained about very weak signal receptions on their phones. The enthusiastic customer response to the iPhone 4 when it was launched in the summer of 2010 indicates good design quality, as customers liked what the iPhone 4 had to offer. The problem with its antenna that caused signals not to be received is a problem of conformance quality, because the phone did not do what it was designed to do. The following diagram illustrates that actual performance can fall short of customer satisfaction because of design-quality failure and because of conformance-quality failure.



We illustrate the issues in managing quality—computing the costs of quality, identifying quality problems, and taking actions to improve quality—using Photon Corporation. While Photon makes many products, we will focus only on Photon's photocopying machines, which earned an operating income of \$24 million on revenues of \$300 million (from sales of 20,000 copiers) in 2011.

Quality has both financial and nonfinancial components relating to customer satisfaction, improving internal quality processes, reducing defects, and the training and empowering of workers. To provide some structure, we discuss quality from the four perspectives of the balanced scorecard: financial, customer, internal business process, and learning and growth.

The Financial Perspective: Costs of Quality

The financial perspective of Photon's balanced scorecard includes measures such as revenue growth and operating income, financial measures that are impacted by quality. The most direct financial measure of quality, however, is *costs of quality*. **Costs of quality (COQ)**

Learning Objective 1

Explain the four cost categories in a costs-of-quality program

... prevention, appraisal, internal failure, and external failure costs

are the costs incurred to prevent, or the costs arising as a result of, the production of a low-quality product. Costs of quality are classified into four categories; examples for each category are listed in Exhibit 19-1.

1. **Prevention costs**—costs incurred to preclude the production of products that do not conform to specifications
2. **Appraisal costs**—costs incurred to detect which of the individual units of products do not conform to specifications
3. **Internal failure costs**—costs incurred on defective products *before* they are shipped to customers
4. **External failure costs**—costs incurred on defective products *after* they have been shipped to customers

The items in Exhibit 19-1 come from all business functions of the value chain, and they are broader than the internal failure costs of spoilage, rework, and scrap described in Chapter 18.

An important role for management accountants is preparing COQ reports for managers. Photon determines the COQ of its photocopying machines by adapting the seven-step activity-based costing approach described in Chapter 5.

Step 1: Identify the Chosen Cost Object. The cost object is the quality of the photocopying machine that Photon made and sold in 2011. Photon’s goal is to calculate the total costs of quality of these 20,000 machines.

Step 2: Identify the Direct Costs of Quality of the Product. The photocopying machines have no direct costs of quality because there are no resources such as inspection or repair workers dedicated to managing the quality of the photocopying machines.

Step 3: Select the Activities and Cost-Allocation Bases to Use for Allocating Indirect Costs of Quality to the Product. Column 1 of Exhibit 19-2, Panel A, classifies the activities that result in prevention, appraisal, and internal and external failure costs of quality at Photon Corporation and the business functions of the value chain in which these costs occur. For example, the quality-inspection activity results in appraisal costs and occurs in the manufacturing function. Photon identifies the total number of inspection-hours (across all products) as the cost-allocation base for the inspection activity. (To avoid details not needed to explain the concepts here, we do not show the total quantities of each cost-allocation base.)

Step 4: Identify the Indirect Costs of Quality Associated with Each Cost-Allocation Base. These are the total costs (variable and fixed) incurred for each of the costs-of-quality activities, such as inspections, across all of Photon’s products. (To avoid details not needed to understand the points described here, we do not present these total costs.)

Step 5: Compute the Rate per Unit of Each Cost-Allocation Base. For each activity, total costs (identified in Step 4) are divided by total quantity of the cost-allocation base (calculated in Step 3) to compute the rate per unit of each cost-allocation base. Column 2 of Exhibit 19-2, Panel A, shows these rates (without supporting calculations).

Prevention Costs	Appraisal Costs	Internal Failure Costs	External Failure Costs
Design engineering	Inspection	Spoilage	Customer support
Process engineering	Online product	Rework	Manufacturing/
Supplier evaluations	manufacturing	Scrap	process
Preventive equipment	and process	Machine repairs	engineering
maintenance	inspection	Manufacturing/	for external
Quality training	Product testing	process	failures
Testing of new		engineering on	Warranty repair
materials		internal failures	costs
			Liability claims

Exhibit 19-1
Items Pertaining to
Costs-of-Quality
Reports

Exhibit 19-2

Analysis of Activity-Based Costs of Quality (COQ) for Photocopying Machines at Photon Corporation

							
	A	B	C	D	E	F	G
1	PANEL A: ACCOUNTING COQ REPORT						Percentage of
2		Cost Allocation Rate^a		Quantity of Cost Allocation Base		Total Costs	Revenues
3	Cost of Quality and Value-Chain Category						(5) = (4) ÷
4	(1)	(2)		(3)		(4) = (2) x (3)	\$300,000,000
5	<i>Prevention costs</i>						
6	Design engineering (R&D/Design)	\$ 80	per hour	40,000	hours	\$ 3,200,000	1.1%
7	Process engineering (R&D/Design)	\$ 60	per hour	45,000	hours	<u>2,700,000</u>	<u>0.9%</u>
8	Total prevention costs					<u>5,900,000</u>	<u>2.0%</u>
9	<i>Appraisal costs</i>						
10	Inspection (Manufacturing)	\$ 40	per hour	240,000	hours	<u>9,600,000</u>	<u>3.2%</u>
11	Total appraisal costs					<u>9,600,000</u>	<u>3.2%</u>
12	<i>Internal failure costs</i>						
13	Rework (Manufacturing)	\$100	per hour	100,000	hours	<u>10,000,000</u>	<u>3.3%</u>
14	Total internal failure costs					<u>10,000,000</u>	<u>3.3%</u>
15	<i>External failure costs</i>						
16	Customer support (Marketing)	\$ 50	per hour	12,000	hours	600,000	0.2%
17	Transportation (Distribution)	\$240	per load	3,000	loads	720,000	0.2%
18	Warranty repair (Customer service)	\$110	per hour	120,000	hours	<u>13,200,000</u>	<u>4.4%</u>
19	Total external failure costs					<u>14,520,000</u>	<u>4.8%</u>
20	Total costs of quality					<u>\$40,020,000</u>	<u>13.3%</u>
21							
22	^a Calculations not shown.						
23							
24	PANEL B: OPPORTUNITY COST ANALYSIS						
25						Total Estimated	Percentage
26						Contribution	of Revenues
27	Cost of Quality Category					Margin Lost	(3) = (2) ÷
28	(1)					(2)	\$300,000,000
29	<i>External failure costs</i>						
30	Estimated forgone contribution margin						
31	and income on lost sales					<u>\$12,000,000^b</u>	<u>4.0%</u>
32	Total external failure costs					<u>\$12,000,000</u>	<u>4.0%</u>
33							
34	^b Calculated as total revenues minus all variable costs (whether output-unit, batch, product-sustaining, or facility-sustaining) on						
35	lost sales in 2011. If poor quality causes Photon to lose sales in subsequent years as well, the opportunity costs will be						
36	even greater.						

Step 6: Compute the Indirect Costs of Quality Allocated to the Product. The indirect costs of quality of the photocopying machines, shown in Exhibit 19-2, Panel A, column 4, equal the cost-allocation rate from Step 5 (column 2) multiplied by the total quantity of the cost-allocation base used by the photocopying machines for each activity (column 3). For example, inspection costs for assuring the quality of the photocopying machines are \$9,600,000 (\$40 per hour × 240,000 inspection-hours).

Step 7: Compute the Total Costs of Quality by Adding All Direct and Indirect Costs of Quality Assigned to the Product. Photon's total costs of quality in the COQ report for photocopying machines is \$40.02 million (Exhibit 19-2, Panel A, column 4) or 13.3% of current revenues (column 5).

As we have seen in Chapter 11, opportunity costs are not recorded in financial accounting systems. Yet, a very significant component of costs of quality is the opportunity cost of the contribution margin and income forgone from lost sales, lost production, and lower prices resulting from poor design and conformance quality. Photon's market research department estimates that design and conformance quality problems experienced by some customers resulted in lost sales of 2,000 photocopying machines in 2011 and forgone contribution margin and operating income of \$12 million (Exhibit 19-2, Panel B). Total costs of quality, including opportunity costs, equal \$52.02 million (\$40.02 million recorded in the accounting system and shown in Panel A + \$12 million of opportunity costs shown in Panel B), or 17.3% of current revenues. Opportunity costs account for 23.1% ($\$12 \text{ million} \div \52.02 million) of Photon's total costs of quality.

We turn next to the leading indicators of the costs of quality, the nonfinancial measures of customer satisfaction about the quality of Photon's photocopiers.

The Customer Perspective: Nonfinancial Measures of Customer Satisfaction

Similar to Unilever, Federal Express, and TiVo, Photon tracks the following measures of customer satisfaction:

- Market research information on customer preferences for and customer satisfaction with specific product features (to measure design quality)
- Market share
- Percentage of highly satisfied customers
- Number of defective units shipped to customers as a percentage of total units shipped
- Number of customer complaints (Companies estimate that for every customer who actually complains, there are 10–20 others who have had bad experiences with the product or service but did not complain.)
- Percentage of products that fail soon after delivery
- Average delivery delays (difference between the scheduled delivery date and the date requested by the customer)
- On-time delivery rate (percentage of shipments made on or before the scheduled delivery date)

Photon's management monitors whether these numbers improve or deteriorate over time. Higher customer satisfaction should lead to lower costs of quality and higher future revenues from greater customer retention, loyalty, and positive word-of-mouth advertising. Lower customer-satisfaction indicates that costs of quality will likely increase in the future. We next turn to the driver of customer satisfaction, the internal business processes to identify and analyze quality problems and to improve quality.

The Internal-Business-Process Perspective: Analyzing Quality Problems and Improving Quality

We present three techniques for identifying and analyzing quality problems: control charts, Pareto diagrams, and cause-and-effect diagrams.

Control Charts

Statistical quality control (SQC), also called statistical process control (SPC), is a formal means of distinguishing between random and nonrandom variations in an operating process. Random variations occur, for example, when chance fluctuations in the speed of equipment cause defective products to be produced such as copiers that produce fuzzy and unclear copies or copies that are too light or too dark. Nonrandom variations occur when defective products are produced as a result of a systematic problem such as an incorrect speed setting, a flawed part design, or mishandling of a component part. A **control chart**, an important tool in SQC, is a graph of a series of successive observations of a particular step, procedure, or operation taken at regular intervals of time. Each observation is plotted relative to specified ranges that represent the limits within which

Decision Point

What are the four cost categories of a costs-of-quality program?

Learning Objective 2

Develop nonfinancial measures

... customer satisfaction measures such as number of customer complaints, internal-business process measures such as percentage of defective and reworked products, and learning and growth measures such as employee empowerment and training

and methods to improve quality

... control charts, Pareto diagrams, and cause-and-effect diagrams

observations are expected to fall. Only those observations outside the control limits are ordinarily regarded as nonrandom and worth investigating.

Exhibit 19-3 presents control charts for the daily defect rates (defective copiers divided by the total number of copiers produced) observed at Photon's three photocopying-machine production lines. Defect rates in the prior 60 days for each production line were assumed to provide a good basis from which to calculate the distribution of daily defect rates. The arithmetic mean (μ , read as mu) and standard deviation (σ , read as sigma, how much an observation deviates from the mean) are the two parameters of the distribution that are used in the control charts in Exhibit 19-3. On the basis of experience, the company decides that any observation outside the $\mu \pm 2\sigma$ range should be investigated.

For production line A, all observations are within the range of $\mu \pm 2\sigma$, so management believes no investigation is necessary. For production line B, the last two observations signal that a much higher percentage of copiers are not performing as they should, indicating that the problem is probably because of a nonrandom, out-of-control occurrence such as an incorrect speed setting or mishandling of a component part. Given the $\pm 2\sigma$ rule, both observations would be investigated. Production line C illustrates a process that would not prompt an investigation under the $\pm 2\sigma$ rule but that may well be out of control, because the last eight observations show a clear direction, and over the last six days, the percentage of defective copiers are increasing and getting further and further away from the mean. The pattern of observations moving away from the mean could be due, for example, to the tooling on a machine beginning to wear out, resulting in poorly machined parts. As the tooling deteriorates further, the trend in producing defective copiers is likely to persist until the production line is no longer in statistical control. Statistical procedures have been developed using the trend as well as the variation to evaluate whether a process is out of control.

Pareto Diagrams

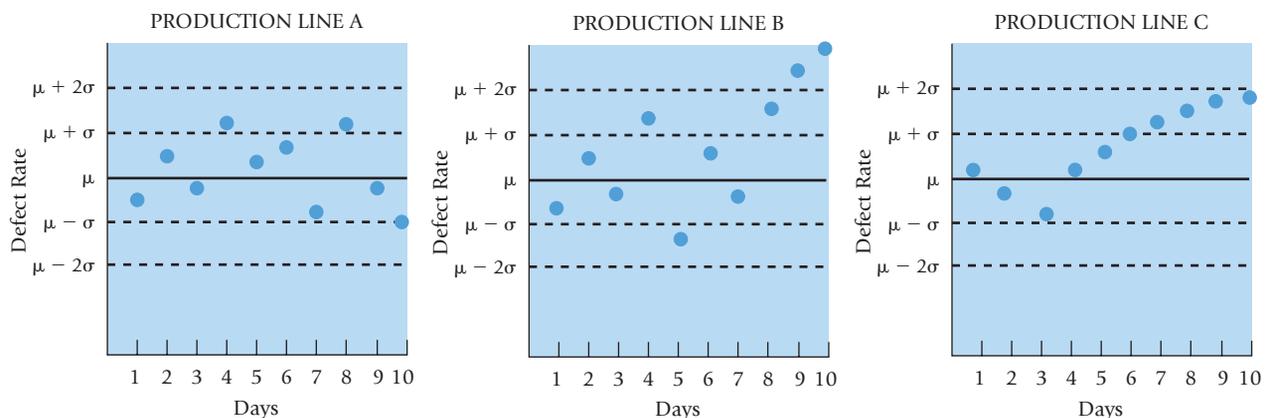
Observations outside control limits serve as inputs for Pareto diagrams. A **Pareto diagram** is a chart that indicates how frequently each type of defect occurs, ordered from the most frequent to the least frequent. Exhibit 19-4 presents a Pareto diagram of quality problems for all observations outside the control limits at the final inspection point in 2011. Fuzzy and unclear copies are the most frequently recurring problem. Fuzzy and unclear copies result in high rework costs. Sometimes fuzzy and unclear copies occur at customer sites and result in high warranty and repair costs and low customer satisfaction.

Cause-and-Effect Diagrams

The most frequently recurring and costly problems identified by the Pareto diagram are analyzed using cause-and-effect diagrams. A **cause-and-effect diagram** identifies potential causes of defects using a diagram that resembles the bone structure of a fish (hence, cause-and-effect diagrams are also called *fishbone diagrams*).² Exhibit 19-5 presents the

Exhibit 19-3

Statistical Quality Control Charts: Daily Defect Rate for Photocopying Machines at Photon Corporation



² See P. Clark, "Getting the Most from Cause-and-Effect Diagrams," *Quality Progress* (June 2000).

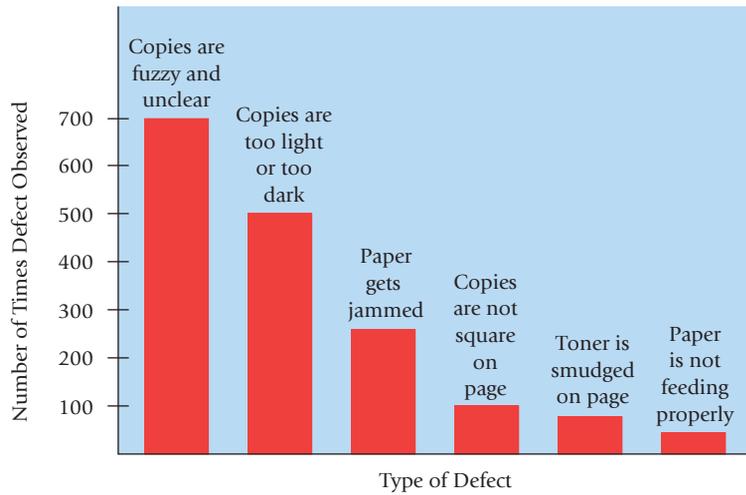


Exhibit 19-4
 Pareto Diagram for Photocopying Machines at Photon Corporation

cause-and-effect diagram describing potential reasons for fuzzy and unclear copies. The “backbone” of the diagram represents the problem being examined. The large “bones” coming off the backbone represent the main categories of potential causes of failure. The exhibit identifies four of these: human factors, methods and design factors, machine-related factors, and materials and components factors. Photon’s engineers identify the materials and components factor as an important reason for the fuzzy and unclear copies. Additional arrows or bones are added to provide more-detailed reasons for each higher-level cause. For example, the engineers determine that two potential causes of material and component problems are variation in purchased components and incorrect component specification. They quickly settle on variation in purchased components as the likely cause and focus on the use of multiple suppliers and mishandling of purchased parts as the root causes of variation in purchased components. Further analysis leads them to conclude that mishandling of the steel frame that holds in place various components of the copier such as drums, mirrors, and lenses results in the misalignment of these components, causing fuzzy and unclear copies.

The analysis of quality problems is aided by automated equipment and computers that record the number and types of defects and the operating conditions that existed at the time the defects occurred. Using these inputs, computer programs simultaneously and iteratively prepare control charts, Pareto diagrams, and cause-and-effect diagrams with the goal of continuously reducing the mean defect rate, μ , and the standard deviation, σ .

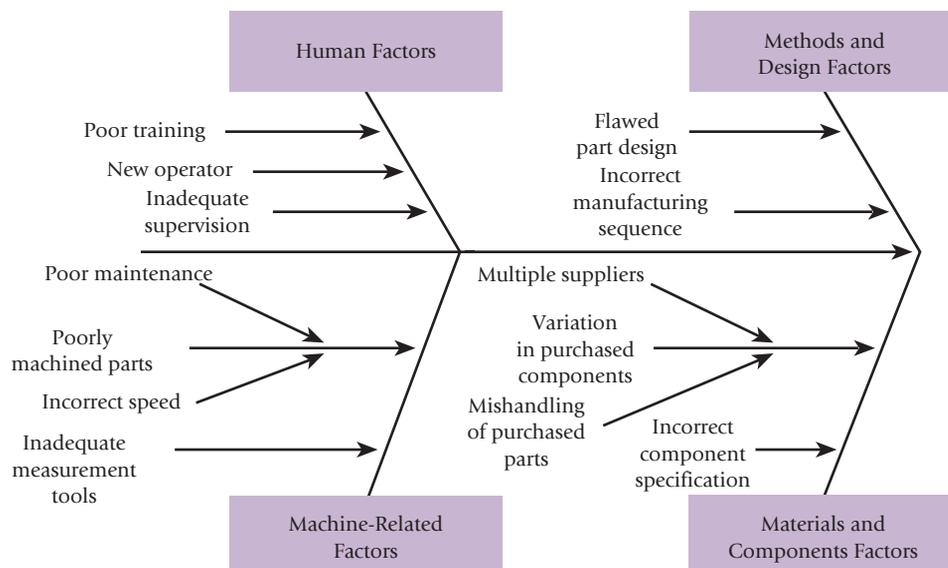


Exhibit 19-5
 Cause-and-Effect Diagram for Fuzzy and Unclear Photocopies at Photon Corporation

Six Sigma Quality

The ultimate goal of quality programs at companies such as Motorola, Honeywell, and General Electric is to achieve Six Sigma quality.³ This means that the process is so well-understood and tightly controlled that the mean defect rate, μ , and the standard deviation, σ , are both very small. As a result, the upper and lower control limits in Exhibit 19-3 can be set at a distance of 6σ (six sigma) from the mean (μ). The implication of controlling a process at a Six Sigma level is that the process produces only 3.4 defects per million products produced.

To implement Six Sigma, companies use techniques such as control charts, Pareto diagrams, and cause-and-effect diagrams to define, measure, analyze, improve, and control processes to minimize variability in manufacturing and achieve almost zero defects. Critics of Six Sigma argue that it emphasizes incremental rather than dramatic or disruptive innovation. Nevertheless, companies report substantial benefits from Six Sigma initiatives.

Companies routinely use nonfinancial measures to track the quality improvements they are making.

Nonfinancial Measures of Internal-Business-Process Quality

Photon uses the following measures of internal-business-process quality:

- Percentage of defective products
- Percentage of reworked products
- Number of different types of defects analyzed using control charts, Pareto diagrams, and cause-and-effect diagrams
- Number of design and process changes made to improve design quality or reduce costs of quality

Photon's managers believe that improving these measures will lead to greater customer satisfaction, lower costs of quality, and better financial performance.

The Learning-and-Growth Perspective: Quality Improvements

What are the drivers of internal-business-process quality? Photon believes that recruiting outstanding design engineers, providing more employee training, and lowering employee turnover as a result of greater employee empowerment and satisfaction will reduce the number of defective products and increase customer satisfaction, leading to better financial performance. Photon measures the following factors in the learning-and-growth perspective in the balanced scorecard:

- Experience and qualifications of design engineers
- Employee turnover (ratio of number of employees who leave the company to the average total number of employees)
- Employee empowerment (ratio of the number of processes in which employees have the right to make decisions without consulting supervisors to the total number of processes)
- Employee satisfaction (ratio of employees indicating high satisfaction ratings to the total number of employees surveyed)
- Employee training (percentage of employees trained in different quality-enhancing methods)

Making Decisions and Evaluating Quality Performance

Relevant Costs and Benefits of Quality Improvement

When making decisions and evaluating performance, companies combine financial and nonfinancial information. We use the Photon example to illustrate relevant revenues and relevant costs in the context of decisions to improve quality.

Decision Point

What nonfinancial measures and methods can managers use to improve quality?

³ Six Sigma is a registered trademark of Motorola Inc.

Recall that Photon’s cause-and-effect diagram reveals that the steel frame (or chassis) of the copier is often mishandled as it travels from a supplier’s warehouse to Photon’s plant. The frame must meet very precise specifications or else copier components (such as drums, mirrors, and lenses) will not fit exactly on the frame. Mishandling frames during transport causes misalignment and results in fuzzy and unclear copies.

A team of engineers offers two solutions: (1) inspect the frames immediately on delivery or (2) redesign and strengthen the frames and their shipping containers to withstand mishandling during transportation. The cost structure for 2012 is expected to be the same as the cost structure for 2011 presented in Exhibit 19-2.

To evaluate each alternative versus the status quo, management identifies the relevant costs and benefits for each solution by focusing on *how total costs and total revenues will change under each alternative*. As explained in Chapter 11, relevant-cost and relevant-revenue analysis ignores allocated amounts.

Photon uses only a one-year time horizon (2012) for the analysis because it plans to introduce a completely new line of copiers at the end of 2012. The new line is so different that the choice of either the inspection or the redesign alternative will have no effect on the sales of copiers in future years.

Exhibit 19-6 shows the relevant costs and benefits for each alternative.

- Estimated incremental costs:** \$400,000 for the inspection alternative; \$460,000 for the redesign alternative.
- Cost savings from less rework, customer support, and repairs:** Exhibit 19-6, line 10, shows that reducing rework results in savings of \$40 per hour. Exhibit 19-2, Panel A, column 2, line 13, shows total rework cost per hour of \$100. Why the difference? Because as it improves quality, Photon will only save the \$40 variable cost per rework-hour, not the \$60 fixed cost per rework-hour. Exhibit 19-6, line 10, shows total savings of \$960,000 (\$40 per hour × 24,000 rework-hours saved) if it inspects the frames and \$1,280,000 (\$40 per rework-hour × 32,000 rework-hours saved) if it redesigns the frames. Exhibit 19-6 also shows expected variable-cost savings in customer support, transportation, and warranty repair for the two alternatives.
- Increased contribution margin from higher sales as a result of building a reputation for quality and performance (Exhibit 19-6, line 14):** \$1,500,000 for 250 copiers under the inspection alternative and \$1,800,000 for 300 copiers under the redesign alternative. Management should always look for opportunities to generate higher revenues, not just cost reductions, from quality improvements.

Learning Objective 3

Combine financial and nonfinancial measures to make decisions and evaluate quality performance

... Identify relevant incremental and opportunity costs to evaluate tradeoffs across costs of quality and nonfinancial measures to identify problem areas and to highlight leading indicators of future performance

Exhibit 19-6

Estimated Effects of Quality-Improvement Actions on Costs of Quality for Photocopying Machines at Photon Corporation

										
	A	B	C	D	E	F	G	H	I	J
1	Relevant Costs and Benefits of									
2	Further Inspecting Incoming Frames					Redesigning Frames				
3	Relevant Items		Relevant Benefit per Unit		Quantity		Total Benefits			
4	(1)		(2)		(3)		(4)		(5) (6)	
5	Additional inspection and testing costs						\$ (400,000)			
6	Additional process engineering costs								\$ (300,000)	
7	Additional design engineering costs								(160,000)	
8										
9							(2) × (3)		(2) × (5)	
10	Savings in rework costs		\$ 40 per hour		24,000 hours		\$ 960,000		32,000 hours \$1,280,000	
11	Savings in customer-support costs		\$ 20 per hour		2,000 hours		40,000		2,800 hours 56,000	
12	Savings in transportation costs for repair parts		\$ 180 per load		500 loads		90,000		700 loads 126,000	
13	Savings in warranty repair costs		\$ 45 per hour		20,000 hours		900,000		28,000 hours 1,260,000	
14	Total contribution margin from additional sales		\$6,000 per copier		250 copiers		1,500,000		300 copiers 1,800,000	
15										
16	Net cost savings and additional contribution margin						3,090,000		4,062,000	
17										
18	Difference in favor of redesigning frames (J16) – (F16)								\$972,000	

Exhibit 19-6 shows that both the inspection and the redesign alternatives yield net benefits relative to the status quo. However, the net benefits from the redesign alternative are expected to be \$972,000 greater.

Note how making improvements in internal business processes affects the COQ numbers reported in the financial perspective. In our example, redesigning the frame increases prevention costs (design and process engineering), decreases internal failure costs (rework), and decreases external failure costs (customer support and warranty repairs). COQ reports provide more insight about quality improvements when managers compare trends over time. In successful quality programs, companies decrease costs of quality and, in particular, internal and external failure costs, as a percentage of revenues. Many companies, such as Hewlett-Packard, go further and believe they should eliminate all failure costs and have zero defects.

How should Photon use financial and nonfinancial measures to evaluate quality performance? They should utilize both types of measures because financial (COQ) and nonfinancial measures of quality have different advantages.

Advantages of COQ Measures

- Consistent with the attention-directing role of management accounting, COQ measures focus managers' attention on the costs of poor quality.
- Total COQ provides a measure of quality performance for evaluating trade-offs among prevention costs, appraisal costs, internal failure costs, and external failure costs.
- COQ measures assist in problem solving by comparing costs and benefits of different quality-improvement programs and setting priorities for cost reduction.

Advantages of Nonfinancial Measures of Quality

- Nonfinancial measures of quality are often easy to quantify and understand.
- Nonfinancial measures direct attention to physical processes and hence help managers identify the precise problem areas that need improvement.
- Nonfinancial measures, such as number of defects, provide immediate short-run feedback on whether quality-improvement efforts are succeeding.
- Nonfinancial measures such as measures of customer satisfaction and employee satisfaction are useful indicators of long-run performance.

COQ measures and nonfinancial measures complement each other. Without financial quality measures, companies could be spending more money on improving nonfinancial quality measures than it is worth. Without nonfinancial quality measures, quality problems might not be identified until it is too late. Most organizations use both types of measures to gauge quality performance. McDonald's, for example, evaluates employees and individual franchisees on multiple measures of quality and customer satisfaction. A mystery shopper, an outside party contracted by McDonald's to evaluate restaurant performance, scores individual restaurants on quality, cleanliness, service, and value. A restaurant's performance on these dimensions is evaluated over time and against other restaurants. In its balanced scorecard, Photon evaluates whether improvements in various nonfinancial quality measures eventually lead to improvements in financial measures.

Decision Point

How do managers identify the relevant costs and benefits of quality improvement programs and use financial and nonfinancial measures to evaluate quality?

Time as a Competitive Tool

Companies increasingly view time as a driver of strategy.⁴ For example, CapitalOne has increased business on its Web site by promising home-loan approval decisions in 30 minutes or less. Companies such as AT&T, General Electric, and Wal-Mart attribute not only higher revenues but also lower costs to doing things faster and on time. They cite, for example, the need to carry less inventory due to their ability to respond rapidly to customer demands.

⁴ See K. Eisenhardt and S. Brown, "Time Pacing: Competing in Strategic Markets That Won't Stand Still," *Harvard Business Review* (March–April 1998); and T. Willis and A. Jurkus, "Product Development: An Essential Ingredient of Time-Based Competition," *Review of Business* (2001).

Companies need to measure time to manage it properly. In this section, we focus on two *operational measures of time*: *customer-response time*, which reveals how quickly companies respond to customers' demands for their products and services, and *on-time performance*, which indicates how reliably they meet scheduled delivery dates. We also show how companies measure the causes and costs of delays.

Customer-Response Time and On-Time Performance

Customer-response time is how long it takes from the time a customer places an order for a product or service to the time the product or service is delivered to the customer. Fast responses to customers are of strategic importance in industries such as construction, banking, car rental, and fast food. Some companies, such as Airbus, have to pay penalties to compensate their customers (airline companies) for lost revenues and profits (from being unable to operate flights) as a result of delays in delivering aircraft to them.

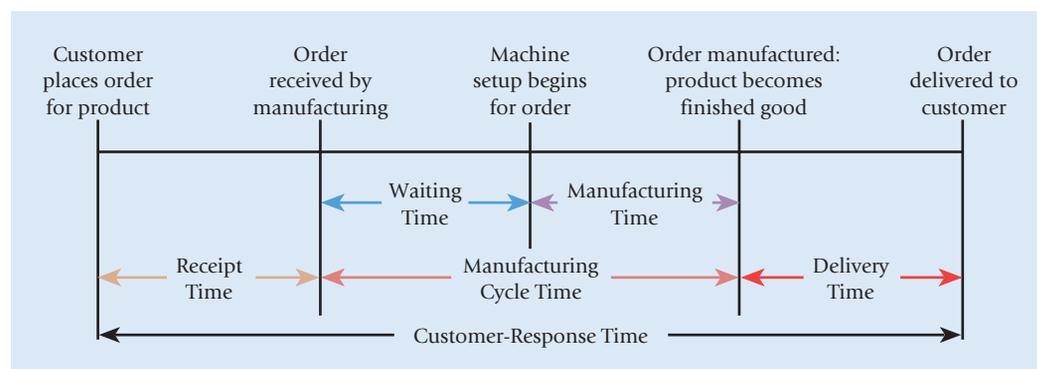
Exhibit 19-7 describes the components of customer-response time. *Receipt time* is how long it takes the marketing department to specify to the manufacturing department the exact requirements in the customer's order. **Manufacturing cycle time** (also called **manufacturing lead time**) is how long it takes from the time an order is received by manufacturing to the time a finished good is produced. Manufacturing cycle time is the sum of waiting time and manufacturing time for an order. For example, an aircraft order received by Airbus may need to wait before the equipment required to process it becomes available. *Delivery time* is how long it takes to deliver a completed order to a customer.

Some companies evaluate their response time improvement efforts using a measure called **manufacturing cycle efficiency (MCE)**:

$$\text{MCE} = (\text{Value-added manufacturing time} \div \text{Manufacturing cycle time})$$

As discussed in Chapter 12, value-added manufacturing activities are activities that customers perceive as adding value or utility to a product. The time actually spent assembling the product is value-added manufacturing time. The rest of manufacturing cycle time, such as the time the product spends waiting for parts or for the next stage in the production process, and being repaired, represents nonvalue-added manufacturing time. Identifying and minimizing the sources of nonvalue-added manufacturing time increases customer responsiveness and reduces costs.

Similar measures apply to service-sector companies. Consider a 40-minute doctor's office visit, of which 9 minutes is spent on administrative tasks such as filling out forms, 20 minutes is spent waiting in the reception area and examination room, and 11 minutes is spent with a nurse or doctor. The service cycle efficiency for this visit equals $11 \div 40$, or 0.275. In other words, only 27.5% of the time in the office added value to the customer. Minimizing nonvalue-added service time in their medical delivery processes has allowed hospitals such as Alle-Kiski Medical Center in Pennsylvania to treat more patients in less time.



Learning Objective 4

Describe customer-response time

... time between receipt of customer order and product delivery

and explain why delays happen and their costs

... uncertainty about the timing of customer orders and limited capacity lead to lower revenues and higher inventory carrying costs

Exhibit 19-7

Components of Customer-Response Time

On-time performance is delivery of a product or service by the time it is scheduled to be delivered. Consider Federal Express, which specifies a price per package and a next-day delivery time of 10:30 A.M. for its overnight courier service. Federal Express measures on-time performance by how often it meets its stated delivery time of 10:30 A.M. On-time performance increases customer satisfaction. For example, commercial airlines gain loyal passengers as a result of consistent on-time service. But there is a trade-off between a customer's desire for shorter customer-response time and better on-time performance. Scheduling longer customer-response times, such as airlines lengthening scheduled arrival times, displeases customers on the one hand but increases customer satisfaction on the other hand by improving on-time performance.

Bottlenecks and Time Drivers

Managing customer-response time and on-time performance requires understanding the causes and costs of delays that occur, for example, at a machine in a manufacturing plant or at a checkout counter in a store.

A **time driver** is any factor that causes a change in the speed of an activity when the factor changes. Two time drivers are as follows:

1. **Uncertainty about when customers will order products or services.** For example, the more randomly Airbus receives orders for its airplanes, the more likely queues will form and delays will occur.
2. **Bottlenecks due to limited capacity.** A **bottleneck** occurs in an operation when the work to be performed approaches or exceeds the capacity available to do it. For example, a bottleneck results and causes delays when products that must be processed at a particular machine arrive while the machine is being used to process other products. Bottlenecks also occur on the Internet, for example, when many users try to operate wireless mobile devices at the same time (see *Concepts in Action*, p. 684). Many banks, such as Bank of China; grocery stores, such as Krogers; and entertainment parks, such as Disneyland, actively work to reduce queues and delays to better serve their customers.

Consider Falcon Works (FW), which uses one turning machine to convert steel bars into a special gear for planes. FW makes this gear, which is its sole product, only after customers have ordered it. To focus on manufacturing cycle time, we assume FW's receipt time and delivery time are minimal. FW's strategy is to differentiate itself from competitors by offering faster delivery. The company's manager is examining opportunities to sell other products to increase profits without sacrificing the competitive advantage provided by short customer-response times. The manager examines these opportunities using the five-step decision-making process introduced in Chapter 1.

Step 1: Identify the problem and uncertainties. FW's manager is considering introducing a second product, a piston for pumps. The primary uncertainty is how the introduction of a second product will affect manufacturing cycle times for gears.

Step 2: Obtain information. The manager gathers data on the number of orders for gears FW has received in the past, the time it takes to manufacture gears, the available capacity, and the average manufacturing cycle time for gears. FW typically receives 30 orders for gears, but it could receive 10, 30, or 50 orders. Each order is for 1,000 units and takes 100 hours of manufacturing time (8 hours of setup time to clean and prepare the machine, and 92 hours of processing time). Annual capacity of the machine is 4,000 hours. If FW receives the 30 orders it expects, the total amount of manufacturing time required on the machine is 3,000 hours (100 hours per order \times 30 orders), which is within the available machine capacity of 4,000 hours. Even though capacity utilization is not strained, queues and delays still occur, because uncertainty about when FW's customers place their orders causes an order to be received while the machine is processing an earlier order.

Average waiting time, the average amount of time that an order waits in line before the machine is set up and the order is processed, equals,⁵

$$\frac{\text{Annual average number of orders for gears} \times \left(\frac{\text{Manufacturing time per order for gears}}{\text{for gears}} \right)^2}{2 \times \left[\frac{\text{Annual machine capacity}}{\text{capacity}} - \left(\frac{\text{Annual average number of orders for gears}}{\text{of orders for gears}} \times \frac{\text{Manufacturing time per order for gears}}{\text{time per order for gears}} \right) \right]}$$

$$= \frac{30 \times (100)^2}{2 \times [4,000 - (30 \times 100)]} = \frac{30 \times 10,000}{2 \times (4,000 - 3,000)} = \frac{300,000}{2 \times 1,000} = \frac{300,000}{2,000} = 150 \text{ hours per order (for gears)}$$

Therefore, the average manufacturing cycle time for an order is 250 hours (150 hours of average waiting time + 100 hours of manufacturing time). Note that manufacturing time per order is a squared term in the numerator. It indicates the disproportionately large impact manufacturing time has on waiting time. As the manufacturing time lengthens, there is a much greater chance that the machine will be in use when an order arrives, leading to longer delays. The denominator in this formula is a measure of the unused capacity, or cushion. As the unused capacity becomes smaller, the chance that the machine is processing an earlier order becomes more likely, leading to greater delays.

The formula describes only the *average* waiting time. A particular order might arrive when the machine is free, in which case manufacturing will start immediately. In another situation, FW may receive an order while two other orders are waiting to be processed, which means the delay will be longer than 150 hours.

Step 3: Make predictions about the future. The manager makes the following predictions about pistons: FW expects to receive 10 orders for pistons, each order for 800 units, in the coming year. Each order will take 50 hours of manufacturing time, comprising 3 hours for setup and 47 hours of processing. Expected demand for FW's gears will be unaffected by whether FW introduces pistons.

Average waiting time *before* machine setup begins is expected to be (the formula is an extension of the preceding formula for the single-product case) as follows:

$$\frac{\left[\text{Annual average number of orders for gears} \times \left(\frac{\text{Manufacturing time per order for gears}}{\text{for gears}} \right)^2 \right] + \left[\text{Annual average number of orders for pistons} \times \left(\frac{\text{Manufacturing time per order for pistons}}{\text{for pistons}} \right)^2 \right]}{2 \times \left[\frac{\text{Annual machine capacity}}{\text{capacity}} - \left(\frac{\text{Annual average number of orders for gears}}{\text{of orders for gears}} \times \frac{\text{Manufacturing time per order for gears}}{\text{time per order for gears}} \right) - \left(\frac{\text{Annual average number of orders for pistons}}{\text{of orders for pistons}} \times \frac{\text{Manufacturing time per order for pistons}}{\text{time per order for pistons}} \right) \right]}$$

$$= \frac{[30 \times (100)^2] + [10 \times (50)^2]}{2 \times [4,000 - (30 \times 100) - (10 \times 50)]} = \frac{(30 \times 10,000) + (10 \times 2,500)}{2 \times (4,000 - 3,000 - 500)}$$

$$= \frac{300,000 + 25,000}{2 \times 500} = \frac{325,000}{1,000} = 325 \text{ hours per order (for gears and pistons)}$$

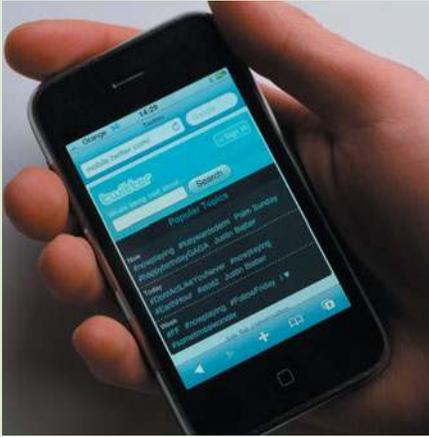
Introducing pistons will cause average waiting time for an order to more than double, from 150 hours to 325 hours. Waiting time increases because introducing pistons will cause unused capacity to shrink, increasing the probability that new orders will arrive while current orders are being manufactured or waiting to be manufactured. Average waiting time is very sensitive to the shrinking of unused capacity.

If the manager decides to make pistons, average manufacturing cycle time will be 425 hours for a gear order (325 hours of average waiting time + 100 hours of manufacturing time), and 375 hours for a piston order (325 hours of average waiting time + 50 hours

⁵ The technical assumptions are (a) that customer orders for the product follow a Poisson distribution with a mean equal to the expected number of orders (30 in our example), and (b) that orders are processed on a first-in, first-out (FIFO) basis. The Poisson arrival pattern for customer orders has been found to be reasonable in many real-world settings. The FIFO assumption can be modified. Under the modified assumptions, the basic queuing and delay effects will still occur, but the precise formulas will be different.

Concepts in Action

Overcoming Wireless Data Bottlenecks



The wired world is quickly going wireless. In 2010, sales of smartphones—such as the Apple iPhone and BlackBerry—in the United States were predicted to be 53 million units. In addition to the smartphone boom, emerging devices including e-book readers and machine-to-machine appliances (the so-called “Internet of things”) will add to rapidly growing data traffic.

With every new device that lets users browse the Internet, and every new business that taps into the convenience and speed of the wireless world, the invisible information superhighway gets a little more crowded. Cisco recently forecast that data traffic will grow at a compound rate of 108% from 90,000 terabytes per month in 2009 to 3.6 million terabytes per month by 2014.

This astronomical growth already causes many users to suffer from mobile bottlenecks caused by too many users trying to transfer mobile data at the same time in a given area. These bottlenecks are most harmful to companies buying and selling products and services over the

mobile Internet. Without access, Amazon.com Kindle owners cannot download new e-books and mobile brokerage users cannot buy and sell stocks “on the go.”

To relieve mobile bottlenecks, wireless providers and other high-tech companies are working on more efficient mobile broadband networks, such as LTE, that make use of complementary technologies to automatically choose the best available wireless network to increase capacity. Technology providers are also deploying Wi-Fi direct, which allows mobile users to freely transfer video, digital music, and photos between mobile devices without choking up valuable bandwidth. Companies and government agencies around the world are also trying to increase the wireless broadband spectrum. In the United States, for example, current holders of spectrum—such as radio stations—are being encouraged to sell their excess capacity to wireless providers in exchange for a share of the profits.

Sources: Edwards, Cliff. 2010. Wi-fi direct seen as way to alleviate network congestion. *BusinessWeek*, January 7. www.businessweek.com/technology/content/jan2010/tc2010017_884186.htm; Morris, John. 2010. CTIA: More spectrum, and other ways to break the wireless data bottleneck. *ZDNet*. “Laptops & Desktops,” blog March 24. <http://www.zdnet.com/blog/computers/ctia-more-spectrum-and-other-ways-to-break-the-wireless-data-bottleneck/1877>; Pyle, George. 2010. Wireless growth leading to bottlenecks. *Buffalo News*, May 9. www.buffalonews.com/2010/05/09/1044893/wireless-growth-leading-to-bottlenecks.html.

of manufacturing time). A gear order will spend 76.5% ($325 \text{ hours} \div 425 \text{ hours}$) of its manufacturing cycle time just waiting for manufacturing to start!

Step 4: Make decisions by choosing among alternatives. Given the anticipated effects on manufacturing cycle time of adding pistons, should FW’s manager introduce pistons? To help the manager make a decision, the management accountant identifies and analyzes the relevant revenues and relevant costs of adding the piston product and, in particular, the cost of delays on all products. The rest of this section focuses on Step 4. While we do not cover Step 5 in this example, we discuss later in the chapter how the balanced scorecard can be a useful tool to evaluate and learn about time-based performance.

Relevant Revenues and Relevant Costs of Time

To determine the relevant revenues and costs of adding pistons under Step 4, the management accountant prepares the following additional information:

Product	Annual Average Number of Orders	Average Selling Price per Order If Average Manufacturing Cycle Time per Order Is		Direct Material Cost per Order	Inventory Carrying Cost per Order per Hour
		Less Than 300 Hours	More Than 300 Hours		
		Gears	30		
Pistons	10	10,000	9,600	8,000	0.50

Manufacturing cycle times affect both revenues and costs. Revenues are affected because customers are willing to pay a higher price for faster delivery. On the cost side, direct material costs and inventory carrying costs are the only relevant costs of introducing pistons (all other costs are unaffected and hence irrelevant). Inventory carrying costs equal the opportunity costs of investment tied up in inventory (see Chapter 11, pp. 403–405) and the relevant costs of storage, such as space rental, spoilage, deterioration, and materials handling. Usually, companies calculate inventory carrying costs on a per-unit, per-year basis. To simplify calculations, the management accountant calculates inventory carrying costs on a per-order, per-hour basis. Also, FW acquires direct materials at the time the order is received by manufacturing and, therefore, calculates inventory carrying costs for the duration of the manufacturing cycle time.

Exhibit 19-8 presents relevant revenues and relevant costs for the “introduce pistons” and “do not introduce pistons” alternatives. Based on the analysis, FW’s managers decide not to introduce pistons, even though pistons have a positive contribution margin of \$1,600 (\$9,600 – \$8,000) per order and FW has the capacity to process pistons. If it produces pistons, FW will, on average, use only 3,500 (Gears: 100 hours per order × 30 orders + Pistons: 50 hours per order × 10 orders) of the available 4,000 machine-hours. So why is FW better off not introducing pistons? *Because of the negative effects that producing pistons will have on the existing product, gears.* The following table presents the *costs of time*, the expected loss in revenues and expected increase in carrying costs as a result of delays caused by using machine capacity to manufacture pistons.

Product	Effect of Increasing Average Manufacturing Cycle Time		Expected Loss in Revenues Plus Expected Increase in Carrying Costs of Introducing Pistons (3) = (1) + (2)
	Expected Loss in Revenues for Gears (1)	Expected Increase in Carrying Costs for All Products (2)	
Gears	\$15,000 ^a	\$5,250 ^b	\$20,250
Pistons	—	1,875 ^c	1,875
Total	<u>\$15,000</u>	<u>\$7,125</u>	<u>\$22,125</u>

^a(\$22,000 – \$21,500) per order × 30 expected orders = \$15,000.

^b(425 – 250) hours per order × \$1.00 per hour × 30 expected orders = \$5,250.

^c(375 – 0) hours per order × \$0.50 per hour × 10 expected orders = \$1,875.

Introducing pistons causes the average manufacturing cycle time of gears to increase from 250 hours to 425 hours. Longer manufacturing cycle times increases inventory carrying costs of gears and decreases gear revenues (average manufacturing cycle time for gears exceeds 300 hours so the average selling price per order decreases from \$22,000 to \$21,500). Together

Relevant Items	Alternative 1: Introduce Pistons (1)	Alternative 2: Do Not Introduce Pistons (2)	Difference (3) = (1) – (2)
	Expected revenues	741,000 ^a	
Expected variable costs	560,000 ^c	480,000 ^d	(80,000)
Expected inventory carrying costs	14,625 ^e	7,500 ^f	(7,125)
Expected total costs	<u>574,625</u>	<u>487,500</u>	<u>(87,125)</u>
Expected revenues minus expected costs	<u>\$166,375</u>	<u>\$172,500</u>	<u>\$ (6,125)</u>

^a(\$21,500 × 30) + (\$9,600 × 10) = \$741,000; average manufacturing cycle time will be more than 300 hours.
^b(\$22,000 × 30) = \$660,000; average manufacturing cycle time will be less than 300 hours.
^c(\$16,000 × 30) + (\$8,000 × 10) = \$560,000.
^d\$16,000 × 30 = \$480,000.
^e(Average manufacturing cycle time for gears × Unit carrying cost per order for gears × Expected number of orders for gears) + (Average manufacturing cycle time for pistons × Unit carrying cost per order for pistons × Expected number of orders for pistons) = (425 × \$1.00 × 30) + (375 × \$0.50 × 10) = \$12,750 + \$1,875 = \$14,625.
^fAverage manufacturing cycle time for gears × Unit carrying cost per order for gears × Expected number of orders for gears = 250 × \$1.00 × 30 = \$7,500.

Exhibit 19-8
 Determining Expected Relevant Revenues and Relevant Costs for Falcon Works’ Decision to Introduce Pistons

Decision Point

What is customer-response time?
 What are the reasons for and the costs of delays?

with the inventory carrying cost of pistons, the expected costs of introducing pistons, \$22,125, exceeds the expected contribution margin of \$16,000 (\$1,600 per order \times 10 expected orders) from selling pistons by \$6,125 (the difference calculated in Exhibit 19-8).

This simple example illustrates that when demand uncertainty is high, some unused capacity is desirable.⁶ Increasing the capacity of a bottleneck resource reduces manufacturing cycle times and delays. One way to increase capacity is to reduce the time required for setups and processing via more-efficient setups and processing. Another way to increase capacity is to invest in new equipment, such as flexible manufacturing systems that can be programmed to switch quickly from producing one product to producing another. Delays can also be reduced through careful scheduling of orders on machines, such as by batching similar jobs together for processing.

Theory of Constraints and Throughput-Margin Analysis

In this section, we consider products that are made from multiple parts and processed on multiple machines. With multiple parts and machines, dependencies arise among operations—that is, some operations cannot be started until parts from the preceding operation are available. Furthermore, some operations are bottlenecks (have limited capacity), and others are not.

Managing Bottlenecks

The **theory of constraints (TOC)** describes methods to maximize operating income when faced with some bottleneck and some nonbottleneck operations.⁷ The TOC defines three measures as follows:

1. **Throughput margin** equals revenues minus the direct material costs of the goods sold.
2. **Investments** equal the sum of material costs in direct materials, work-in-process, and finished goods inventories; R&D costs; and costs of equipment and buildings.
3. **Operating costs** equal all costs of operations (other than direct materials) incurred to earn throughput margin. Operating costs include salaries and wages, rent, utilities, depreciation, and the like.

The objective of the TOC is to increase throughput margin while decreasing investments and operating costs. *The TOC considers a short-run time horizon and assumes operating costs are fixed.* It focuses on managing bottleneck operations as explained in the following steps:

Step 1: Recognize that the bottleneck operation determines throughput margin of the entire system.

Step 2: Identify the bottleneck operation by identifying operations with large quantities of inventory waiting to be worked on.

Step 3: Keep the bottleneck operation busy and subordinate all nonbottleneck operations to the bottleneck operation. That is, the needs of the bottleneck operation determine the production schedule of the nonbottleneck operations.

Step 3 represents one of the key concepts described in Chapter 11: To maximize operating income, the manager must maximize contribution margin (in this case, throughput margin) of the constrained or bottleneck resource (see pp. 405–406). The bottleneck machine must always be kept running; it should not be waiting for jobs. To achieve this objective, companies often maintain a small buffer inventory of jobs at the bottleneck machine. The bottleneck machine sets the pace for all nonbottleneck machines. Workers at nonbottleneck machines do not produce more output than can be

⁶ Other complexities, such as analyzing a network of machines, priority scheduling, and allowing for uncertainty in processing times, are beyond the scope of this book. In these cases, the basic queuing and delay effects persist, but the precise formulas are more complex.

⁷ See E. Goldratt and J. Cox, *The Goal* (New York: North River Press, 1986); E. Goldratt, *The Theory of Constraints* (New York: North River Press, 1990); E. Noreen, D. Smith, and J. Mackey, *The Theory of Constraints and Its Implications for Management Accounting* (New York: North River Press, 1995); and M. Woepel, *Manufacturers' Guide to Implementing the Theory of Constraints* (Boca Raton, FL: Lewis Publishing, 2000).

Learning Objective 5

Explain how to manage bottlenecks

... keep bottlenecks busy and increase their efficiency and capacity by increasing throughput margin

processed by the bottleneck machine, because producing more nonbottleneck output only creates excess inventory; it does not increase throughput margin.

Step 4: Take actions to increase the efficiency and capacity of the bottleneck operation as long as throughput margin exceeds the incremental costs of increasing efficiency and capacity. We illustrate Step 4 using data from Cardinal Industries (CI). CI manufactures car doors in two operations: stamping and pressing.

	Stamping	Pressing
Capacity per hour	20 units	15 units
Annual capacity (6,000 hours of capacity available in each operation)		
6,000 hours \times 20 units/hour; 6,000 hours \times 15 units/hour)	120,000 units	90,000 units
Annual production and sales	90,000 units	90,000 units
Other fixed operating costs (excluding direct materials)	\$720,000	\$1,080,000
Other fixed operating costs per unit produced		
(\$720,000 \div 90,000 units; \$1,080,000 \div 90,000 units)	\$8 per unit	\$12 per unit

Each door sells for \$100 and has a direct material cost of \$40. Variable costs in other functions of the value chain—design of products and processes, marketing, distribution, and customer service—are negligible. CI's output is constrained by the capacity of 90,000 units in the pressing operation. What can CI do to relieve the bottleneck constraint of the pressing operation?

Desirable actions include the following:

- 1. Eliminate idle time at the bottleneck operation (time when the pressing machine is neither being set up to process products nor actually processing products).** CI's manager is evaluating permanently positioning two workers at the pressing operation to unload finished units as soon as one batch of units is processed and to set up the machine to begin processing the next batch. This action will cost \$48,000 and bottleneck output will increase by 1,000 doors per year. Should CI incur the additional costs? Yes, because CI's throughput margin will increase by \$60,000 [(selling price per door, \$100 – direct material cost per door, \$40) \times 1,000 doors], which is greater than the incremental cost of \$48,000. All other costs are irrelevant.
- 2. Process only those parts or products that increase throughput margin, not parts or products that will be placed in finished goods or spare parts inventories.** Making products that remain in inventory will not increase throughput margin.
- 3. Shift products that do not have to be made on the bottleneck machine to nonbottleneck machines or to outside processing facilities.** Suppose Spartan Corporation, an outside contractor, offers to press 1,500 doors at \$15 per door from stamped parts that CI supplies. Spartan's quoted price is greater than CI's own operating costs in the pressing department of \$12 per door. Should CI accept the offer? Yes, because pressing is the bottleneck operation. Getting additional doors pressed by Spartan will increase throughput margin by \$90,000 [(\$100 – \$40) per door \times 1,500 doors], while the relevant cost of increasing capacity will be \$22,500 (\$15 per door \times 1,500 doors). The fact that CI's unit cost is less than Spartan's quoted price is irrelevant.

Suppose Gemini Industries, another outside contractor, offers to stamp 2,000 doors from direct materials that CI supplies at \$6 per door. Gemini's price is lower than CI's operating cost of \$8 per door in the stamping department. Should CI accept the offer? No, because other operating costs are fixed costs. CI will not save any costs by subcontracting the stamping operations. Instead, its costs will increase by \$12,000 (\$6 per door \times 2,000 doors) with no increase in throughput margin, which is constrained by pressing capacity.

- 4. Reduce setup time and processing time at bottleneck operations (for example, by simplifying the design or reducing the number of parts in the product).** Suppose CI can press 2,500 more doors at a cost of \$55,000 a year by reducing setup time at the pressing operation. Should CI incur this cost? Yes, because throughput margin will increase by \$150,000 [(\$100 – \$40) per door \times 2,500 doors], which is greater than

the incremental costs of \$55,000. Will CI find it worthwhile to incur costs to reduce machining time at the nonbottleneck stamping operation? No. Other operating costs will increase, while throughput margin will remain unchanged because bottleneck capacity of the pressing operation will not increase.

5. **Improve the quality of parts or products manufactured at the bottleneck operation.** Poor quality is more costly at a bottleneck operation than at a nonbottleneck operation. The cost of poor quality at a nonbottleneck operation is the cost of materials wasted. If CI produces 1,000 defective doors at the stamping operation, the cost of poor quality is \$40,000 (direct material cost per door, \$40, \times 1,000 doors). No throughput margin is forgone because stamping has unused capacity. Despite the defective production, stamping can produce and transfer 90,000 good-quality doors to the pressing operation. At a bottleneck operation, the cost of poor quality is the cost of materials wasted *plus* the opportunity cost of lost throughput margin. Bottleneck capacity not wasted in producing defective units could be used to generate additional throughput margin. If CI produces 1,000 defective units at the pressing operation, the cost of poor quality is the lost revenue of \$100,000, or alternatively stated, direct material costs of \$40,000 (direct material cost per door, \$40, \times 1,000 doors) plus forgone throughput margin of \$60,000 [$(\$100 - \$40)$ per door \times 1,000 doors].

The high cost of poor quality at the bottleneck operation means that bottleneck time should not be wasted processing units that are defective. That is, parts should be inspected before the bottleneck operation to ensure that only good-quality parts are processed at the bottleneck operation. Furthermore, quality-improvement programs should place special emphasis on minimizing defects at bottleneck machines.

If successful, the actions in Step 4 will increase the capacity of the pressing operation until it eventually exceeds the capacity of the stamping operation. The bottleneck will then shift to the stamping operation. CI would then focus continuous-improvement actions on increasing stamping efficiency and capacity. For example, the contract with Gemini Industries to stamp 2,000 doors at \$6 per door from direct material supplied by CI will become attractive because throughput margin will increase by $(\$100 - \$40)$ per door \times 2,000 doors = \$120,000, which is greater than the incremental costs of \$12,000 ($\6 per door \times 2,000 doors).

The theory of constraints emphasizes management of bottleneck operations as the key to improving performance of production operations as a whole. It focuses on short-run maximization of throughput margin, revenues minus direct material costs of goods sold. Because TOC regards operating costs as difficult to change in the short run, it does not identify individual activities and drivers of costs. TOC is, therefore, less useful for the long-run management of costs. In contrast, activity-based costing (ABC) systems take a long-run perspective and focus on improving processes by eliminating nonvalue-added activities and reducing the costs of performing value-added activities. ABC systems, therefore, are more useful for long-run pricing, cost control, and capacity management. The short-run TOC emphasis on maximizing throughput margin by managing bottlenecks complements the long-run strategic-cost-management focus of ABC.⁸

Balanced Scorecard and Time-Related Measures

In this section, we focus on the final step of the five-step decision-making process by tracking changes in time-based measures, evaluating and learning whether these changes affect financial performance, and modifying decisions and plans to achieve the company's goals. We use the structure of the balanced scorecard perspectives—financial, customer, internal business processes, and learning and growth—to summarize how financial and nonfinancial measures of time relate to one another, reduce delays, and increase output of bottleneck operations.

Financial measures

- Revenue losses or price discounts attributable to delays
- Carrying cost of inventories
- Throughput margin minus operating costs

⁸ For an excellent evaluation of TOC, operations management, cost accounting, and the relationship between TOC and activity-based costing, see A. Atkinson, "Cost Accounting, the Theory of Constraints, and Costing," (Issue Paper, CMA Canada, December 2000).

Customer measures

- Customer-response time (the time it takes to fulfill a customer order)
- On-time performance (delivering a product or service by the scheduled time)

Internal-business-process measures

- Average manufacturing time for key products
- Manufacturing cycle efficiency for key processes
- Idle time at bottleneck operations
- Defective units produced at bottleneck operations
- Average reduction in setup time and processing time at bottleneck operations

Learning-and-growth measures

- Employee satisfaction
- Number of employees trained in managing bottleneck operations

To see the cause-and-effect linkages across these balanced scorecard perspectives, consider the example of the Bell Group, a designer and manufacturer of equipment for the jewelry industry. Based on TOC analysis, the company determined that a key financial measure was improving throughput margin by 18% for a specific product line. In the customer perspective, the company set a goal of a two-day turn-around time on all orders for the product. To achieve this goal, the internal-business-process measure was the amount of time a bottleneck machine operated, with a goal of running 22 hours per day, six days a week. Finally, in the learning perspective, the company focused on training new employees to carry out nonbottleneck operations in order to free experienced employees to operate the bottleneck machine. The Bell Group’s emphasis on time-related measures in its balanced scorecard has allowed the company to substantially increase manufacturing throughput and slash response times, leading to higher revenues and increased profits.⁹

Decision Point

What are the steps managers can take to manage bottlenecks?

Problem for Self-Study

The Sloan Moving Corporation transports household goods from one city to another within the continental United States. It measures quality of service in terms of (a) time required to transport goods, (b) on-time delivery (within two days of agreed-upon delivery date), and (c) number of lost or damaged items. Sloan is considering investing in a new scheduling-and-tracking system costing \$160,000 per year, which should help it improve performance with respect to items (b) and (c). The following information describes Sloan’s current performance and the expected performance if the new system is implemented:

	Current Performance	Expected Future Performance
On-time delivery performance	85%	95%
Variable cost per carton lost or damaged	\$60	\$60
Fixed cost per carton lost or damaged	\$40	\$40
Number of cartons lost or damaged per year	3,000 cartons	1,000 cartons

Sloan expects each percentage point increase in on-time performance to increase revenue by \$20,000 per year. Sloan’s contribution margin percentage is 45%.

1. Should Sloan acquire the new system? Show your calculations.
2. Sloan is very confident about the cost savings from fewer lost or damaged cartons as a result of introducing the new system but unsure about the increase in revenues. Calculate the minimum amount of increase in revenues needed to make it worthwhile for Sloan to invest in the new system.

Required

⁹ Management Roundtable, “The Bell Group Uses the Balanced Scorecard with the Theory of Constraints to Keep Strategic Focus,” FastTrack.roundtable.com, fasttrack.roundtable.com/app/content/knowledgesource/item/197 (accessed May 15, 2007).

Solution

- Additional costs of the new scheduling-and-tracking system are \$160,000 per year. Additional annual benefits of the new scheduling-and-tracking system are as follows:

Additional annual revenues from a 10% improvement in on-time performance, from 85% to 95%, \$20,000 per 1% × 10 percentage points	<u>\$200,000</u>
45% contribution margin from additional annual revenues (0.45 × \$200,000)	<u>\$ 90,000</u>
Decrease in costs per year from fewer cartons lost or damaged (only variable costs are relevant)[\$60 per carton × (3,000 – 1,000) cartons]	<u>120,000</u>
Total additional benefits	<u>\$210,000</u>

Because the benefits of \$210,000 exceed the costs of \$160,000, Sloan should invest in the new system.

- As long as Sloan earns a contribution margin of \$40,000 (to cover incremental costs of \$160,000 minus relevant variable-cost savings of \$120,000) from additional annual revenues, investing in the new system is beneficial. This contribution margin corresponds to additional revenues of $\$40,000 \div 0.45 = \$88,889$.

Decision Points

The following question-and-answer format summarizes the chapter's learning objectives. Each decision presents a key question related to a learning objective. The guidelines are the answer to that question.

Decision

- What are the four cost categories of a costs-of-quality program?
- What nonfinancial measures and methods can managers use to improve quality?
- How do managers identify the relevant costs and benefits of quality improvement programs and use financial and nonfinancial measures to evaluate quality?

Guidelines

Four cost categories in a costs-of-quality program are prevention costs (costs incurred to preclude the production of products that do not conform to specifications), appraisal costs (costs incurred to detect which of the individual units of products do not conform to specifications), internal failure costs (costs incurred on defective products before they are shipped to customers), and external failure costs (costs incurred on defective products after they are shipped to customers).

Nonfinancial quality measures managers can use include customer satisfaction measures such as number of customer complaints and percentage of defective units shipped to customers; internal-business process measures such as percentage of defective and reworked products; and learning and growth measures such as percentage of employees trained in and empowered to use quality principles.

Three methods to identify quality problems and to improve quality are (a) control charts, to distinguish random from nonrandom variations in an operating process; (b) Pareto diagrams, to indicate how frequently each type of failure occurs; and (c) cause-and-effect diagrams, to identify and respond to potential causes of failure.

The relevant costs of quality improvement programs are the expected incremental costs to implement the program. The relevant benefits are the cost savings and the estimated increase in contribution margin from the higher revenues expected from quality improvements.

Financial measures are helpful to evaluate trade-offs among prevention costs, appraisal costs, and failure costs. Nonfinancial measures identify problem areas that need improvement and serve as indicators of future long-run performance.

4. What is customer-response time? What are the reasons for and the costs of delays? Customer-response time is how long it takes from the time a customer places an order for a product or service to the time the product or service is delivered to the customer. Delays occur because of (a) uncertainty about when customers will order products or services and (b) bottlenecks due to limited capacity. Bottlenecks are operations at which the work to be performed approaches or exceeds available capacity. Costs of delays include lower revenues and increased inventory carrying costs.
5. What are the steps managers can take to manage bottlenecks? The four steps in managing bottlenecks are (1) recognize that the bottleneck operation determines throughput margin, (2) identify the bottleneck, (3) keep the bottleneck busy and subordinate all nonbottleneck operations to the bottleneck operation, and (4) increase bottleneck efficiency and capacity.

Terms to Learn

This chapter and the Glossary at the end of the book contain definitions of the following important terms:

appraisal costs (p. 673)	design quality (p. 672)	on-time performance (p. 682)
average waiting time (p. 683)	external failure costs (p. 673)	Pareto diagram (p. 676)
bottleneck (p. 682)	internal failure costs (p. 673)	prevention costs (p. 673)
cause-and-effect diagram (p. 676)	manufacturing cycle efficiency (MCE) (p. 681)	quality (p. 671)
conformance quality (p. 672)	manufacturing cycle time (p. 681)	theory of constraints (TOC) (p. 686)
control chart (p. 675)	manufacturing lead time (p. 681)	throughput margin (p. 686)
costs of quality (COQ) (p. 672)		time driver (p. 682)
customer-response time (p. 681)		

Assignment Material

Questions

- 19-1** Describe two benefits of improving quality.
- 19-2** How does conformance quality differ from design quality? Explain.
- 19-3** Name two items classified as prevention costs.
- 19-4** Distinguish between internal failure costs and external failure costs.
- 19-5** Describe three methods that companies use to identify quality problems.
- 19-6** “Companies should focus on financial measures of quality because these are the only measures of quality that can be linked to bottom-line performance.” Do you agree? Explain.
- 19-7** Give two examples of nonfinancial measures of customer satisfaction relating to quality.
- 19-8** Give two examples of nonfinancial measures of internal-business-process quality.
- 19-9** Distinguish between customer-response time and manufacturing cycle time.
- 19-10** “There is no trade-off between customer-response time and on-time performance.” Do you agree? Explain.
- 19-11** Give two reasons why delays occur.
- 19-12** “Companies should always make and sell all products whose selling prices exceed variable costs.” Assuming fixed costs are irrelevant, do you agree? Explain.
- 19-13** Describe the three main measures used in the theory of constraints.
- 19-14** Describe the four key steps in managing bottleneck operations.
- 19-15** Describe three ways to improve the performance of a bottleneck operation.

Exercises

- 19-16 Costs of quality.** (CMA, adapted) Costen, Inc., produces cell phone equipment. Jessica Tolmy, Costen’s president, decided to devote more resources to the improvement of product quality after learning that her company had been ranked fourth in product quality in a 2009 survey of cell phone users. Costen’s quality-improvement program has now been in operation for two years, and the cost report shown here has recently been issued.

					
	A	B	C	D	E
1	Semi-Annual COQ Report, Costen, Inc.				
2	(in thousands)				
3		6/30/2010	12/31/2010	6/30/2011	12/31/2011
4	Prevention costs				
5	Machine maintenance	\$ 440	\$ 440	\$ 390	\$ 330
6	Supplier training	20	100	50	40
7	Design reviews	50	214	210	200
8	Total prevention costs	510	754	650	570
9	Appraisal costs				
10	Incoming inspections	108	123	90	63
11	Final testing	332	332	293	203
12	Total appraisal costs	440	455	383	266
13	Internal failure costs				
14	Rework	231	202	165	112
15	Scrap	124	116	71	67
16	Total internal failure costs	355	318	236	179
17	External failure costs				
18	Warranty repairs	165	85	72	68
19	Customer returns	570	547	264	188
20	Total external failure costs	735	632	336	256
21	Total quality costs	\$2,040	\$2,159	\$1,605	\$1,271
22					
23	Total revenues	\$8,240	\$9,080	\$9,300	\$9,020

Required

- For each period, calculate the ratio of each COQ category to revenues and to total quality costs.
- Based on the results of requirement 1, would you conclude that Costen's quality program has been successful? Prepare a short report to present your case.
- Based on the 2009 survey, Jessica Tolmy believed that Costen had to improve product quality. In making her case to Costen management, how might Tolmy have estimated the opportunity cost of not implementing the quality-improvement program?

19-17 Costs of quality analysis. Dream Rider produces car seats for children from newborn to two years old. The company is worried because one of its competitors has recently come under public scrutiny because of product failure. Historically, Dream Rider's only problem with its car seats was stitching in the straps. The problem can usually be detected and repaired during an internal inspection. The cost of the inspection is \$4, and the repair cost is \$0.75. All 250,000 car seats were inspected last year and 9% were found to have problems with the stitching in the straps during the internal inspection. Another 3% of the 250,000 car seats had problems with the stitching, but the internal inspection did not discover them. Defective units that were sold and shipped to customers needed to be shipped back to Dream Rider and repaired. Shipping costs are \$7, and repair costs are \$0.75. However, the out-of-pocket costs (shipping and repair) are not the only costs of defects not discovered in the internal inspection. For 20% of the external failures, negative word of mouth will result in a loss of sales, lowering the following year's profits by \$300 for each of the 20% of units with external failures.

Required

- Calculate appraisal cost.
- Calculate internal failure cost.
- Calculate out-of-pocket external failure cost.
- Determine the opportunity cost associated with the external failures.
- What are the total costs of quality?
- Dream Rider is concerned with the high up-front cost of inspecting all 250,000 units. It is considering an alternative internal inspection plan that will cost only \$1.00 per car seat inspected. During the internal inspection, the alternative technique will detect only 5.0% of the 250,000 car seats that have stitching problems. The other 7.0% will be detected after the car seats are sold and shipped. What are the total costs of quality for the alternative technique?
- What factors other than cost should Dream Rider consider before changing inspection techniques?

19-18 Costs of quality, ethical considerations. Refer to information in Exercise 19-17 in answering this question. Dream Rider has discovered a more serious problem with the plastic core of its car seats. An accident can cause the plastic in some of the seats to crack and break, resulting in serious injuries to the occupant. It is estimated that this problem will affect about 175 car seats in the next year. This problem could be corrected by using a higher quality of plastic that would increase the cost of every car seat produced by \$15. If this problem is not corrected, Dream Rider estimates that out of the 175 accidents, customers will realize that the problem is due to a defect in the seats in only three cases. Dream Rider's legal team has estimated that each of these three accidents would result in a lawsuit that could be settled for about \$775,000. All lawsuits settled would include a confidentiality clause, so Dream Rider's reputation would not be affected.

1. Assuming that Dream Rider expects to sell 250,000 car seats next year, what would be the cost of increasing the quality of all 250,000 car seats?
2. What will be the total cost of the lawsuits next year if the problem is not corrected?
3. Suppose Dream Rider has decided not to increase the quality of the plastic because the cost of increasing the quality exceeds the benefits (saving the cost of lawsuits). What do you think of this decision? (Note: Because of the confidentiality clause, the decision will have no effect on Dream Rider's reputation.)
4. Are there any other costs or benefits that Dream Rider should consider?

Required

19-19 Nonfinancial measures of quality and time. Worldwide Cell Phones (WCP) has developed a cell phone that can be used anywhere in the world (even countries like Japan that have a relatively unique cell phone system). WCP has been receiving complaints about the phone. For the past two years, WCP has been test marketing the phones and gathering nonfinancial information related to actual and perceived aspects of the phone's quality. The company expects that, given the lack of competition in this market, increasing the quality of the phone will result in higher sales and thereby higher profits.

Quality data for 2010 and 2011 include the following:

	2010	2011
Cell phones produced and shipped	2,000	10,000
Number of defective units shipped	100	400
Number of customer complaints	150	250
Units reworked before shipping	120	700
Manufacturing cycle time	15 days	16 days
Average customer response time	30 days	28 days

1. For each year, 2010 and 2011, calculate the following:
 - a. Percentage of defective units shipped
 - b. Customer complaints as a percentage of units shipped
 - c. Percentage of units reworked during production
 - d. Manufacturing cycle time as a percentage of total time from order to delivery
2. Referring to the information computed in requirement 1, explain whether WCP's quality and timeliness have improved.
3. Why would manufacturing cycle time have increased while customer response time decreased? (It may be useful to first describe what is included in each time measurement—see Exhibit 19-7, p. 681.)

Required

19-20 Quality improvement, relevant costs, relevant revenues. SpeedPrint manufactures and sells 18,000 high-technology printing presses each year. The variable and fixed costs of rework and repair are as follows:

	Variable Cost	Fixed Cost	Total Cost
Rework cost per hour	\$ 79	\$115	\$194
Repair costs			
Customer support cost per hour	35	55	90
Transportation cost per load	350	115	465
Warranty repair cost per hour	89	150	239

SpeedPrint's current presses have a quality problem that causes variations in the shade of some colors. Its engineers suggest changing a key component in each press. The new component will cost \$70 more than the old one. In the next year, however, SpeedPrint expects that with the new component it will (1) save 14,000 hours of rework, (2) save 850 hours of customer support, (3) move 225 fewer loads, (4) save

8,000 hours of warranty repairs, and (5) sell an additional 140 printing presses, for a total contribution margin of \$1,680,000. SpeedPrint believes that even as it improves quality, it will not be able to save any of the fixed costs of rework or repair. SpeedPrint uses a one-year time horizon for this decision because it plans to introduce a new press at the end of the year.

Required

1. Should SpeedPrint change to the new component? Show your calculations.
2. Suppose the estimate of 140 additional printing presses sold is uncertain. What is the minimum number of additional printing presses that SpeedPrint needs to sell to justify adopting the new component?

19-21 Quality improvement, relevant costs, relevant revenues. Flagstar Conference Center and Catering is a conference center and restaurant facility that hosts over 300 national and international events each year attended by 50,000 professionals. Due to increased competition and soaring customer expectations, the company has been forced to revisit its quality standards. In the company's 25 year history, customer demand has never been greater for high quality products and services. Flagstar has the following budgeted fixed and variable costs for 2011:

	Total Conference Center Fixed Cost	Variable Cost per Conference Attendee
Building and facilities	\$3,600,000	
Management salaries	\$1,400,000	
Customer support and service personnel		\$ 55
Food and drink		\$100
Conference materials		\$ 35
Incidental products and services		\$ 15

The company's budgeted operating income is \$3,500,000.

After conducting a survey of 3,000 conference attendees, the company has learned that its customers would most like to see the following changes in the quality of the company's products and services: 1) more menu options and faster service, 2) more incidental products and services (wireless access in all meeting rooms, computer stations for internet use, free local calling, etc.), and 3) upscale and cleaner meeting facilities. To satisfy these customer demands, the company would be required to increase fixed costs by 50% per year and increase variable costs by \$10 per attendee as follows:

	Additional Variable Cost per Conference Attendee
Customer support and service personnel	\$3
Food and drink	\$5
Conference materials	\$0
Incidental products and services	\$2

Flagstar believes that the preceding improvements in product and service quality would increase overall conference attendance by 40%.

Required

1. What is the budgeted revenue per conference attendee?
2. Assuming budgeted revenue per conference attendee is unchanged, should Flagstar implement the proposed changes?
3. Assuming budgeted revenue per conference attendee is unchanged, what is the variable cost per conference attendee at which Flagstar would be indifferent between implementing and not implementing the proposed changes?

19-22 Waiting time, service industry. The registration advisors at a small midwestern university (SMU) help 4,200 students develop each of their class schedules and register for classes each semester. Each advisor works for 10 hours a day during the registration period. SMU currently has 10 advisors. While advising an individual student can take anywhere from 2 to 30 minutes, it takes an average of 12 minutes per student. During the registration period, the 10 advisors see an average of 300 students a day on a first-come, first-served basis.

Required

1. Using the formula on page 683, calculate how long the average student will have to wait in the advisor's office before being advised.

2. The head of the registration advisors would like to increase the number of students seen each day, because at 300 students a day it would take 14 working days to see all of the students. This is a problem because the registration period lasts for only two weeks (10 working days). If the advisors could advise 420 students a day, it would take only two weeks (10 days). However, the head advisor wants to make sure that the waiting time is not excessive. What would be the average waiting time if 420 students were seen each day?
3. SMU wants to know the effect of reducing the average advising time on the average wait time. If SMU can reduce the average advising time to 10 minutes, what would be the average waiting time if 420 students were seen each day?

19-23 Waiting time, cost considerations, customer satisfaction. Refer to the information presented in Exercise 19-22. The head of the registration advisors at SMU has decided that the advisors must finish their advising in two weeks and therefore must advise 420 students a day. However, the average waiting time given a 12-minute advising period will result in student complaints, as will reducing the average advising time to 10 minutes. SMU is considering two alternatives:

- A. Hire two more advisors for the two-week (10-working day) advising period. This will increase the available number of advisors to 12 and therefore lower the average waiting time.
 - B. Increase the number of days that the advisors will work during the two-week registration period to six days a week. If SMU increases the number of days worked to six per week, then the 10 advisors need only see 350 students a day to advise all of the students in two weeks.
1. What would the average wait time be under alternative A and under alternative B?
 2. If advisors earn \$100 per day, which alternative would be cheaper for SMU (assume that if advisors work six days in a given work week, they will be paid time and a half for the sixth day)?
 3. From a student satisfaction point of view, which of the two alternatives would be preferred? Why?

Required

19-24 Nonfinancial measures of quality, manufacturing cycle efficiency. (CMA, adapted) Torrance Manufacturing evaluates the performance of its production managers based on a variety of factors, including cost, quality, and cycle time. The following are nonfinancial measures for quality and time for 2010 and 2011 for its only product:

Nonfinancial Quality Measures	2010	2011
Number of returned goods	385	462
Number of defective units reworked	1,122	834
Annual hours spent on quality training per employee	32	36
Number of units delivered on time	12,438	14,990
Annual Totals	2010	2011
Units of finished goods shipped	14,240	16,834
Average total hours worked per employee	2,000	2,000

The following information relates to the average amount of time needed to complete an order:

Time to Complete an Order	2010	2011
Wait time		
From order being placed to start of production	8	6
From start of production to completion	6	7
Inspection time	2	1
Process time	4	4
Move time	2	2

1. Compute the manufacturing cycle efficiency for an order for 2010 and 2011.
2. For each year 2010 and 2011, calculate the following:
 - a. Percentage of goods returned
 - b. Defective units reworked as a percentage of units shipped
 - c. Percentage of on-time deliveries
 - d. Percentage of hours spent by each employee on quality training
3. Evaluate management's performance on quality and timeliness over the two years.

Required

19-25 Theory of constraints, throughput margin, relevant costs. The Mayfield Corporation manufactures filing cabinets in two operations: machining and finishing. It provides the following information:

	Machining	Finishing
Annual capacity	100,000 units	80,000 units
Annual production	80,000 units	80,000 units
Fixed operating costs (excluding direct materials)	\$640,000	\$400,000
Fixed operating costs per unit produced ($\$640,000 \div 80,000$; $\$400,000 \div 80,000$)	\$8 per unit	\$5 per unit

Each cabinet sells for \$72 and has direct material costs of \$32 incurred at the start of the machining operation. Mayfield has no other variable costs. Mayfield can sell whatever output it produces. The following requirements refer only to the preceding data. There is no connection between the requirements.

Required

1. Mayfield is considering using some modern jigs and tools in the finishing operation that would increase annual finishing output by 1,000 units. The annual cost of these jigs and tools is \$30,000. Should Mayfield acquire these tools? Show your calculations.
2. The production manager of the machining department has submitted a proposal to do faster setups that would increase the annual capacity of the machining department by 10,000 units and would cost \$5,000 per year. Should Mayfield implement the change? Show your calculations.
3. An outside contractor offers to do the finishing operation for 12,000 units at \$10 per unit, double the \$5 per unit that it costs Mayfield to do the finishing in-house. Should Mayfield accept the subcontractor's offer? Show your calculations.
4. The Hunt Corporation offers to machine 4,000 units at \$4 per unit, half the \$8 per unit that it costs Mayfield to do the machining in-house. Should Mayfield accept Hunt's offer? Show your calculations.

19-26 Theory of constraints, throughput margin, quality. Refer to the information in Exercise 19-25 in answering the following requirements. There is no connection between the requirements.

Required

1. Mayfield produces 2,000 defective units at the machining operation. What is the cost to Mayfield of the defective items produced? Explain your answer briefly.
2. Mayfield produces 2,000 defective units at the finishing operation. What is the cost to Mayfield of the defective items produced? Explain your answer briefly.



Problems

19-27 Quality improvement, relevant costs, and relevant revenues. The Thomas Corporation sells 300,000 V262 valves to the automobile and truck industry. Thomas has a capacity of 110,000 machine-hours and can produce 3 valves per machine-hour. V262's contribution margin per unit is \$8. Thomas sells only 300,000 valves because 30,000 valves (10% of the good valves) need to be reworked. It takes one machine-hour to rework 3 valves, so 10,000 hours of capacity are used in the rework process. Thomas's rework costs are \$210,000. Rework costs consist of the following:

- Direct materials and direct rework labor (variable costs): \$3 per unit
- Fixed costs of equipment, rent, and overhead allocation: \$4 per unit

Thomas's process designers have developed a modification that would maintain the speed of the process and ensure 100% quality and no rework. The new process would cost \$315,000 per year. The following additional information is available:

- The demand for Thomas's V262 valves is 370,000 per year.
- The Jackson Corporation has asked Thomas to supply 22,000 T971 valves (another product) if Thomas implements the new design. The contribution margin per T971 valve is \$10. Thomas can make two T971 valves per machine-hour with 100% quality and no rework.

Required

1. Suppose Thomas's designers implement the new design. Should Thomas accept Jackson's order for 22,000 T971 valves? Show your calculations.
2. Should Thomas implement the new design? Show your calculations.
3. What nonfinancial and qualitative factors should Thomas consider in deciding whether to implement the new design?

19-28 Quality improvement, relevant costs, and relevant revenues. The Tan Corporation uses multicolor molding to make plastic lamps. The molding operation has a capacity of 200,000 units per year. The demand for lamps is very strong. Tan will be able to sell whatever output quantities it can produce at \$40 per lamp.

Tan can start only 200,000 units into production in the molding department because of capacity constraints on the molding machines. If a defective unit is produced at the molding operation, it must be

scrapped at a net disposal value of zero. Of the 200,000 units started at the molding operation, 30,000 defective units (15%) are produced. The cost of a defective unit, based on total (fixed and variable) manufacturing costs incurred up to the molding operation, equals \$25 per unit, as follows:

Direct materials (variable)	\$16 per unit
Direct manufacturing labor, setup labor, and materials-handling labor (variable)	3 per unit
Equipment, rent, and other allocated overhead, including inspection and testing costs on scrapped parts (fixed)	<u>6 per unit</u>
Total	<u>\$25 per unit</u>

Tan’s designers have determined that adding a different type of material to the existing direct materials would result in no defective units being produced, but it would increase the variable costs by \$4 per lamp in the molding department.

1. Should Tan use the new material? Show your calculations.
2. What nonfinancial and qualitative factors should Tan consider in making the decision?

Required

19-29 Statistical quality control. Keltrex Cereals produces a wide variety of breakfast products. The company’s three best selling breakfast cereals are Double Bran Bits, Honey Wheat Squares, and Sugar King Pops. Each box of a particular type of cereal is required to meet pre-determined weight specifications, so that no single box contains more or less cereal than another. The company measures the mean weight per production run to determine if there are variances over or under the company’s specified upper and lower level control limits. A production run that falls outside of the specified control limit does not meet quality standards and is investigated further by management to determine the cause of the variance. The three Keltrex breakfast cereals had the following weight standards and production run data for the month of March:

Quality Standard: Mean Weight per Production Run			
Double Bran Bits	Honey Wheat Squares	Sugar King Pops	
17.97 ounces	14 ounces	16.02 ounces	
Actual Mean Weight per Production Run (Ounces)			
Production Run	Double Bran Bits	Honey Wheat Squares	Sugar King Pops
1	18.23	14.11	15.83
2	18.14	14.13	16.11
3	18.22	13.98	16.24
4	18.30	13.89	15.69
5	18.10	13.91	15.95
6	18.05	14.01	15.50
7	17.84	13.94	15.86
8	17.66	13.99	16.23
9	17.60	14.03	16.15
10	17.52	13.97	16.60
Standard Deviation	0.28	0.16	0.21

1. Using the $\pm 2\sigma$ rule, what variance investigation decisions would be made?
2. Present control charts for each of the three breakfast cereals for March. What inferences can you draw from the charts?
3. What are the costs of quality in this example? How could Keltrex employ Six Sigma programs to improve quality?

Required

19-30 Compensation linked with profitability, waiting time, and quality measures. East Coast Healthcare operates two medical groups, one in Philadelphia and one in Baltimore. The semi-annual bonus plan for each medical group’s president has three components:

- a. Profitability performance. Add 0.75% of operating income.
- b. Average patient waiting time. Add \$40,000 if the average waiting time for a patient to see a doctor after the scheduled appointment time is less than 10 minutes. If average patient waiting time is more than 10 minutes, add nothing.
- c. Patient satisfaction performance. Deduct \$40,000 if patient satisfaction (measured using a survey asking patients about their satisfaction with their doctor and their overall satisfaction with East Coast Healthcare) falls below 65 on a scale from 0 (lowest) to 100 (highest). No additional bonus is awarded for satisfaction scores of 65 or more.

Semi-annual data for 2011 for the Philadelphia and Baltimore groups are as follows:

	January–June	July–December
Philadelphia		
Operating income	\$11,150,000	\$10,500,000
Average waiting time	13 minutes	12 minutes
Patient satisfaction	74	72
Baltimore		
Operating income	\$ 9,500,000	\$ 5,875,000
Average waiting time	12 minutes	9.5 minutes
Patient satisfaction	59	68

Required

1. Compute the bonuses paid in each half year of 2011 to the Philadelphia and Baltimore medical group presidents.
2. Discuss the validity of the components of the bonus plan as measures of profitability, waiting time performance, and patient satisfaction. Suggest one shortcoming of each measure and how it might be overcome (by redesign of the plan or by another measure).
3. Why do you think East Coast Healthcare includes measures of both operating income and waiting time in its bonus plan for group presidents? Give one example of what might happen if waiting time was dropped as a performance measure.

19-31 Waiting times, manufacturing cycle times. The Seawall Corporation uses an injection molding machine to make a plastic product, Z39, after receiving firm orders from its customers. Seawall estimates that it will receive 50 orders for Z39 during the coming year. Each order of Z39 will take 80 hours of machine time. The annual machine capacity is 5,000 hours.

Required

1. Calculate (a) the average amount of time that an order for Z39 will wait in line before it is processed and (b) the average manufacturing cycle time per order for Z39.
2. Seawall is considering introducing a new product, Y28. The company expects it will receive 25 orders of Y28 in the coming year. Each order of Y28 will take 20 hours of machine time. Assuming the demand for Z39 will not be affected by the introduction of Y28, calculate (a) the average waiting time for an order received and (b) the average manufacturing cycle time per order for each product, if Seawall introduces Y28.

19-32 Waiting times, relevant revenues, and relevant costs (continuation of 19-31). Seawall is still debating whether it should introduce Y28. The following table provides information on selling prices, variable costs, and inventory carrying costs for Z39 and Y28:

Product	Annual Average Number of Orders	Selling Price per Order if Average Manufacturing Cycle Time per Order Is		Variable Cost per Order	Inventory Carrying Cost per Order per Hour
		Less Than 320 Hours	More Than 320 Hours		
		Z39	50		
Y28	25	8,400	8,000	5,000	0.25

Required

1. Using the average manufacturing cycle times calculated in Problem 19-31, requirement 2, should Seawall manufacture and sell Y28? Show your calculations.
2. Should Seawall manufacture and sell Y28 if the data are changed as follows:

Product	Annual Average Number of Orders	Selling Price per Order if Average Manufacturing Cycle Time per Order Is		Variable Cost per Order	Inventory Carrying Cost per Order per Hour
		Less Than 320 Hours	More Than 320 Hours		
		Z39	50		
Y28	25	6,400	6,000	5,000	0.25

19-33 Manufacturing cycle times, relevant revenues, and relevant costs. The Brandt Corporation makes wire harnesses for the aircraft industry only upon receiving firm orders from its customers. Brandt has recently purchased a new machine to make two types of wire harnesses, one for Boeing airplanes (B7)

and the other for Airbus Industries airplanes (A3). The annual capacity of the new machine is 6,000 hours. The following information is available for next year:

Customer	Annual Average Number of Orders	Manufacturing Time Required	Selling Price per Order if Average Manufacturing Cycle Time per Order Is		Variable Cost per Order	Inventory Carrying Cost per Order per Hour
			Less Than 200 Hours	More Than 200 Hours		
			B7	125		
A3	10	50 hours	13,500	12,960	9,000	0.45

1. Calculate the average manufacturing cycle times per order (a) if Brandt manufactures only B7 and (b) if Brandt manufactures both B7 and A3.
2. Even though A3 has a positive contribution margin, Brandt's managers are evaluating whether Brandt should (a) make and sell only B7 or (b) make and sell both B7 and A3. Which alternative will maximize Brandt's operating income? Show your calculations.
3. What other factors should Brandt consider in choosing between the alternatives in requirement 2?

Required

19-34 Theory of constraints, throughput margin, and relevant costs. Nevada Industries manufactures electronic testing equipment. Nevada also installs the equipment at customers' sites and ensures that it functions smoothly. Additional information on the manufacturing and installation departments is as follows (capacities are expressed in terms of the number of units of electronic testing equipment):

	Equipment Manufactured	Equipment Installed
Annual capacity	400 units per year	250 units per year
Equipment manufactured and installed	250 units per year	250 units per year

Nevada manufactures only 250 units per year because the installation department has only enough capacity to install 250 units. The equipment sells for \$60,000 per unit (installed) and has direct material costs of \$35,000. All costs other than direct material costs are fixed. The following requirements refer only to the preceding data. There is no connection between the requirements.

1. Nevada's engineers have found a way to reduce equipment manufacturing time. The new method would cost an additional \$60 per unit and would allow Nevada to manufacture 20 additional units a year. Should Nevada implement the new method? Show your calculations.
2. Nevada's designers have proposed a change in direct materials that would increase direct material costs by \$3,000 per unit. This change would enable Nevada to install 280 units of equipment each year. If Nevada makes the change, it will implement the new design on all equipment sold. Should Nevada use the new design? Show your calculations.
3. A new installation technique has been developed that will enable Nevada's engineers to install 7 additional units of equipment a year. The new method will increase installation costs by \$45,000 each year. Should Nevada implement the new technique? Show your calculations.
4. Nevada is considering how to motivate workers to improve their productivity (output per hour). One proposal is to evaluate and compensate workers in the manufacturing and installation departments on the basis of their productivities. Do you think the new proposal is a good idea? Explain briefly.

Required

19-35 Theory of constraints, throughput margin, quality, and relevant costs. Aardee Industries manufactures pharmaceutical products in two departments: mixing and tablet making. Additional information on the two departments follows. Each tablet contains 0.5 gram of direct materials.

	Mixing	Tablet Making
Capacity per hour	150 grams	200 tablets
Monthly capacity (2,000 hours available in each department)	300,000 grams	400,000 tablets
Monthly production	200,000 grams	390,000 tablets
Fixed operating costs (excluding direct materials)	\$16,000	\$39,000
Fixed operating cost per unit (\$16,000 ÷ 200,000 grams; \$39,000 ÷ 390,000 tablets)	\$0.08 per gram	\$0.10 per tablet

The mixing department makes 200,000 grams of direct materials mixture (enough to make 400,000 tablets) because the tablet-making department has only enough capacity to process 400,000 tablets. All direct material costs of \$156,000 are incurred in the mixing department. The tablet-making department manufactures only 390,000 tablets from the 200,000 grams of mixture processed; 2.5% of the direct materials mixture is lost in the

tablet-making process. Each tablet sells for \$1. All costs other than direct material costs are fixed costs. The following requirements refer only to the preceding data. There is no connection between the requirements.

Required

1. An outside contractor makes the following offer: If Aardee will supply the contractor with 10,000 grams of mixture, the contractor will manufacture 19,500 tablets for Aardee (allowing for the normal 2.5% loss of the mixture during the tablet-making process) at \$0.12 per tablet. Should Aardee accept the contractor's offer? Show your calculations.
2. Another company offers to prepare 20,000 grams of mixture a month from direct materials Aardee supplies. The company will charge \$0.07 per gram of mixture. Should Aardee accept the company's offer? Show your calculations.
3. Aardee's engineers have devised a method that would improve quality in the tablet-making department. They estimate that the 10,000 tablets currently being lost would be saved. The modification would cost \$7,000 a month. Should Aardee implement the new method? Show your calculations.
4. Suppose that Aardee also loses 10,000 grams of mixture in its mixing department. These losses can be reduced to zero if the company is willing to spend \$9,000 per month in quality-improvement methods. Should Aardee adopt the quality-improvement method? Show your calculations.
5. What are the benefits of improving quality in the mixing department compared with improving quality in the tablet-making department?

19-36 Theory of constraints, contribution margin, sensitivity analysis. Fun Time Toys (FTT) produces dolls in two processes: molding and assembly. FTT is currently producing two models: Chatty Chelsey and Talking Tanya. Production in the molding department is limited by the amount of materials available. Production in the assembly department is limited by the amount of trained labor available. The only variable costs are materials in the molding department and labor in the assembly department. Following are the requirements and limitations by doll model and department:

	Molding Materials	Assembly Time	Selling Price
Chatty Chelsey	1.5 pounds per doll	20 minutes per doll	\$39 per doll
Talking Tanya	2 pounds per doll	30 minutes per doll	\$51 per doll
Materials/Labor Available	30,000 pounds	8,500 hours	
Cost	\$12 per pound	\$18 per hour	

Required

1. If there were enough demand for either doll, which doll would FTT produce? How many of these dolls would it make and sell?
2. If FTT sells two Chatty Chelseys for each Talking Tanya, how many dolls of each type would it produce and sell? What would be the total contribution margin?
3. If FTT sells two Chatty Chelseys for each Talking Tanya, how much would production and contribution margin increase if the molding department could buy 15 more pounds of materials for \$12 per pound?
4. If FTT sells two Chatty Chelseys for each Talking Tanya, how much would production and contribution margin increase if the assembly department could get 10 more labor hours at \$18 per hour?

19-37 Quality improvement, Pareto diagram, cause-and-effect diagram. Pauli's Pizza has recently begun collecting data on the quality of its customer order processing and delivery. Pauli's made 1,800 deliveries during the first quarter of 2012. The following quality data pertains to first quarter deliveries:

Type of Quality Failure	Quality Failure Incidents First Quarter 2012
Late delivery	50
Damaged or spoiled product delivered	5
Incorrect order delivered	12
Service complaints by customer of delivery personnel	8
Failure to deliver incidental items with order (drinks, side items, etc.)	18

Required

1. Draw a Pareto diagram of the quality failures experienced by Pauli's Pizza.
2. Give examples of prevention activities that could reduce the failures experienced by Pauli's.
3. Draw a cause-and-effect diagram of possible causes for late deliveries.

19-38 Ethics and quality. Wainwright Corporation manufactures auto parts for two leading Japanese automakers. Nancy Evans is the management accountant for one of Wainwright's largest manufacturing plants. The plant's General Manager, Chris Sheldon, has just returned from a meeting at corporate headquarters where quality expectations were outlined for 2012. Chris calls Nancy into his office to relay the corporate quality objective that total quality costs will not exceed 10% of total revenues by plant under any circumstances. Chris asks Nancy to provide him with a list of options for

meeting corporate headquarter's quality objective. The plant's initial budgeted revenues and quality costs for 2012 are as follows:

Revenue	3,400,000
Quality Costs:	
Testing of purchased materials	32,000
Quality control training for production staff	5,000
Warranty repairs	82,000
Quality design engineering	48,000
Customer support	37,000
Materials scrap	12,000
Product inspection	102,000
Engineering redesign of failed parts	21,000
Rework of failed parts	18,000

Prior to receiving the new corporate quality objective, Nancy had collected information for all of the plant's possible options for improving both product quality and costs of quality. She was planning to introduce the idea of reengineering the manufacturing process at a one-time cost of \$75,000, which would decrease product inspection costs by approximately 25% per year and was expected to reduce warranty repairs and customer support by an estimated 40% per year. After seeing the new corporate objective, Nancy is reconsidering the reengineering idea.

Nancy returns to her office and crunches the numbers again to look for other alternatives. She concludes that by increasing the cost of quality control training for production staff by \$15,000 per year, the company would reduce inspection costs by 10% annually and reduce warranty repairs and customer support costs by 20% per year, as well. She is leaning toward only presenting this latter option to Chris, the general manager, since this is the only option that meets the new corporate quality objective.

1. Calculate the ratio of each costs-of-quality category (prevention, appraisal, internal failure, and external failure) to revenues for 2012. Are the total costs of quality as a percentage of revenues currently less than 10%?
2. Which of the two quality options should Nancy propose to the general manager, Chris Sheldon? Show the two-year outcome for each option: (a) reengineer the manufacturing process for \$75,000 and (b) increase quality training expenditure by \$15,000 per year.
3. Suppose Nancy decides not to present the reengineering option to Chris. Is Nancy's action unethical? Explain.

Required

Collaborative Learning Problem

19-39 Quality improvement, theory of constraints. The Wellesley Corporation makes printed cloth in two departments: weaving and printing. Currently, all product first moves through the weaving department and then through the printing department before it is sold to retail distributors for \$1,250 per roll. Wellesley provides the following information:

	Weaving	Printing
Monthly capacity	10,000 rolls	15,000 rolls
Monthly production	9,500 rolls	8,550 rolls
Direct material cost per roll of cloth processed at each operation	\$500	\$100
Fixed operating costs	\$2,850,000	\$427,500

Wellesley can start only 10,000 rolls of cloth in the weaving department because of capacity constraints of the weaving machines. Of the 10,000 rolls of cloth started in the weaving department, 500 (5%) defective rolls are scrapped at zero net disposal value. The good rolls from the weaving department (called gray cloth) are sent to the printing department. Of the 9,500 good rolls started at the printing operation, 950 (10%) defective rolls are scrapped at zero net disposal value. The Wellesley Corporation's total monthly sales of printed cloth equal the printing department's output.

1. The printing department is considering buying 5,000 additional rolls of gray cloth from an outside supplier at \$900 per roll, which is much higher than Wellesley's cost to manufacture the roll. The printing department expects that 10% of the rolls obtained from the outside supplier will result in defective products. Should the printing department buy the gray cloth from the outside supplier? Show your calculations.
2. Wellesley's engineers have developed a method that would lower the printing department's rate of defective products to 6% at the printing operation. Implementing the new method would cost \$350,000 per month. Should Wellesley implement the change? Show your calculations.
3. The design engineering team has proposed a modification that would lower the weaving department's rate of defective products to 3%. The modification would cost the company \$175,000 per month. Should Wellesley implement the change? Show your calculations.

Required