LEARNING OBJECTIVES

- **LO1** Definecapacity 298
- **LO12** Determinedesign capacity, effective capacity, and utilization 300
- **LO3** Performbottleneck analysis 304
- **LO4** Computebreak-even 307
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When designing a concert hall, management hopes that the forecasted capacity (the product mix—opera, symphony, and special events—and the technology needed for these events) is accurate and adequate for operation above the break-even point. However, in many concert halls, even when operating at full capacity, break-even is not achieved, and supplemental funding must be obtained.

Capacity

LO1 *Define* capacity

What should be the seating capacity of a concert hall? How many customers per day should an Olive Garden or a Hard Rock Cafe be able to serve? How large should a Frito-Lay plant be to produce 75,000 bags of Ruffles in an 8-hour shift? In this supplement we look at tools that help a manager make these decisions.

After selection of a production process (Chapter 7), managers need to determine capacity. **Capacity** is the "throughput," or the number of units a facility can hold, receive, store, or produce in a given time. Capacity decisions often determine capital requirements and therefore a large portion of fixed cost. Capacity also determines whether demand will be satisfied or whether facilities will be idle. If a facility is too large, portions of it will sit unused and add cost to existing production. If a facility is too small, customers—and perhaps entire markets—will be lost. Determining facility size, with an objective of achieving high levels of utilization and a high return on investment, is critical.

Capacity

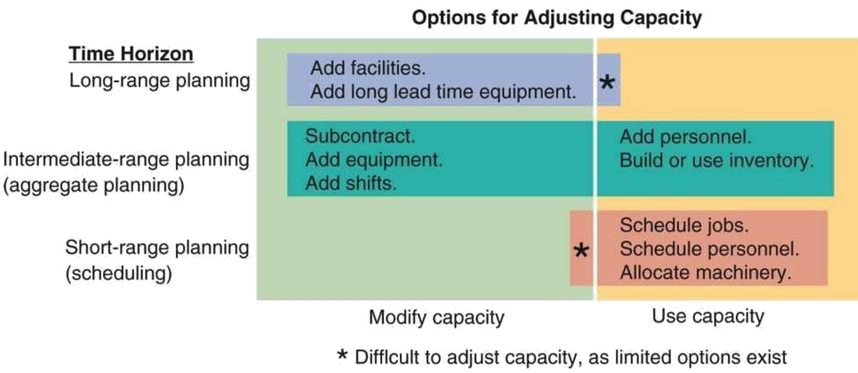
The "throughput," or number of units a facility can hold, receive, store, or produce in a period of time.

Capacity planning can be viewed in three time horizons. In Figure S7.1 we note that long-range capacity (generally greater than 3 years) is a function of adding facilities and equipment that have a long lead time. In the intermediate range (usually 3 to 36 months), we can add equipment, personnel, and shifts; we can subcontract; and we can build or use inventory. This is the "aggregate planning" task. In the short run (usually up to 3 months), we are primarily concerned with scheduling jobs and people, as well as allocating machinery. Modifying capacity in the short run is difficult, as we are usually constrained by existing capacity.

STUDENT TIP

Too little capacity loses customers and too much capacity is expensive. Like Goldilocks's porridge, capacity needs to be *just* right.

Figure S7.1 Time Horizons and Capacity Options



Design and Effective Capacity

Design capacity is the maximum theoretical output of a system in a given period under ideal conditions. It is normally expressed as a rate, such as the number of tons of steel that can be produced per week, per month, or per year. For many companies, measuring capacity can be straightforward: it is the maximum number of units the company is capable of producing in a specific time. However, for some organizations, determining capacity can be more difficult. Capacity can be measured in terms of beds (a hospital), active members (a church), or billable hours (a CPA firm). Other organizations use total work time available as a measure of overall capacity.

Design capacity

The theoretical maximum output of a system in a given period under ideal conditions.

Most organizations operate their facilities at a rate less than the design capacity. They do so because they have found that they can operate more efficiently when their resources are not stretched to the limit. For example, Ian's Bistro has tables set with 2 or 4 chairs seating a total of 270 guests. But the tables are never filled that way. Some tables will have 1 or 3 guests; tables can be pulled together for parties of 6 or 8. There are always unused chairs. *Design capacity* is 270, but *effective capacity* is often closer to 220, which is 81% of design capacity.

Effective capacity is the capacity a firm *expects* to achieve given the current operating constraints. Effective capacity is often lower than design capacity because the facility may have been designed for an earlier version of the product or a different product mix than is currently being produced.

Effective capacity

The capacity a firm can expect to achieve, given its product mix, methods of scheduling, maintenance, and standards of quality.

Two measures of system performance are particularly useful: utilization and efficiency. **utilization** is simply the percent of *design capacity* actually achieved. **Efficiency** is the percent of *effective capacity* actually achieved. Depending on how facilities are used and managed, it may be difficult or impossible to reach 100% efficiency. Operations managers tend to be evaluated on efficiency. The key to improving efficiency is often found in correcting quality problems and in effective scheduling, training, and maintenance. Utilization and efficiency are computed below:

utilization

Actual output as a percent of design capacity.

Efficiency

Actual output as a percent of effective capacity.

Utilization = Actual output/Design capacity (S7-1)

Efficiency = Actual output/Effective capacity (S7-2)

In Example 1 we determine these values.

Example S1 DETERMINING CAPACITY UTILIZATION AND EFFICIENCY

Sara James Bakery has a plant for processing *Deluxe* breakfast rolls and wants to better understand its capability. Determine the design capacity, utilization, and efficiency for this plant when producing this *Deluxe* roll.

APPROACH Last week the facility produced 148,000 rolls. The effective capacity is 175,000 rolls. The production line operates 7 days per week, with three 8-hour shifts per day. The line was designed to process the nut-filled, cinnamon-flavored *Deluxe* roll at a rate of 1,200 per hour. The firm first computes the design capacity and then uses Equation (S7-1) to determine utilization and Equation (S7-2) to determine efficiency.

Solution

Design capacity = (7 days × 3 shifts × 8 hours) × (1,200 rolls per hour) = 201,600 rolls

Utilization = Actual output/Design capacity = 148,000/201,600 = 73.4%

Efficiency = Actual output/Effective capacity = 148,000/175,600 = 84.6%

INSIGHT The bakery now has the information necessary to evaluate efficiency.

LEARNING EXERCISE If the actual output is 150,000, what is the efficiency? [Answer: 85.7%.]

RELATED PROBLEMS S7.1, S7.2, S7.4, S7.5, S7.7

ACTIVE MODEL S7.1 This example is further illustrated in Active Model S7.1 at www.pearsonhighered.com/heizer.

LO2 *Determine* design capacity, effective capacity, and utilization

Design capacity, utilization, and efficiency are all important measures for an operations manager. But managers often need to know the expected output of a facility or process. To do this, we solve for actual (or in this case, future or expected) output as shown in Equation (S7-3):

Actual (or Expected) output = (Effective capacity)(Efficiency) (S7-3)

Expected output is sometimes referred to as *rated capacity*. With a knowledge of effective capacity and efficiency, a manager can find the expected output of a facility. We do so in Example S2.

Example S2 DETERMINING EXPECTED OUTPUT

The manager of Sara James Bakery (see Example S1) now needs to increase production of the increasingly popular *Deluxe* roll. To meet this demand, she will be adding a second production line.

APPROACH The manager must determine the expected output of this second line for the sales department. Effective capacity on the second line is the same as on the first line, which is 175,000 *Deluxe* rolls. The first line is operating at an efficiency of 84.6%, as computed in Example S1. But output on the second line will be less than the first line because the crew will be primarily new hires; so the efficiency can be expected to be no more than 75%. What is the expected output?

Solution Use Equation (S7-3) to determine the expected output:

Expected output = (Effective capacity) (Efficiency) = (175,000) (.75) = 131,250 rolls

INSIGHT The sales department can now be told the expected output is 131,250 *Deluxe* rolls.

LEARNING EXERCISE After 1 month of training, the crew on the second production line is expected to perform at 80% efficiency. What is the revised expected output of *Deluxe* rolls? [Answer: 140,000.]

RELATED PROBLEMS S7.3, S7.6, S7.8

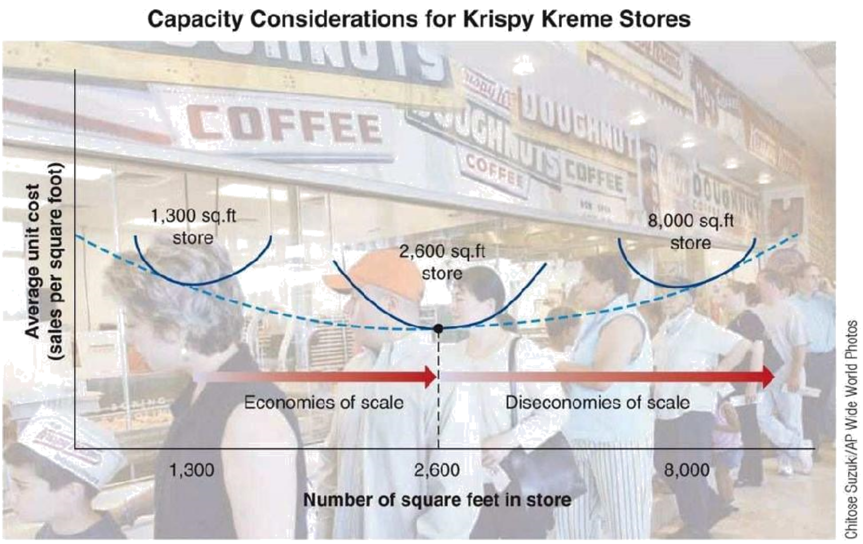
If the expected output is inadequate, additional capacity may be needed. Much of the remainder of this supplement addresses how to effectively and efficiently add that capacity.

Capacity and Strategy

Sustained profits come from building competitive advantage, not just from a good financial return on a specific process. Capacity decisions must be integrated into the organization's mission and strategy. Investments are not to be made as isolated expenditures, but as part of a coordinated plan that will place the firm in an advantageous position. The questions to be asked are, "Will these investments eventually win profitable customers?" and "What competitive advantage (such as process flexibility, speed of delivery, improved quality, and so on) do we obtain?"

All 10 OM decisions we discuss in this text, as well as other organizational elements such as marketing and finance, are affected by changes in capacity. Change in capacity will have sales and cash flow implications, just as capacity changes have quality, supply chain, human resource, and maintenance implications. All must be considered.

Figure S7.2 Economies and Diseconomies of Scale



Krispy Kreme originally had 8,000-square-foot stores but found them too large and too expensive for many markets. Then they tried tiny 1,300-square-foot stores, which required less investment, but such stores were too small to provide the mystique of seeing and smelling Krispy Kreme doughnuts being made. Krispy Kreme finally got it right with a 2,600-foot-store.

Capacity Considerations

☆ STUDENT TIP

Each industry and technology has an optimum size.

In addition to tight integration of strategy and investments, there are four special considerations for a good capacity decision:

- **1.** *Forecast demand accurately:* Product additions and deletions, competition actions, product life cycle, and unknown sales volumes all add challenge to accurate forecasting.
- **2.** *Match technology increments and sales volume:* Capacity options are often constrained by technology. Some capacity increments may be large (e.g., steel mills or power plants), while others may be small (hand-crafted Louis Vuitton handbags). This complicates the difficult but necessary job of matching capacity to sales.
- **3.** *Find the optimum operating size (volume):* Economies and diseconomies of scale often dictate an optimal size for a facility. As Figure S7.2 suggests, most businesses have an optimal size—at least until someone comes along with a new business model. For decades, very large integrated steel mills were considered optimal. Then along came Nucor, CMC, and other minimills, with a new process and a new business model that radically reduced the optimum size of a steel mill.
- **4.** *Build for change:* Managers build flexibility into facilities and equipment; changes will occur in processes, as well as products, product volume, and product mix.

Next, we note that rather than strategically manage capacity, managers may tactically manage demand.

Managing Demand

Even with good forecasting and facilities built to accomodate that forecast, there may be a poor match between the actual demand that occurs and available capacity. A poor match may mean demand exceeds capacity or capacity exceeds demand. However, in both cases, firms have options.

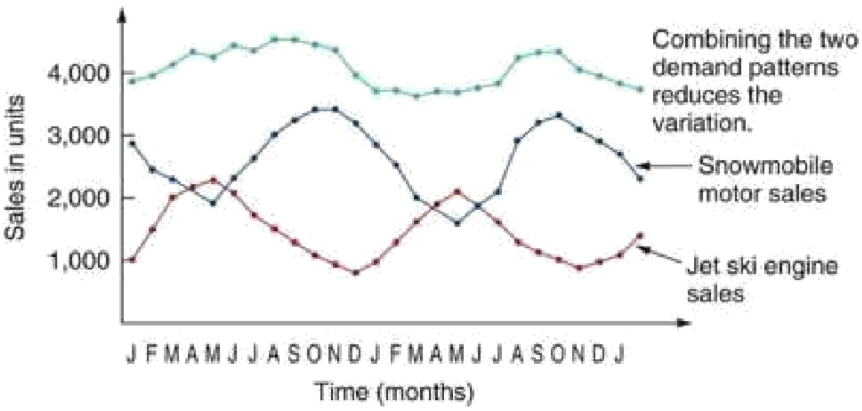
Demand Exceeds Capacity

When *demand exceeds capacity*, the firm may be able to curtail demand simply by raising prices, scheduling long lead times (which may be inevitable), and discouraging marginally profitable business. However, because inadequate facilities reduce revenue below what is possible, the long-term solution is usually to increase capacity.

Capacity Exceeds Demand

When *capacity exceeds demand*, the firm may want to stimulate demand through price reductions or aggressive marketing, or it may accommodate the market through product changes. When decreasing customer demand is combined with old and inflexible processes, layoffs and plant closings may be necessary to bring capacity in line with demand.

Figure S7.3 By Combining Products That Have Complementary Seasonal Patterns, Capacity Can Be Better Utilized



Adjusting to Seasonal Demands

A seasonal or cyclical pattern of demand is another capacity challenge. In such cases, management may find it helpful to offer products with complementary demand patterns—that is, products for which the demand is high for one when low for the other. For example, in Figure S7.3 the firm is adding a line of snowmobile motors to its line of jet skis to smooth demand. With appropriate complementing of products, perhaps the utilization of facility, equipment, and personnel can be smoothed (as we see in the *OM in Action* box "Matching Airline Capacity to Demand").

Tactics for Matching Capacity to Demand

Various tactics for adjusting capacity to demand include:

- **1.** Making staffing changes (increasing or decreasing the number of employees or shifts)

- **2.** Adjusting equipment (purchasing additional machinery or selling or leasing out existing equipment)
- **3.** Improving processes to increase throughput (e.g., reducing setup times at M2 Global Technology added the equivalent of 17 shifts of capacity)
- **4.** Redesigning products to facilitate more throughput
- **5.** Adding process flexibility to better meet changing product preferences
- **6.** Closing facilities

The foregoing tactics can be used to adjust demand to existing facilities. The strategic issue is, of course, how to have a facility of the correct size.

Service-Sector Demand and Capacity Management

In the service sector, scheduling customers is *demand management,* and scheduling the workforce is *capacity management.*

Joe McNally/Getty Images

Recessions (e.g., 2008—2010) and terrorist attacks (e.g., September 11, 2001) can make even the best capacity decision for an airline look bad. And excess capacity for an airline can be very expensive, with storage costs running as high as $60,000 per month per aircraft. Here, as a testimonial to excess capacity, aircraft sit idle in the Mojave Desert.

OM in Action: Matching Airline Capacity to Demand

Airlines constantly struggle to control their capital expenditures and to adapt to unstable demand patterns.

Southwest and Lufthansa have each taken their own approach to increasing capacity while holding down capital investment. To manage capacity constraints on the cheap, Southwest squeezes seven flight segments out of its typical plane schedule per day—one more than most competitors. Its operations personnel find that quick ground turnaround, long a Southwest strength, is a key to this capital-saving technique.

Lufthansa has cut hundreds of millions of dollars in new jet purchases by squashing rows of seats 2 inches closer together. On the A320, for example, Lufthansa added two rows of seats, giving the plane 174 seats instead of 162. For its European fleet, this is the equivalent of having 12 more Airbus A320 jets. But Lufthansa will tell you that squeezing in more seats is not quite as bad as it sounds, as the new generation of ultra-thin seats provides passengers with more leg room. Using a strong mesh, similar to that in fancy office chairs (instead of inches of foam padding), and moving magazine pockets to the top of seat backs, there is actually more knee room than with the old chairs.

Unstable demands in the airline industry provide another capacity challenge. Seasonal patterns (e.g., fewer people fly in the winter), compounded by spikes in demand during major holidays and summer vacations, play havoc with efficient use of capacity. Airlines attack costly seasonality in several ways. First, they schedule more planes for maintenance and renovations during slow winter months, curtailing winter capacity; second, they seek out contra-seasonal routes. And when capacity is substantially above demand, placing planes in storage (as shown in the photo) may be the most economical answer.

Airlines also use revenue management (see Chapter 13) to maximize perseat pricing of available capacity, regardless of current demand patterns.

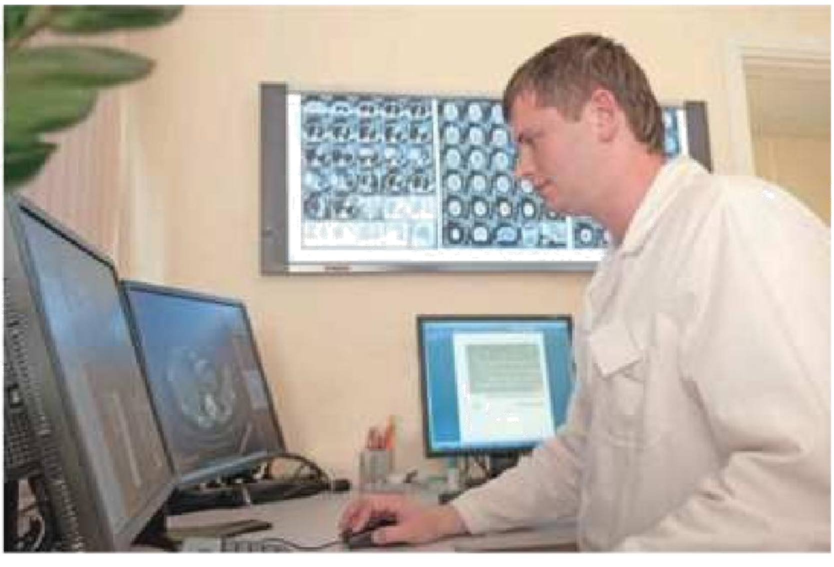
Sources: The Wall Street Journal (February 29, 2012) and (October 6, 2011).

Demand Management

When demand and capacity are fairly well matched, demand management can often be handled with appointments, reservations, or a first-come, first-served rule. In some businesses, such as doctors' and lawyers' offices, an *appointment system* is the schedule and is adequate. *Reservations systems* work well in rental car agencies, hotels, and some restaurants as a means of minimizing customer waiting time and avoiding disappointment over unfilled service. In retail shops, a post office, or a fast-food restaurant, a *first-come, first-served* rule for serving customers may suffice. Each industry develops its own approaches to matching demand and capacity. Other more aggressive approaches to demand management include many variations of discounts: "early bird" specials in restaurants, discounts for matinee performances or for seats at odd hours on an airline, and cheap weekend hotel rooms.

Capacity Management

When managing demand is not feasible, then managing capacity through changes in full-time, temporary, or part-time staff may be an option. This is the approach in many services. For instance, hospitals may find capacity limited by a shortage of board-certified radiologists willing to cover the graveyard shifts. Getting fast and reliable radiology readings can be the difference between life and death for an emergency room patient. As the photo below illustrates, when an overnight reading is required (and 40% of CT scans are done between 8 p.m. and 8 a.m.), the image can be sent by e-mail to a doctor in Europe or Australia for immediate analysis.



Many U.S. hospitals use services abroad to manage capacity for radiologists during night shifts. Night Hawk, an Idaho-based service with 50 radiologists in Zurich and Sydney, contracts with 900 facilities (20% of all U.S. hospitals). These trained experts, wide awake and alert in their daylight hours, usually return a diagnosis in 10 to 20 minutes, with a guarantee of 30 minutes.

Bottleneck Analysis and the Theory of Constraints

As managers seek to match capacity to demand, decisions must be made about the size of specific operations or work areas in the larger system. Each of the interdependent work areas can be expected to have its own unique capacity. **Capacity analysis** involves determining the throughput capacity of workstations in a system and ultimately the capacity of the entire system.

Capacity analysis

A means of determining throughput capacity of workstations or an entire production system.

A key concept in capacity analysis is the role of a constraint or bottleneck. A **bottleneck** is an operation that is the limiting factor or constraint. The term *bottleneck* refers to the literal neck of a bottle that constrains flow or, in the case of a production system, constrains throughput. A bottleneck has the lowest effective capacity of any operation in the system and thus limits the system's output. Bottlenecks occur in all facets of life—from job shops where a machine is constraining the work flow to highway traffic where two lanes converge into one inadequate lane, resulting in traffic congestion.

Bottleneck

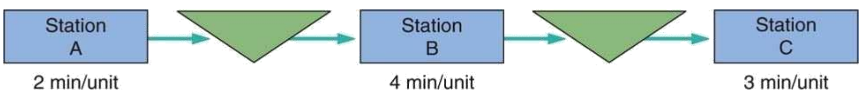
The limiting factor or constraint in a system.

The **bottleneck time** is the time of the slowest workstation (the one that takes the longest) in a production system. For example, the flowchart in Figure S7.4 shows a simple assembly line. Individual station times are 2, 4, and 3 minutes, respectively. The bottleneck time is 4 minutes. This is because station B is the slowest station. Even if we were to speed up station A, the entire production process would not be faster. Inventory would simply pile up in front of station B even more than now. Likewise, if station C could work faster, we could not tap its excess capacity because station B will not be able to feed products to it any faster than 1 every 4 minutes.

Bottleneck time

The time of the longest (slowest) process; the bottleneck.

Figure S7.4 Three-Station Assembly Line



A box represents an operation, a triangle represents inventory, and arrows represent precedence relationships

The **throughput time**, on the other hand, is the time it takes a unit to go through production from start to end. The time to produce a new completed unit in Figure S7.4 is 9 minutes (= 2 minutes + 4 minutes + 3 minutes).

Throughput time

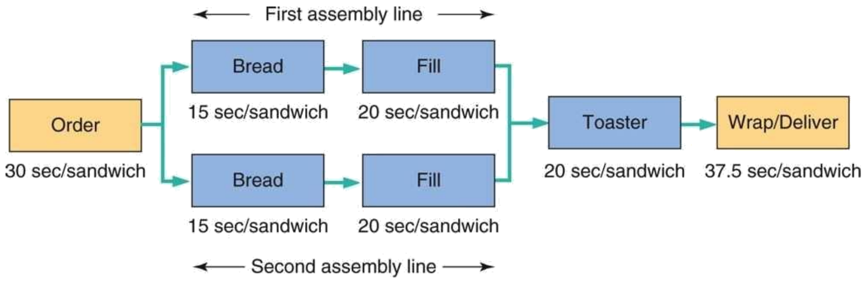
The time it takes for a product to go through the production process with no waiting.

The following two examples illustrate capacity analysis for slightly more complex systems. Example S3 introduces the concept of parallel processes.

Example S3 CAPACITY ANALYSIS WITH PARALLEL PROCESSES

Howard Kraye's sandwich shop provides healthy sandwiches for customers. Howard has two identical sandwich assembly lines. A customer first places an order. The order is then sent to one of two assembly lines. Each assembly line has two workers and two operations: (1) worker 1 retrieves and cuts the bread (15 seconds/sandwich) and (2) worker 2 adds ingredients (20 seconds/sandwich) and places the sandwich onto the toaster conveyor belt. The toaster then heats the sandwich (20 seconds/sandwich). Finally, another employee wraps and packages the heated sandwich coming out of the toaster, and delivers it to the customers (37.5 seconds/sandwich). A flowchart of the process is shown below.

LO3 *Perform* bottleneck analysis



APPROACH Howard should first determine the bottleneck of the process and the throughput time of the entire operation.

SOLUTION The wrapping and delivering operation, with a time of 37.5 seconds, appears to be the bottleneck for the entire operation. The capacity per hour equals 3,600 seconds per hour/37.5 seconds per sandwich = 96 sandwiches per hour. The throughput time equals 30 + 15 + 20 + 20 + 37.5 = 122.5 seconds (or 2 minutes and 2.5 seconds), assuming no wait time in line to begin with.

INSIGHT Doubling the resources at a workstation effectively cuts the time at that station in half (If n parallel [redundant] operations are added, the time of the combined workstation operation will equal $1/n$ times the original time).

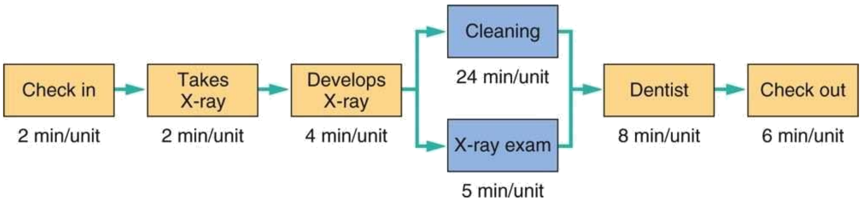
LEARNING EXERCISE If Howard hires an additional wrapper, what will be the new hourly capacity? [Answer: The new bottleneck is now the order-taking station: Capacity = 3,600 seconds per hour/30 seconds per sandwich = 120 sandwiches per hour]

RELATED PROBLEMS S7.9, S7.10, S7.11, S7.12, S7.13

Example 4 introduces the concept of simultaneous processing.

Example S4 CAPACITY ANALYSIS WITH SIMULTANEOUS PROCESSES

Dr. Cynthia Knott's dentistry practice has been cleaning customers' teeth for decades. The process for a basic dental cleaning is relatively straightforward: (1) the customer checks in (2 minutes); (2) a lab technician takes and develops four X-rays (2 and 4 minutes, respectively); (3) the dentist processes and examines the X-rays (5 minutes) *while* the hygienist cleans the teeth (24 minutes); (4) the dentist meets with the patient to poke at a few teeth, explain the X-ray results, and tell the patient to floss more often (8 minutes); and (5) the customer pays and books her next appointment (6 minutes). A flowchart of the customer visit is shown below.



APPROACH With simultaneous processes, an order or a product is essentially *split* into different paths to be rejoined later on. To find the bottleneck time, each operation is treated separately, just as though all operations were on a sequential path. To find the throughput time, the time over *all* paths must be computed, and it is the *longest* path.

SOLUTION The bottleneck in this system is cleaning (the hygienist) at 24 minutes per patient, resulting in an hourly system capacity of 60 minutes/24 minutes per patient = 2.5 patients. The throughput time is the maximum of the two paths through the system. The path through the X-ray exam is 2 + 2 + 4 + 5 + 8 + 6 = 27 minutes, while the path through the hygienist is 2 + 2 + 4 + 24 + 8 + 6 = 46 minutes. Thus a patient should be out the door after 46 minutes (i.e., the maximum of 27 and 46).

INSIGHT With simultaneous processing, all operation times in the entire system are not simply added together to compute throughput time because some operations are occurring simultaneously. Instead, the longest path through the system is deemed the throughput time.

LEARNING EXERCISE Suppose that the same technician now has the hygienist start immediately after the X-rays are taken (allowing the hygienist to start 4 minutes sooner). The technician then develops the X-rays while the hygienist is cleaning teeth. The dentist still examines the X-rays while the teeth cleaning is occurring. What would be the new system capacity and throughput time? [Answer: The X-ray development operation is now on the parallel path with cleaning and X-ray exam, reducing the total patient visit duration by 4 minutes, for a throughput time of 42 minutes (the maximum of 27 and 42). However, the hygienist is still the bottleneck, so the capacity remains 2.5 patients per hour.]

RELATED PROBLEMS S7.14, S7.15

To summarize: (1) the *bottleneck* is the operation with the longest (slowest) process time, after dividing by the number of parallel (redundant) operations, (2) the *system capacity* is the inverse of the *bottleneck time*, and (3) the *throughput time* is the total time through the longest path in the system, assuming no waiting.

Theory of Constraints

The **theory of constraints (TOC)** has been popularized by the book *The Goal: A Process of Ongoing Improvement,* by Goldratt and Cox.[1] TOC is a body of knowledge that deals with anything that limits or constrains an organization's ability to achieve its goals. Constraints can be physical (e.g., process or personnel availability, raw materials, or supplies) or non-physical (e.g., procedures, morale, and training). Recognizing and managing these limitations through a five-step process is the basis of TOC.

Theory of constraints (TOC)

A body of knowledge that deals with anything that limits an organization's ability to achieve its goals.

Step 1: Identify the constraints.

Step 2: Develop a plan for overcoming the identified constraints.

Step 3: Focus resources on accomplishing Step 2.

Step 4:
Reduce the effects of the constraints by offloading work or by expanding capability.
Make sure that the constraints are recognized by all those who can have an impact on them.

Step 5: When one set of constraints is overcome, go back to Step 1 and identify new constraints.

Bottleneck Management

STUDENT TIP

There are always bottlenecks; a manager must identify and manage them.

A crucial constraint in any system is the bottleneck, and managers must focus significant attention on it. We present four principles of bottleneck management:

- **1.** *Release work orders to the system at the pace set by the bottleneck's capacity:* The theory of constraints utilizes the concept of drum, buffer, rope to aid in the implementation of bottleneck and non-bottleneck scheduling. In brief, the *drum* is the beat of the system. It provides the schedule—the pace of production. The *buffer* is the resource, usually inventory, which may be helpful to keep the bottleneck operating at the pace of the drum. Finally, the *rope* provides the synchronization or communication necessary to pull units through the system. The rope can be thought of as signals between workstations.
- **2.** *Lost time at the bottleneck represents lost capacity for the whole system:* This principle implies that the bottleneck should always be kept busy with work. Well-trained and cross-trained employees and inspections prior to the bottleneck can reduce lost capacity at a bottleneck.
- **3.** *Increasing the capacity of a non-bottleneck station is a mirage:* Increasing the capacity of *non-bottleneck* stations has no impact on the system's overall capacity. Working faster on a non-bottleneck station may just create extra inventory, with all of its adverse effects. This implies that non-bottlenecks should have planned idle time. Extra work or setups at non-bottleneck stations will not cause delay, which allows for smaller batch sizes and more frequent product changeovers at non-bottleneck stations.
- **4.** *Increasing the capacity of the bottleneck increases capacity for the whole system:* Managers should focus improvement efforts on the bottleneck. Bottleneck capacity may be improved by various means, including offloading some of the bottleneck operations to another workstation (e.g., let the beer foam settle next to the tap at the bar, not under it, so the next beer can be poured), increasing capacity of the bottleneck (adding resources, working longer or working faster), subcontracting, developing alternative routings, and reducing setup times.

Even when managers have process and quality variability under control, changing technology, personnel, products, product mixes, and volumes can create multiple and shifting bottlenecks. Identifying and managing bottlenecks is a required operations task, but by definition, bottlenecks cannot be "eliminated." A system will always have at least one.

[1]See E. M. Goldratt and J. Cox, *The Goal: A Process of Ongoing Improvement*, 3rd rev. ed., Great Barrington, MA: North

River Press, 2004.

Break-Even Analysis

Break-even analysis is the critical tool for determining the capacity a facility must have to achieve profitability. The objective of **break-even analysis** is to find the point, in dollars and units, at which costs equal revenue. This point is the break-even point. Firms must operate above this level to achieve profitability. As shown in Figure S7.5, break-even analysis requires an estimation of fixed costs, variable costs, and revenue.

Break-even analysis

A means of finding the point, in dollars and units, at which costs equal revenues.

Fixed costs are costs that continue even if no units are produced. Examples include depreciation, taxes, debt, and mortgage payments. *Variable costs* are those that vary with the volume of units produced. The major components of variable costs are labor and materials. However, other costs, such as the portion of the utilities that varies with volume, are also variable costs. The difference between selling price and variable cost is *contribution*. Only when total contribution exceeds total fixed cost will there be profit.

Another element in break-even analysis is the *revenue function*. In Figure S7.5, revenue begins at the origin and proceeds upward to the right, increasing by the selling price of each unit. Where the revenue function crosses the total cost line (the sum of fixed and variable costs) is the break-even point, with a profit corridor to the right and a loss corridor to the left.

Assumptions

A number of assumptions underlie the basic break-even model. Notably, costs and revenue are shown as straight lines. They are shown to increase linearly—that is, in direct proportion to the volume of units being produced. However, neither fixed costs nor variable costs (nor, for that matter, the revenue function) need be a straight line. For example, fixed costs change as more capital equipment or warehouse space is used; labor costs change with overtime or as marginally skilled workers are employed; the revenue function may change with such factors as volume discounts.

Single-Product Case

LO4 *Compute* break-even

The formulas for the break-even point in units and dollars for a single product are shown below. Let:

BEP_x = break-even point in units

$BEP_\$$ = break-even point in dollars

P = price per unit (after all discounts)

x = number of units produced

TR = total revenue = Px

F = fixed costs

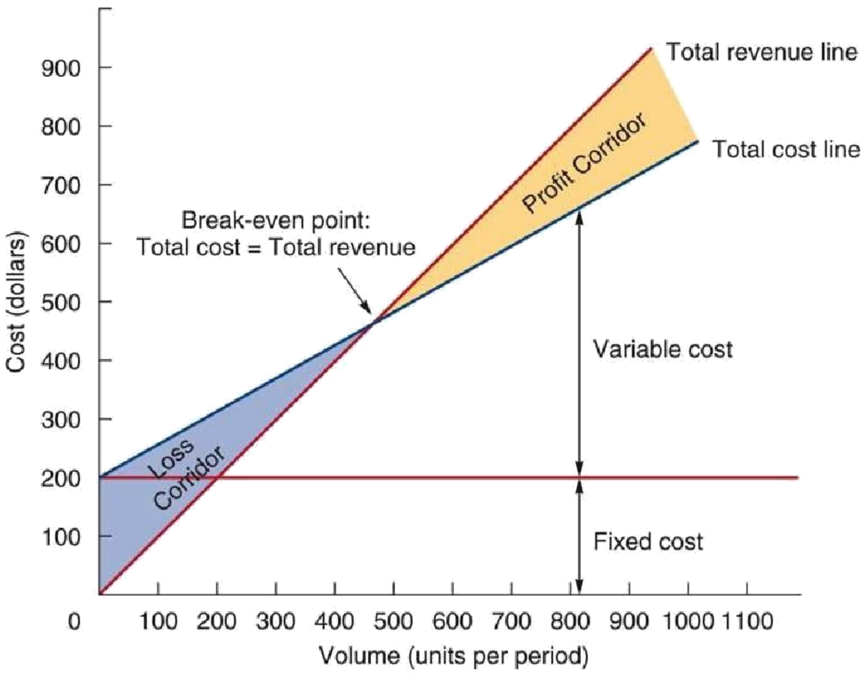
V = variable costs per unit

TC = total costs = $F+Vx$

The break-even point occurs where total revenue equals total costs. Therefore:

$$TR = TC \text{ or } Px = F + Vx$$

Figure S7.5 Basic Break-Even Point



Solving for x, we get:

$$\text{Break-even point in units } (BEP_x) = \frac{F}{P - V}$$

and:

$$\text{Break-even point in dollars } (BEP_\$) = BEP_x P = \frac{F}{P - V}P = \frac{F}{(P - V)/P} = \frac{F}{1 - V/P}$$

$$\text{Profit} = TR - TC = Px - (F + Vx) = Px - F - Vx = (P - V)x - F$$

Using these equations, we can solve directly for break-even point and profitability. The two break-even formulas of particular interest are:

$$\text{Break-even in units } (BEP_x) = \frac{\text{Total fixed cost}}{\text{Price} - \text{Variable cost}} = \frac{F}{P - V} \quad \text{(S7-4)}$$

$$\text{Break-even in dollars } (BEP_\$) = \frac{\text{Total fixed cost}}{1 - \frac{\text{Variable cost}}{\text{Price}}} = \frac{F}{1 - \frac{V}{P}} \quad \text{(S7-5)}$$

In Example S5, we determine the break-even point in dollars and units for one product.

Example S5 SINGLE PRODUCT BREAK-EVEN ANALYSIS

Stephens, Inc., wants to determine the minimum dollar volume and unit volume needed at its new facility to break even.

APPROACH The firm first determines that it has fixed costs of $10,000 this period. Direct labor is $1.50 per unit, and material is $.75 per unit. The selling price is $4.00 per unit.

SOLUTION The break-even point in dollars is computed as follows:

$$BEP_\$ = \frac{F}{1 - (V/P)} = \frac{\$10{,}000}{1 - [(1.50 + .75)/(4{,}.00)]} = \frac{\$10{,}000}{.4375} = \$22{,}857.14$$

The break-even point in units is:

$$BEP_x = \frac{F}{P - V} = \frac{\$10{,}000}{4.00 - (1.50 + .75)} = 5{,}714$$

Note that we use total variable costs (that is, both labor and material).

INSIGHT The management of Stevens, Inc., now has an estimate in both units and dollars of the volume necessary for the new facility.

LEARNING EXERCISE If Stevens finds that fixed cost will increase to $12,000, what happens to the break-even in units and dollars? [Answer: The break-even in units increases to 6,857, and break-even in dollars increases to $27,428.57.]

RELATED PROBLEMS S7.16, S7.17, S7.18, S7.19, S7.20, S7.21, S7.22, S7.23, S7.24, S7.25

EXCEL **OM** Data File **Ch07SExS3.xls** can be found at **www.pearsonhighered.com/heizer**.

ACTIVE **MODEL** S7.2 This example is further illustrated in Active Model S7.2 at **www.pearsonhighered.com/heizer**.

Multiproduct Case

Most firms, from manufacturers to restaurants, have a variety of offerings. Each offering may have a different selling price and variable cost. Utilizing break-even analysis, we modify Equation (S7-5) to reflect the proportion of sales for each product. We do this by "weighting" each product's contribution by its proportion of sales. The formula is then:

$$\text{Break-even point in dollars } (BEP_\$) = \frac{F}{\Sigma\left[\left(1 - \frac{V_i}{P_i}\right) \times (W_i)\right]} \quad \text{(S7-6)}$$

Paper machines such as the one shown here require a high capital investment. This investment results in a high fixed cost but allows production of paper at a very low variable cost. The production manager's job is to maintain utilization above the break-even point to achieve profitability.

where V = variable cost per unit

P = price per unit

F = fixed cost

W = percent each product is of total dollar sales

i = each product

Example S6 shows how to determine the break-even point for the multiproduct case at the Le Bistro restaurant.

Example S6 MULTIPRODUCT BREAK-EVEN ANALYSIS

Le Bistro, like most other resturants, makes more than one product and would like to know its break-even point in dollars.

APPROACH Information for Le Bistro follows. Fixed costs are $3,000 per month.

ITEM	PRICE	COST	ANNUAL FORECASTED SALES UNITS
Sandwich	$5.00	$3.00	9,000
Drinks	1.50	.50	9,000
Baked potato	2.00	1.00	7,000

With a variety of offerings, we proceed with break-even analysis just as in a single-product case, except that we weight each of the products by its proportion of total sales using Equation (S7-6).

SOLUTION Multiproduct Break-Even: Determining Contribution

1	2	3	4	5	6	7	8
ITEM (i)	SELLING PRICE (P)	VARIABLE COST (V)	(V/P)	1 − (V/P)	ANNUAL FORECASTED SALES $	% OF SALES	WEIGHTED CONTRIBUTION (COL. 5 × COL. 7)
Sandwich	$5.00	$3.00	.60	.40	$45,000	.621	.248
Drinks	1.50	0.50	.33	.67	13,500	.186	.125
Baked potato	2.00	1.00	.50	.50	14,000	.193	.097
					$72,500	1.000	.470

Note: Revenue for sandwiches is $45,000 (=5.00 × 9,000), which is 62.1% of the total revenue of $72,500. Therefore, the contribution for sandwiches is "weighted" by .621. The weighted contribution is .621 × .40 = .248. In this manner, its *relative* contribution is properly reflected.

Using this approach for each product, we find that the total weighted contribution is .47 for each dollar of sales, and the break-even point in dollars is $76,596:

$$BEP_{\$} = \frac{F}{\Sigma\left[\left(1 - \frac{V_i}{P_i}\right) \times (W_i)\right]} = \frac{\$3{,}000 \times 12}{.47} = \frac{\$36{,}000}{.47} = \$76{,}596$$

The information given in this example implies total daily sales (52 weeks at 6 days each) of:

$$\frac{\$76{,}596}{312 \text{ days}} = \$245.50$$

INSIGHT The management of Le Bistro now knows that it must generate average sales of $245.50 each day to break even. Management also knows that if the forecasted sales of $72,500 are correct, Le Bistro will lose money, as break-even is $76,596.

LEARNING EXERCISE If the manager of Le Bistro wants to make an additional $1,000 per month in salary, and considers this a fixed cost, what is the new break-even point in average sales per day? [Answer: $327.33.]

RELATED PROBLEMS S7.26, S7.27

Break-even figures by product provide the manager with added insight as to the realism of his or her sales forecast. They indicate exactly what must be sold each day, as we illustrate in Example S7.

Example S7 UNIT SALES AT BREAK-EVEN

Le Bistro also wants to know the break-even for the number of sandwiches that must be sold every day.

APPROACH Using the data in Example 6, we take the forecast sandwich sales of 62.1% times the daily break-even of $245.50 divided by the selling price of each sandwich ($5.00).

SOLUTION At break-even, sandwich sales must then be:

$$\frac{.621 \times \$245.50}{5.00} = \text{Number of sandwiches} = 30.5 \approx 31 \text{ sandwiches each day}$$

INSIGHT With knowledge of individual product sales, the manager has a basis for determining material and labor requirements.

LEARNING EXERCISE At a dollar break-even of $327.33 per day, how many sandwiches must Le Bistro sell each day? [Answer: ≈ 41.]

RELATED PROBLEMS S7.26b, S7.27b

Once break-even analysis has been prepared, analyzed, and judged to be reasonable, decisions can be made about the type and capacity of equipment needed. Indeed, a better judgment of the likelihood of success of the enterprise can now be made.

Reducing Risk with Incremental Changes

When demand for goods and services can be forecast with a reasonable degree of precision, determining a break-even point and capacity requirements can be rather straightforward. But, more likely, determining the capacity and how to achieve it will be complicated, as many factors are difficult to measure and quantify. Factors such as technology, competitors, building restrictions, cost of capital, human resource options, and regulations make the decision interesting. To complicate matters further, demand growth is usually in small units, while capacity additions are likely to be both instantaneous and in large units. This contradiction adds to the capacity decision risk. To reduce risk, incremental changes that hedge demand forecasts may be a good option. Figure S7.6 illustrates four approaches to

new capacity.

☆ STUDENT TIP

Capacity decisions require matching capacity to forecasts, which is always difficult.

Alternative Figure S7.6(a) *leads* capacity—that is, acquires capacity to stay ahead of demand, with new capacity being acquired at the beginning of period 1. This capacity handles increased demand until the beginning of period 2. At the beginning of period 2, new capacity is again acquired, allowing the organization to stay ahead of demand until the beginning of period 3. This process can be continued indefinitely into the future. Here capacity is acquired *incrementally*—at the beginning of period 1 *and* at the beginning of period 2.

VIDEO S7.1

Capacity Planning at Arnold Palmer Hospital

But managers can also elect to make a larger increase at the beginning of period 1 [Figure S7.6(b)]—an increase that may satisfy expected demand until the beginning of period 3. Excess capacity gives operations managers flexibility. For instance, in the hotel industry, added (extra) capacity in the form of rooms can allow a wider variety of room options and perhaps flexibility in room cleanup schedules. In manufacturing, excess capacity can be used to do more setups, shorten production runs, and drive down inventory costs.

Figure S7.6 Four Approaches to Capacity Expansion

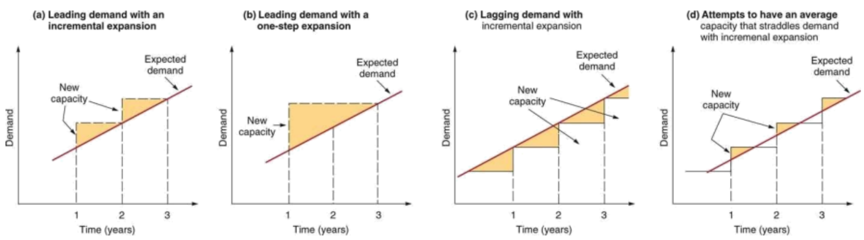


Figure S7.6(c) shows an option that *lags* capacity, perhaps using overtime or subcontracting to accommodate excess demand. Finally, Figure S7.6(d) *straddles* demand by building capacity that is “average,” sometimes lagging demand and sometimes leading it. Both the lag and straddle option have the advantage of delaying capital expenditure.

☆ STUDENT TIP

Uncertainty in capacity decisions makes EMV a helpful tool.

In cases where the business climate is stable, deciding between alternatives can be relatively easy. The total cost of each alternative can be computed, and the alternative with the least total cost can be selected. However, when capacity requirements are subject to significant unknowns, “probabilistic” models may be appropriate. One technique for making successful capacity planning decisions with an uncertain demand is decision theory, including the use of expected monetary value.

Applying Expected Monetary Value (EMV) to Capacity Decisions

Decisions

Determining expected monetary value (EMV) requires specifying alternatives and various states of nature. For capacity-planning situations, the state of nature usually is future demand or market favorability. By assigning probability values to the various states of nature, we can make decisions that maximize the expected value of the alternatives. Example 8 shows how to apply EMV to a capacity decision.

LO5 *Determine* expected monetary value of a capacity decision

Example S8 EMV APPLIED TO CAPACITY DECISION

Southern Hospital Supplies, a company that makes hospital gowns, is considering capacity expansion.

APPROACH: Southern's major alternatives are to do nothing, build a small plant, build a medium plant, or build a large plant. The new facility would produce a new type of gown, and currently the potential or marketability for this product is unknown. If a large plant is built and a favorable market exists, a profit of $100,000 could be realized. An unfavorable market would yield a $90,000 loss. However, a medium plant would earn a $60,000 profit with a favorable market. A $10,000 loss would result from an unfavorable market. A small plant, on the other hand, would return $40,000 with favorable market conditions and lose only $5,000 in an unfavorable market. Of course, there is always the option of doing nothing.

Recent market research indicates that there is a .4 probability of a favorable market, which means that there is also a .6 probability of an unfavorable market. With this information, the alternative that will result in the highest expected monetary value (EMV) can be selected.

SOLUTION Compute the EMV for each alternative:

EMV (large plant) = (.4) ($100,000) + (.6) (−$90,000) = − $14,000

EMV (medium plant) = (.4) ($60,000) + (.6) (−$10,000) = + $18,000

EMV (small plant) = (.4) ($40,000) + (.6) (−$5,000) = + $13,000

EMV (do nothing) = $0

Based on EMV criteria, Southern should build a medium plant.

INSIGHT If Southern makes many decisions like this, then determining the EMV for each alternative and selecting the highest EMV is a good decision criterion.

LEARNING EXERCISE If a new estimate of the loss from a medium plant in an unfavorable market increases to –$20,000, what is the new EMV for this alternative? [Answer: $12,000, which changes the decision because the small plant EMV is now higher.]

RELATED PROBLEMS S7.28, S7.29

Applying Investment Analysis to Strategy-Driven Investments

Applying Investment Analysis to Strategy-Driven Investments

Once the strategy implications of potential investments have been considered, traditional investment analysis is appropriate. We introduce the investment aspects of capacity next.

STUDENT TIP

An operations manager may be held responsible for return on investment (ROI).

Investment, Variable Cost, and Cash Flow

Because capacity and process alternatives exist, so do options regarding capital investment and variable cost. Managers must choose from among different financial options as well as capacity and process alternatives. Analysis should show the capital investment, variable cost, and cash flows as well as net present value for each alternative.

Net Present Value

Determining the discount value of a series of future cash receipts is known as the **net present value** technique. By way of introduction, let us consider the time value of money. Say you invest \$100.00 in a bank at 5% for 1 year. Your investment will be worth \$100.00 + (\$100.00)(.05) = \$105.00. If you invest the \$105.00 for a second year, it will be worth \$105.00 + (\$105.00)(.05) = \$110.25 at the end of the second year. Of course, we could calculate the future value of \$100.00 at 5% for as many years as we wanted by simply extending this analysis. However, there is an easier way to express this relationship mathematically. For the first year:

net present value

A means of determining the discounted value of a series of future cash receipts.

$$\$105 = \$100(1 + .05)$$

For the second year:

$$\$110.25 = \$105(1 + .05) = \$100(1 + .05)^2$$

In general:

$$F = P(1 + i)^N \quad \text{(S7-7)}$$

where F = future value (such as \$110.25 or \$105)

P = present value (such as \$100.00)

i = interest rate (such as .05)

N = number of years (such as 1 year or 2 years)

LO6 *Compute* net present value

In most investment decisions, however, we are interested in calculating the present value of a series of future cash receipts. Solving for P, we get:

$$P = \frac{F}{(1+i)^N} \quad (S7\text{-}8)$$