Capacity and Constraint Management

SUPPLEMENT 7

SUPPLEMENT OUTLINE

Alaska Airlines

Alaska Airlines

LEARNING OBJECTIVES

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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.

Klaus Lang/All Canada Photos/Alamy

Capacity

LO S7.1 *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.

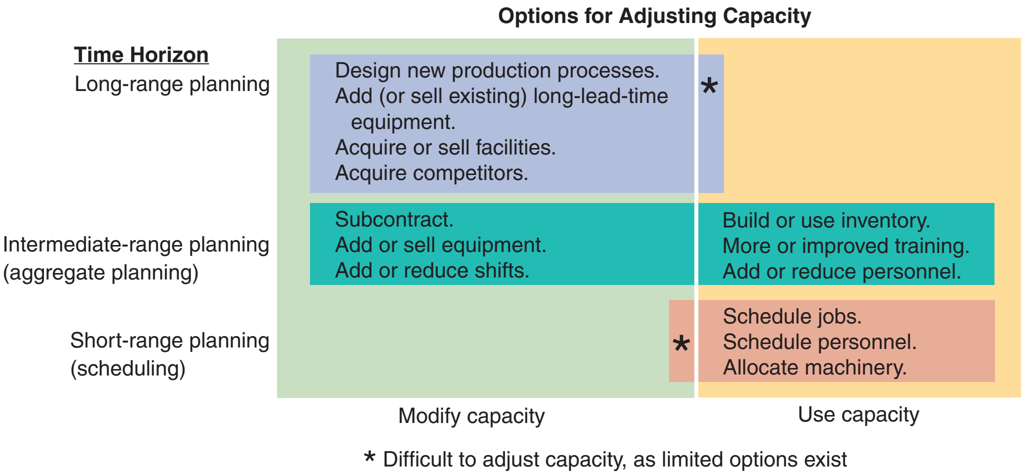


Figure S7.1
Time Horizons and Capacity Options

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.

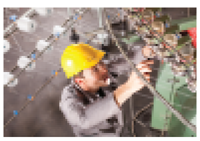
Design capacity
The theoretical maximum output of a system in a given period under ideal conditions.

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. Table S7.1 further illustrates the relationship between design capacity, effective capacity, and *actual output*.

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

TABLE S7.1 Capacity Measurements

MEASURE	DEFINITION	EXAMPLE
Design capacity  Andrey Eremin/123rf	Ideal conditions exist during the time that the system is available.	If machines at Frito-Lay are designed to produce 1,000 bags of chips/hr., and the plant operates 16 hrs./day. **Design Capacity = 1,000 bags/hr. × 16 hrs. = 16,000 bags/day**
Effective capacity  Hongqi Zhang/123rf	Design capacity minus lost output because of *planned* resource unavailability (e.g., preventive maintenance, machine setups/changeovers, changes in product mix, scheduled breaks)	If Frito-Lay loses 3 hours of output per day (namely 0.5 hrs./day on preventive maintenance + 1 hr./day on employee breaks + 1.5 hrs./day setting up machines for different products). **Effective Capacity = 16,000 bags/day − (1,000 bags/hr.)(3 hrs./day) = 16,000 bags/day − 3,000 bags/day = 13,000 bags/day**
Actual output  Hongqi Zhang/123rf	Effective capacity minus lost output during *unplanned* resource idleness (e.g., absenteeism, machine breakdowns, unavailable parts, quality problems)	On average, if machines at Frito-Lay are not running 1 hr./day due to late parts and machine breakdowns. **Actual Output = 13,000 bags/day − (1,000 bags/hr.)(1 hr./day) = 13,000 bags/day − 1,000 bags/day = 12,000 bags/day**

Utilization
Actual output as a percent of design capacity.

Efficiency
Actual output as a percent of effective capacity.

LO S7.2 *Determine* design capacity, effective capacity, and utilization

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:

$$\text{Utilization} = \text{Actual output}/\text{Design capacity} \tag{S7-1}$$

$$\text{Efficiency} = \text{Actual output}/\text{Effective capacity} \tag{S7-2}$$

In Example S1 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. 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. Determine the design capacity, utilization, and efficiency for this plant when producing this *Deluxe* roll.

APPROACH ▶ First compute the design capacity and then use Equation (S7-1) to determine utilization and Equation (S7-2) to determine efficiency.

SOLUTION ▶

$$\text{Design capacity} = (7 \text{ days} \times 3 \text{ shifts} \times 8 \text{ hours}) \times (1{,}200 \text{ rolls per hour}) = 201{,}600 \text{ rolls}$$

$$\text{Utilization} = \text{Actual output}/\text{Design capacity} = 148{,}000/201{,}600 = 73.4\%$$

$$\text{Efficiency} = \text{Actual output}/\text{Effective capacity} = 148{,}000/175{,}000 = 84.6\%$$

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, S7.3, S7.4, S7.5, S7.6, S7.7, S7.8

ACTIVE MODEL S7.1 This example is further illustrated in Active Model S7.1 in MyOMLab.

In Example S2 we see how the effectiveness of new capacity additions depends on how well management can perform on the utilization and efficiency of those additions.

Example S2

EXPANDING CAPACITY

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. The second line has the same design capacity (201,600) and effective capacity (175,000) as the first line; however, new workers will be operating the second line. Quality problems and other inefficiencies stemming from the inexperienced workers are expected to reduce output on the second line to 130,000 (compared to 148,000 on the first). The utilization and efficiency were 73.4% and 84.6%, respectively, on the first line. Determine the new utilization and efficiency for the *Deluxe* roll operation after adding the second line.

APPROACH ▶ First, determine the new design capacity, effective capacity, and actual output after adding the second line. Then, use Equation (S7-1) to determine utilization and Equation (S7-2) to determine efficiency.

SOLUTION ▶ Design capacity = 201,600 × 2 = 403,200 rolls

$$\text{Effective capacity} = 175{,}000 \times 2 = 350{,}000 \text{ rolls}$$

$$\text{Actual output} = 148{,}000 + 130{,}000 = 278{,}000 \text{ rolls}$$

$$\text{Utilization} = \text{Actual output/Design capacity} = 278{,}000 / 403{,}200 = 68.95\%$$

$$\text{Efficiency} = \text{Actual output/Effective capacity} = 278{,}000 / 350{,}000 = 79.43\%$$

INSIGHT ▶ Although adding equipment increases capacity, that equipment may not be operated as efficiently with new employees as might be the case with experienced employees. For Sara James Bakery, a doubling of equipment investment did not result in a doubling of output; other variables drove both utilization and efficiency lower.

LEARNING EXERCISE ▶ Suppose that Sara James reduces changeover time (setup time) by three fewer hours per week. What will be the new values of utilization and efficiency? [Answer: utilization is still 68.95%, efficiency now increases to 81.10%]

RELATED PROBLEMS ▶ S7.1, S7.2, S7.3, S7.4, S7.5, S7.6, S7.7, S7.8

Actual output, as used in Equation (S7-2), represents current conditions. Alternatively, with a knowledge of effective capacity and a current or target value for efficiency, the future *expected output* can be computed by reversing Equation (S7-2) :

$$\text{Expected output} = \text{Effective capacity} \times \text{Efficiency}$$

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.

Capacity Considerations

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). Large capacity increments complicate 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. *Economies of scale* exist when average cost declines as size increases, whereas *diseconomies of scale* occur when a larger size raises the average cost. 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.

STUDENT TIP
Each industry and technology has an optimum size.

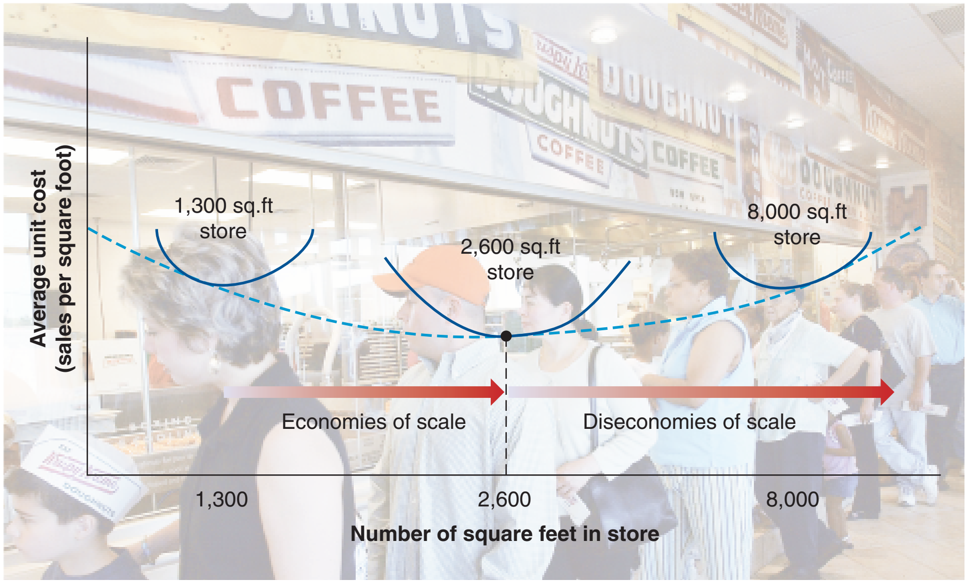
Next, we note that rather than strategically manage capacity, managers may tactically manage demand.

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 for Krispy Kreme Stores



Chitose Suzuki/AP Images

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.

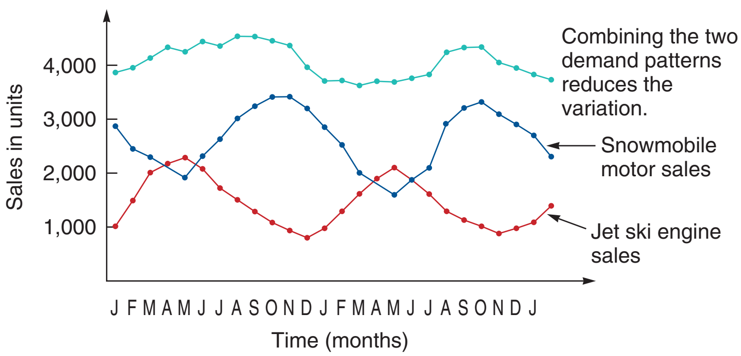
Demand Exceeds Capacity When *demand exceeds capacity*, the firm may be able to curtail demand simply by raising prices, scheduling long lead times (which may be inevitable), and discouraging marginally profitable business. However, because inadequate facilities reduce revenue below what is possible,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

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 "Capacity Management at the PizzaFactory").

Figure **S7.3**

By Combining Products That Have Complementary Seasonal Patterns, Capacity Can Be Better Utilized



OM in Action Capacity management at the PizzaFactory

PizzaGyár (PizzaFactory) is a pizza delivery company,which operates in the southern part of Hungary in a city of 160,000 people. In 2010, it faced a problem with the utilization of its capacities. Although their sales were at an acceptable level, and the company was profitable, they realized that they always had excess capacity regarding their kitchen appliances, labour, delivery and procurement. The cooks were working full time, even if sales were low. The ovens had to be heated up and kept warm even if there were idle times in the production. The delivery staff were running under the optimal number of pizzas per route, and the van delivering the ingredients had a large unused capacity. In order to overcome the problems, they tried increasing their sales, but it became evident that they could not realistically sell more at the current price level. Decreasing their price was not an option, since their profit margin was already very low. Also, their pizza was known for its high quality, so purchasing lower quality ingredients was out of the question.

After careful assessment of the situation, the owner decided to create a new line of pizza, which would sell under a different brand name, but still be prepared and sold from the company's currently operating facilities. Apart from a minor one time marketing cost, no capital needed to be invested in the business idea. Their goal was to use the excess capacity to produce the new brand and it at a lower price level, which was now possible, since the new brand's pizza used the already operating capacities, did not have fixed costs associated to it, and as a result, could sell closer to its variable cost.

To make sure that the new brand (Don Gatto) did not increase its costs in the production phase, the process practically did not change: Mostly the same ingredients were used, but the sequence of the toppings was changed in order to distinguish the products from each other. The new brand had the toppings under the cheese as opposed to the original PizzaGyár pizzas where it was the other way around. The new brand also came in a newly designed box.

This idea made it possible for the company to sell pizzas at a lower price level, acquire new market share, and increase total revenue and profit by using their capacity at an optimal level.

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.

Aleksey Khripunkov/Fotolia

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.

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 above 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.

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.

We define the **process time** of a station as the time to produce a unit (or a specified batch size of units) at that workstation. For example, if 16 customers can be checked out in a supermarket line every 60 minutes, then the process time at that station is 3.75 minutes per customer (= 60/16). (Process time is simply the inverse of capacity, which in this case is 60 minutes per hour/3.75 minutes per customer = 16 customers per hour.)

Process time
The time to produce a unit (or specified batch of units) at a workstation.

To determine the bottleneck in a production system, simply identify the station with the slowest process time. The **bottleneck time** is the process 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 process 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 process time of the longest (slowest) process, i.e., the bottleneck.

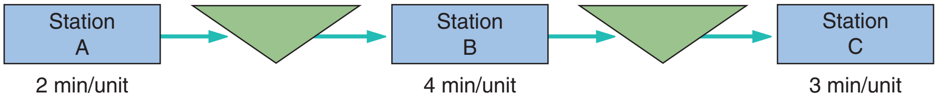


Figure **S7.4**
Three-Station Assembly Line
A box represents an operation, a triangle represents inventory, and arrows represent precedence relationships

The **throughput time**, on the other hand, is the time it takes a unit to go through production from start to end, *with no waiting*. (Throughput time describes the behavior in an empty system. In contrast, flow time describes the time to go through a production process from beginning to end, including idle time waiting for stations to finish working on other units.) The throughput 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*. It is the time of the longest path through the system.

Bottleneck time and *throughput time* may be quite different. For example, a Ford assembly line may roll out a new car every minute (bottleneck time), but it may take 25 hours to actually make a car from start to finish (throughput time). This is because the assembly line has many workstations, with each station contributing to the completed car. Thus, bottleneck time determines the system's capacity (one car per minute), while its throughput time determines potential ability to produce a newly ordered product from scratch in 25 hours.

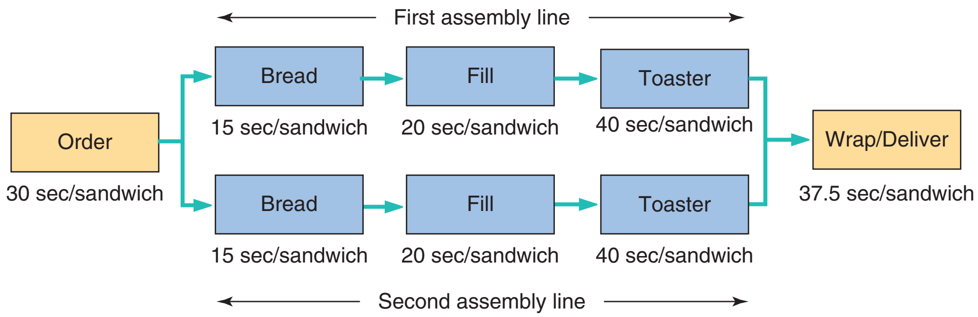
The following two examples illustrate capacity analysis for slightly more complex systems. Example S3 introduces the concept of parallel processes, and Example S4 introduces the concept of simultaneous processing.

Example S3

LO S7.3 *Perform* bottleneck analysis

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, which takes 30 seconds. The order is then sent to one of the two assembly lines. Each assembly line has two workers and three operations: (1) assembly worker 1 retrieves and cuts the bread (15 seconds/sandwich), (2) assembly worker 2 adds ingredients and places the sandwich onto the toaster conveyor belt (20 seconds/sandwich), and (3) the toaster heats the sandwich (40 seconds/sandwich). Finally, another employee wraps the heated sandwich coming out of the toaster and delivers it to the customer (37.5 seconds/sandwich). A flowchart of the process is shown below. Howard wants to determine the bottleneck time and throughput time of this process.



APPROACH ▶ Clearly the toaster is the single-slowest resource in the five-step process, but is it the bottleneck? Howard should first determine the bottleneck time of each of the two assembly lines separately, then the bottleneck time of the combined assembly lines, and finally the bottleneck time of the entire operation. For throughput time, each assembly line is identical, so Howard should just sum the process times for all five operations.

SOLUTION ▶ Because each of the three assembly-line operations uses a separate resource (worker or machine), different partially completed sandwiches can be worked on simultaneously at each station. Thus, the bottleneck time of each assembly line is the longest process time of each of the three operations. In this case, the 40-second toasting time represents the bottleneck time of each assembly line. Next, the bottleneck time of the *combined* assembly line operations is 40 seconds per *two* sandwiches, or 20 seconds per sandwich. Therefore, the wrapping and delivering operation, with a process 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 + 40 + 37.5 = 142.5 seconds (or 2 minutes and 22.5 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 process time of the combined workstation operation will equal $1/n$ times the original process 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]

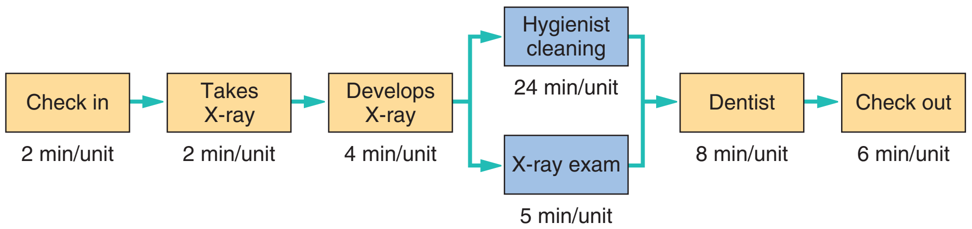
RELATED PROBLEMS ▶ S7.9, S7.10, S7.11, S7.12, S7.13

In Example S3, how could we claim that the process time of the toaster was 20 seconds per sandwich when it takes 40 seconds to toast a sandwich? The reason is that we had two toasters; thus, two sandwiches could be toasted every 40 seconds, for an average of one sandwich every 20 seconds. And that time for a toaster can actually be achieved if the start times for the two are *staggered* (i.e., a new sandwich is placed in a toaster every 20 seconds). In that case, even though each sandwich will sit in the toaster for 40 seconds, a sandwich could emerge from one of the two toasters every 20 seconds. As we see, doubling the number of resources effectively cuts the process time at that station in half, resulting in a doubling of the capacity of those resources.

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 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. Dr. Knott wants to determine the bottleneck time and throughput time of this process.



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 the throughput time is the time of the *longest* path.

SOLUTION ▶ The bottleneck in this system is the hygienist cleaning operation 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 cleaning operation 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 time of 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 cleaning operation 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 nonphysical (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

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

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

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 nonbottleneck 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 nonbottleneck station is a mirage:* Increasing the capacity of *nonbottleneck* stations has no impact on the system's overall capacity. Working faster on

a nonbottleneck station may just create extra inventory, with all of its adverse effects. This implies that nonbottlenecks should have planned idle time. Extra work or setups at nonbottleneck stations will not cause delay, which allows for smaller batch sizes and more frequent product changeovers at nonbottleneck 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.

Break-Even Analysis

Break-even analysis

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

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.

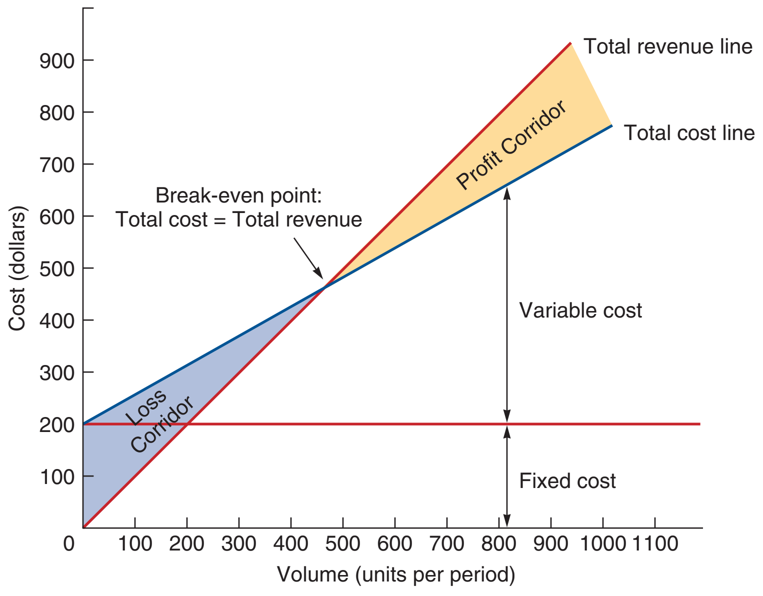
Fixed costs are costs that continue even if no units are produced. Examples include depreciation, taxes, debt, and mortgage payments. *Variable costs* are those that vary with the volume of units produced. The major components of variable costs are labor and materials. However, other costs, such as the 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,

Figure **S7.5**

Basic Break-Even Point



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

LO S7.4 *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:

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

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:

$$\text{Break-even in units } (BEP_x) = \frac{\text{Total fixed cost}}{\text{Price} - \text{Variable cost}} = \frac{F}{P - V} \qquad \text{(S7-3)}$$

$$\text{Break-even in dollars } (BEP_\$) = \frac{\text{Total fixed cost}}{1 - \dfrac{\text{Variable cost}}{\text{Price}}} = \frac{F}{1 - \dfrac{V}{P}} \qquad \text{(S7-4)}$$

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–S7.25 (S7.28–S7.31 are available in MyOMLab)

EXCEL OM Data File **Ch07SExS3**.xls can be found in MyOMLab.

ACTIVE MODEL S7.2 This example is further illustrated in Active Model S7.2 in MyOMLab.

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 (S7-4) 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:

$$\text{Break-even point in dollars } (BEP_{\$}) = \frac{F}{\sum\left[1 - \left(\frac{V_i}{P_i}\right) \times (W_i)\right]} \qquad \text{(S7-5)}$$

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

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.

Image Ideas/Stockbyte/Getty Images

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

ITEM	ANNUAL FORECASTED SALES UNITS	PRICE	COST
Sandwich	9,000	$5.00	$3.00
Drinks	9,000	1.50	0.50
Baked potato	7,000	2.00	1.00

APPROACH ▶ 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 (S7-5).

SOLUTION ▶ Multiproduct Break-Even: Determining Contribution

1	2	3	4	5	6	7	8	9
ITEM (i)	ANNUAL FORECASTED SALES UNITS	SELLING PRICE (P_i)	VARIABLE COST (V_i)	(V_i/P_i)	CONTRIBUTION 1– (V_i/P_i)	ANNUAL FORECASTED SALES $	% OF SALES (W_i)	WEIGHTED CONTRIBUTION (COL. 6 × COL. 8)
Sandwich	9,000	$5.00	$3.00	.60	.40	$45,000	.621	.248
Drinks	9,000	1.50	0.50	.33	.67	13,500	.186	.125
Baked potato	7,000	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:

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

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 S6, 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.

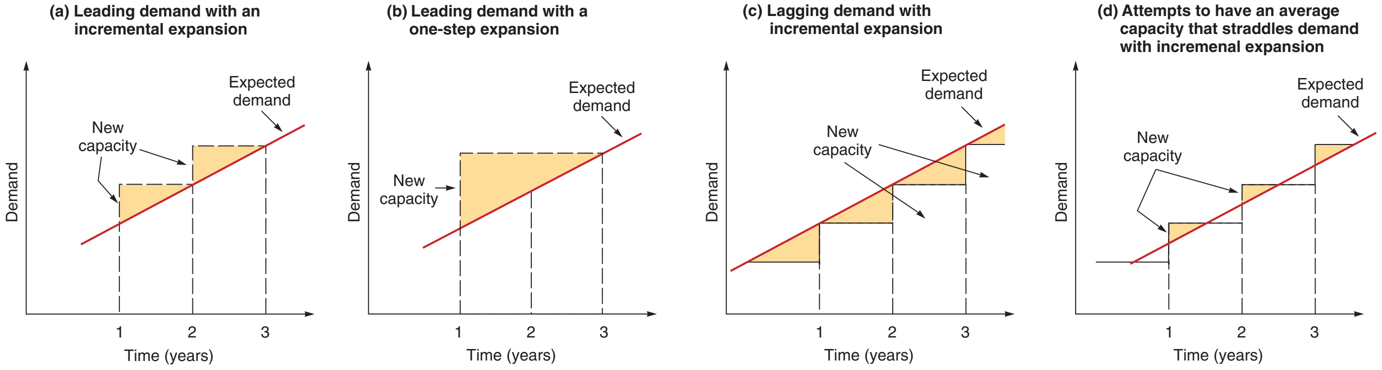


Figure **S7.6**

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.

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.

STUDENT TIP
Uncertainty in capacity decisions makes EMV a helpful tool.

Applying Expected Monetary Value (EMV) to Capacity Decisions

LO S7.5 *Determine* expected monetary value of a capacity decision

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 S8 shows how to apply EMV to 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:

$$
\begin{aligned}
\text{EMV (large plant)} &= (.4)\,(\$100{,}000) + (.6)\,(-\$90{,}000) = -\$14{,}000 \\
\text{EMV (medium plant)} &= (.4)\,(\$60{,}000) + (.6)\,(-\$10{,}000) = +\$18{,}000 \\
\text{EMV (small plant)} &= (.4)\,(\$40{,}000) + (.6)\,(-\$5{,}000) = +\$13{,}000 \\
\text{EMV (do nothing)} &= \$0
\end{aligned}
$$

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 ▶ S7.32, S7.33

Applying Investment Analysis to Strategy-Driven Investments

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

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

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

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

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:

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

For the second year:

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

In general:

$$F = P(1 + i)^N \tag{S7-6}$$

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)

LO S7.6 *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:

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

When the number of years is not too large, the preceding equation is effective. However, when the number of years, N, is large, the formula is cumbersome. For 20 years, you would have to compute $(1 + i)^{20}$. Interest-rate tables, such as Table S7.2, can help. We restate the present value equation:

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

where X = a factor from Table S7.2 defined as $= 1/(1 + i)^N$ and F = future value

Thus, all we have to do is find the factor X and multiply it by F to calculate the present value, P. The factors, of course, are a function of the interest rate, i, and the number of years, N. Table S7.2 lists some of these factors.

Equations (S7-7) and (S7-8) are used to determine the present value of one future cash amount, but there are situations in which an investment generates a series of uniform and equal

TABLE S7.2 Present Value of $1

YEAR	5%	6%	7%	8%	9%	10%	12%	14%
1	.952	.943	.935	.926	.917	.909	.893	.877
2	.907	.890	.873	.857	.842	.826	.797	.769
3	.864	.840	.816	.794	.772	.751	.712	.675
4	.823	.792	.763	.735	.708	.683	.636	.592
5	.784	.747	.713	.681	.650	.621	.567	.519
6	.746	.705	.666	.630	.596	.564	.507	.456
7	.711	.665	.623	.583	.547	.513	.452	.400
8	.677	.627	.582	.540	.502	.467	.404	.351
9	.645	.592	.544	.500	.460	.424	.361	.308
10	.614	.558	.508	.463	.422	.386	.322	.270
15	.481	.417	.362	.315	.275	.239	.183	.140
20	.377	.312	.258	.215	.178	.149	.104	.073

cash amounts. This type of investment is called an *annuity*. For example, an investment might yield $300 per year for 3 years. Easy-to-use factors have been developed for the present value of annuities. These factors are shown in Table S7.3. The basic relationship is:

$$S = RX$$

where $X =$ factor from Table S7.3
$S =$ present value of a series of uniform annual receipts
$R =$ receipts that are received every year for the life of the investment (the annuity)

The present value of a uniform annual series of amounts is an extension of the present value of a single amount, and thus Table S7.3 can be directly developed from Table S7.2. The factors for any given interest rate in Table S7.3 are the cumulative sum of the values in Table S7.2. In Table S7.2, for example, .943, .890, and .840 are the factors for years 1, 2, and 3 when the interest rate is 6%. The cumulative sum of these factors is 2.673. Now look at the point in Table S7.3 where the interest rate is 6% and the number of years is 3. The factor for the present value of an annuity is 2.673, as you would expect. Alternatively, the PV formula in Microsoft Excel can be used: =−PV(interest rate,year,1), e.g., =−PV(.06,3,1) = 2.673.

TABLE S7.3 Present Value of an Annuity of $1

YEAR	5%	6%	7%	8%	9%	10%	12%	14%
1	.952	.943	.935	.926	.917	.909	.893	.877
2	1.859	1.833	1.808	1.783	1.759	1.736	1.690	1.647
3	2.723	2.673	2.624	2.577	2.531	2.487	2.402	2.322
4	3.546	3.465	3.387	3.312	3.240	3.170	3.037	2.914
5	4.329	4.212	4.100	3.993	3.890	3.791	3.605	3.433
6	5.076	4.917	4.766	4.623	4.486	4.355	4.111	3.889
7	5.786	5.582	5.389	5.206	5.033	4.868	4.564	4.288
8	6.463	6.210	5.971	5.747	5.535	5.335	4.968	4.639
9	7.108	6.802	6.515	6.247	5.985	5.759	5.328	4.946
10	7.722	7.360	7.024	6.710	6.418	6.145	5.650	5.216
15	10.380	9.712	9.108	8.559	8.060	7.606	6.811	6.142
20	12.462	11.470	10.594	9.818	9.128	8.514	7.469	6.623

Example S9 shows how to determine the present value of an annuity.

Example S9

DETERMINING NET PRESENT VALUE OF FUTURE RECEIPTS OF EQUAL VALUE

River Road Medical Clinic is thinking of investing in a sophisticated new piece of medical equipment. It will generate $7,000 per year in receipts for 5 years.

APPROACH ▶ Determine the present value of this cash flow; assume an interest rate of 6%.

SOLUTION ▶ The factor from Table S7.3 (4.212) is obtained by finding that value when the interest rate is 6% and the number of years is 5 (alternatively using the Excel formula =−PV (.06,5,1)):

$$S = RX = \$7{,}000(4.212) = \$29{,}484$$

INSIGHT ▶ There is another way of looking at this example. If you went to a bank and took a loan for $29,484 today, your payments would be $7,000 per year for 5 years if the bank used an interest rate of 6% compounded yearly. Thus, $29,484 is the present value.

LEARNING EXERCISE ▶ If the interest rate is 8%, what is the present value? [Answer: $27,951.]

RELATED PROBLEMS ▶ S7.34–S7.39 (S7.40–S7.45 are available in MyOMLab)

EXCEL OM Data File Ch07SExS9.xls can be found in MyOMLab.

The net present value method is straightforward: You simply compute the present value of all cash flows for each investment alternative. When deciding among investment alternatives, you pick the investment with the highest net present value. Similarly, when making several investments, those with higher net present values are preferable to investments with lower net present values.

Solved Problem S7.4 shows how to use the net present value to choose between investment alternatives.

Although net present value is one of the best approaches to evaluating investment alternatives, it does have its faults. Limitations of the net present value approach include the following:

1. Investments with the same net present value may have significantly different projected lives and different salvage values.
2. Investments with the same net present value may have different cash flows. Different cash flows may make substantial differences in the company's ability to pay its bills.
3. The assumption is that we know future interest rates, which we do not.
4. Payments are always made at the end of the period (week, month, or year), which is not always the case.

Summary

Managers tie equipment selection and capacity decisions to the organization's missions and strategy. Four additional considerations are critical: (1) accurately forecasting demand; (2) understanding the equipment, processes, and capacity increments; (3) finding the optimum operating size; and (4) ensuring the flexibility needed for adjustments in technology, product features and mix, and volumes.

Techniques that are particularly useful to operations managers when making capacity decisions include good forecasting, bottleneck analysis, break-even analysis, expected monetary value, cash flow, and net present value.

The single most important criterion for investment decisions is the contribution to the overall strategic plan and the winning of profitable orders. Successful firms select the correct process and capacity.

Key Terms

Capacity (p. 346)
Design capacity (p. 347)
Effective capacity (p. 347)
Utilization (p. 348)
Efficiency (p. 348)
Capacity analysis (p. 352)
Bottleneck (p. 352)
Process time (p. 352)
Bottleneck time (p. 353)
Throughput time (p. 353)
Theory of constraints (TOC) (p. 355)
Break-even analysis (p. 356)
Net present value (p. 362)

Discussion Questions

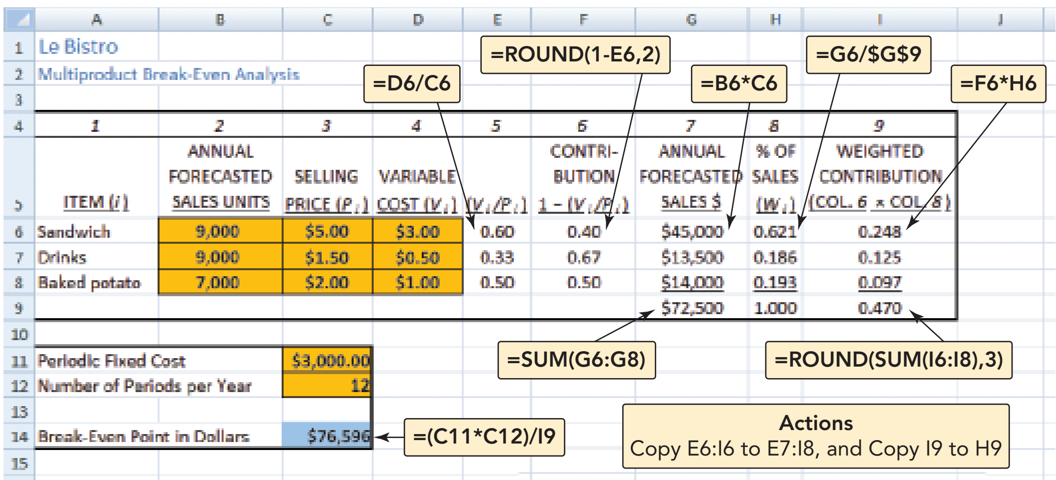
1. Distinguish between design capacity and effective capacity.
2. What is effective capacity?
3. What is efficiency?
4. Distinguish between effective capacity and actual output.
5. Explain why doubling the capacity of a bottleneck may not double the system capacity.
6. Distinguish between bottleneck time and throughput time.
7. What is the theory of constraints?
8. What are the assumptions of break-even analysis?
9. What keeps plotted revenue data from falling on a straight line in a break-even analysis?
10. Under what conditions would a firm want its capacity to lag demand? to lead demand?
11. Explain how net present value is an appropriate tool for comparing investments.
12. Describe the five-step process that serves as the basis of the theory of constraints.
13. What are the techniques available to operations managers to deal with a bottleneck operation? Which of these does not decrease throughput time?

Using Software for Break-Even Analysis

Excel, Excel OM, and POM for Windows all handle break-even and cost–volume analysis problems.

CREATING YOUR OWN EXCEL SPREADSHEETS

It is a straightforward task to develop the formulas to conduct a single-product break-even analysis in Excel. Although we do not demonstrate the basics here, Active Model S7.2 provides a working example. Program S7.1 illustrates how you can make an Excel model to solve Example S6, which is a multiproduct break-even analysis.



	A	B	C	D	E	F	G	H	I
1	Le Bistro								
2	Multiproduct Break-Even Analysis								
3									
4	1	2	3	4	5	6	7	8	9
5	ITEM (i)	ANNUAL FORECASTED SALES UNITS	SELLING PRICE (P_i)	VARIABLE COST (V_i)	(V_i/P_i)	CONTRI-BUTION $1-(V_i/P_i)$	ANNUAL FORECASTED SALES $	% OF SALES (W_i)	WEIGHTED CONTRIBUTION (COL. 6 × COL. 8)
6	Sandwich	9,000	$5.00	$3.00	0.60	0.40	$45,000	0.621	0.248
7	Drinks	9,000	$1.50	$0.50	0.33	0.67	$13,500	0.186	0.125
8	Baked potato	7,000	$2.00	$1.00	0.50	0.50	$14,000	0.193	0.097
9							$72,500	1.000	0.470
10									
11	Periodic Fixed Cost		$3,000.00						
12	Number of Periods per Year		12						
13									
14	Break-Even Point in Dollars		$76,596						
15									

Program **S7.1**

An Excel Spreadsheet for Performing Break-Even Analysis for Example S6

USING EXCEL OM

Excel OM's Break-Even Analysis module provides the Excel formulas needed to compute the break-even points, and the solution and graphical output.

USING POM FOR WINDOWS

Similar to Excel OM, POM for Windows also contains a break-even/cost–volume analysis module.

Solved Problems

Virtual Office Hours help is available in MyOMLab.

SOLVED PROBLEM S7.1

Sara James Bakery, described in Examples S1 and S2, has decided to increase its facilities by adding one additional process line. The firm will have two process lines, each working 7 days a week, 3 shifts per day, 8 hours per shift, with effective capacity of 300,000 rolls. This addition, however, will reduce overall system efficiency to 85%. Compute the expected production with this new effective capacity.

SOLUTION

$$\begin{aligned}\text{Expected production} &= \text{(Effective capacity) (Efficiency)}\\ &= 300{,}000(.85)\\ &= 255{,}000 \text{ rolls per week}\end{aligned}$$

SOLVED PROBLEM S7.2

Marty McDonald has a business packaging software in Wisconsin. His annual fixed cost is $10,000, direct labor is $3.50 per package, and material is $4.50 per package. The selling price will be $12.50 per package. What is the break-even point in dollars? What is break-even in units?

SOLUTION

$$BEP_\$ = \frac{F}{1 - (V/P)} = \frac{\$10{,}000}{1 - (\$8.00/\$12.50)} = \frac{\$10{,}000}{.36} = \$27{,}777$$

$$BEP_x = \frac{F}{P - V} = \frac{\$10{,}000}{\$12.50 - \$8.00} = \frac{\$10{,}000}{\$4.50} = 2{,}222 \text{ units}$$

SOLVED PROBLEM S7.3

John has been asked to determine whether the $22.50 cost of tickets for the community dinner theater will allow the group to achieve break-even and whether the 175 seating capacity is adequate. The cost for each performance of a 10-performance run is $2,500. The facility rental cost for the entire 10 performances is $10,000. Drinks and parking are extra charges and have their own price and variable costs, as shown below:

1	2	3	4	5	6	7	8	9
	SELLING PRICE (P)	VARIABLE COST (V)	PERCENT VARIABLE COST (V/P)	CONTRIBUTION 1 − (V/P)	ESTIMATED QUANTITY OF SALES UNITS (SALES)	DOLLAR SALES (SALES × P)	PERCENT OF SALES	CONTRIBUTION WEIGHTED BY PERCENT SALES (COL.5 × COL. 8)
Tickets with dinner	$22.50	$10.50	0.467	0.533	175	$3,938	0.741	0.395
Drinks	$ 5.00	$ 1.75	0.350	0.650	175	$ 875	0.165	0.107
Parking	$ 5.00	$ 2.00	0.400	0.600	100	$ 500	0.094	0.056
					450	$5,313	1.000	0.558

SOLUTION

$$BEP_\$ = \frac{F}{\sum\left[\left(1 - \frac{V_i}{P_i}\right) \times (W_i)\right]} = \frac{\$(10 \times 2{,}500) + \$10{,}000}{0.558} = \frac{\$35{,}000}{0.558} = \$62{,}724$$

Revenue for each performance (from column 7) $=$ $5,313
Total forecasted revenue for the 10 performances $= (10 \times \$5{,}313) = \$53{,}130$
Forecasted revenue with this mix of sales shows a break-even of $62,724

Thus, given this mix of costs, sales, and capacity John determines that the theater will not break even.

SOLVED PROBLEM S7.4

Your boss has told you to evaluate the cost of two machines. After some questioning, you are assured that they have the costs shown at the right. Assume:

a) The life of each machine is 3 years.
b) The company thinks it knows how to make 14% on investments no riskier than this one.

Determine via the present value method which machine to purchase.

	MACHINE A	MACHINE B
Original cost	$13,000	$20,000
Labor cost per year	2,000	3,000
Floor space per year	500	600
Energy (electricity) per year	1,000	900
Maintenance per year	2,500	500
Total annual cost	$ 6,000	$ 5,000
Salvage value	$ 2,000	$ 7,000

SOLUTION

		MACHINE A			MACHINE B		
		COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4	COLUMN 5	COLUMN 6
Now	Expense	1.000	$13,000	$13,000	1.000	$20,000	$20,000
1 yr.	Expense	.877	6,000	5,262	.877	5,000	4,385
2 yr.	Expense	.769	6,000	4,614	.769	5,000	3,845
3 yr.	Expense	.675	6,000	4,050	.675	5,000	3,375
				$26,926			$31,605
3 yr.	Salvage revenue	.675	$ 2,000	−1,350	.675	$ 7,000	−4,725
				$25,576			$26,880

We use 1.0 for payments with no discount applied against them (that is, when payments are made now, there is no need for a discount). The other values in columns 1 and 4 are from the 14% column and the respective year in Table S7.2 (for example, the intersection of 14% and 1 year is .877, etc.). Columns 3 and 6 are the products of the present value figures times the combined costs. This computation is made for each year and for the salvage value.

The calculation for machine A for the first year is:

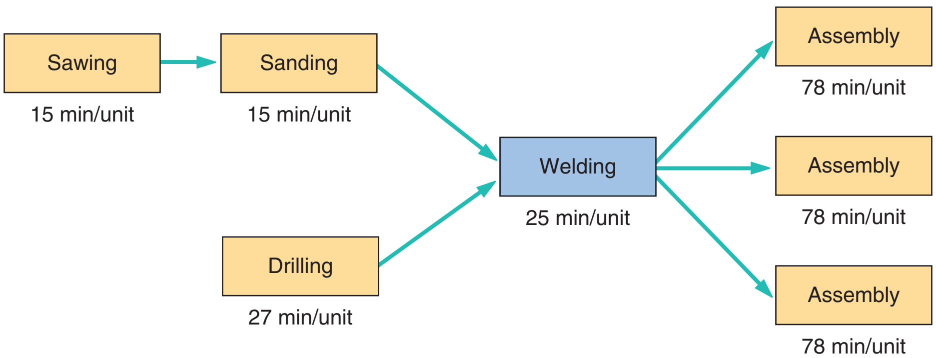
$$.877 \times (\$2{,}000 + \$500 + \$1{,}000 + \$2{,}500) = \$5{,}262$$

The salvage value of the product is subtracted from the summed costs, because it is a receipt of cash. Because the sum of the net costs for machine B is larger than the sum of the net costs for machine A, machine A is the low-cost purchase, and your boss should be so informed.

SOLVED PROBLEM S7.5

T. Smunt Manufacturing Corp. has the process displayed below. The drilling operation occurs separately from and simultaneously with the sawing and sanding operations. The product only needs to go through one of the three assembly operations (the assembly operations are "parallel").

a) Which operation is the bottleneck?
b) What is the throughput time for the overall system?
c) If the firm operates 8 hours per day, 22 days per month, what is the monthly capacity of the manufacturing process?
d) Suppose that a second drilling machine is added, and it takes the same time as the original drilling machine. What is the new bottleneck time of the system?
e) Suppose that a second drilling machine is added, and it takes the same time as the original drilling machine. What is the new throughput time?



SOLUTION

a) The time for *assembly* is 78 minutes/3 operators = 26 minutes per unit, so the station that takes the longest time, hence the bottleneck, is *drilling*, at 27 minutes.
b) System throughput time is the maximum of (15 + 15 + 25 + 78), (27 + 25 + 78) = maximum of (133, 130) = 133 minutes
c) Monthly capacity = (60 minutes)(8 hours)(22 days)/27 minutes per unit = 10,560 minutes per month/27 minutes per unit = 391.11 units/month.
d) The bottleneck shifts to *Assembly*, with a time of 26 minutes per unit.
e) Redundancy does not affect throughput time. It is still 133 minutes.

Problems

Note: **Px** means the problem may be solved with POM for Windows and/or Excel OM.

Problems S7.1–S7.8 relate to Capacity

• **S7.1** Amy Xia's plant was designed to produce 7,000 hammers per day but is limited to making 6,000 hammers per day because of the time needed to change equipment between styles of hammers. What is the utilization?

• **S7.2** For the past month, the plant in Problem S7.1, which has an effective capacity of 6,500, has made only 4,500 hammers per day because of material delay, employee absences, and other problems. What is its efficiency?

•• **S7.3** If a plant has an effective capacity of 6,500 and an efficiency of 88%, what is the actual (planned) output?

• **S7.4** A plant has an effective capacity of 900 units per day and produces 800 units per day with its product mix; what is its efficiency?

• **S7.5** Material delays have routinely limited production of household sinks to 400 units per day. If the plant efficiency is 80%, what is the effective capacity?

•• **S7.6** The effective capacity and efficiency for the next quarter at MMU Mfg. in Waco, Texas, for each of three departments are shown:

DEPARTMENT	EFFECTIVE CAPACITY	RECENT EFFICIENCY
Design	93,600	.95
Fabrication	156,000	1.03
Finishing	62,400	1.05

Compute the expected production for next quarter for each department.

•• **S7.7** Southeastern Oklahoma State University's business program has the facilities and faculty to handle an enrollment of 2,000 new students per semester. However, in an effort to limit class sizes to a "reasonable" level (under 200, generally), Southeastern's dean, Holly Lutze, placed a ceiling on enrollment of 1,500 new students. Although there was ample demand for business courses last semester, conflicting schedules allowed only 1,450 new students to take business courses. What are the utilization and efficiency of this system?

•• **S7.8** Under ideal conditions, a service bay at a Fast Lube can serve 6 cars per hour. The effective capacity and efficiency of a Fast Lube service bay are known to be 5.5 and 0.880, respectively. What is the minimum number of service bays Fast Lube needs to achieve an anticipated servicing of 200 cars per 8-hour day?

Problems S7.9–S7.15 relate to Bottleneck Analysis and the Theory of Constraints

• **S7.9** A production line at V. J. Sugumaran's machine shop has three stations. The first station can process a unit in 10 minutes. The second station has two identical machines, each of which can process a unit in 12 minutes. (Each unit only needs to be processed on one of the two machines.) The third station can process a unit in 8 minutes. Which station is the bottleneck station?

•• **S7.10** A work cell at Chris Ellis Commercial Laundry has a workstation with two machines, and each unit produced at the station needs to be processed by both of the machines. (The same unit cannot be worked on by both machines simultaneously.) Each machine has a production capacity of 4 units per hour. What is the throughput time of the work cell?

•• **S7.11** The three-station work cell illustrated in Figure S7.7 has a product that must go through one of the two machines at station 1 (they are parallel) before proceeding to station 2.

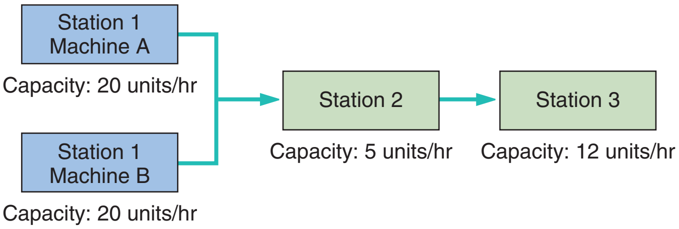


Figure **S7.7**

a) What is the bottleneck time of the system?
b) What is the bottleneck station of this work cell?
c) What is the throughput time?
d) If the firm operates 10 hours per day, 5 days per week, what is the weekly capacity of this work cell?

•• **S7.12** The three-station work cell at Pullman Mfg., Inc. is illustrated in Figure S7.8. It has two machines at station 1 in parallel (i.e., the product needs to go through only one of the two machines before proceeding to station 2).

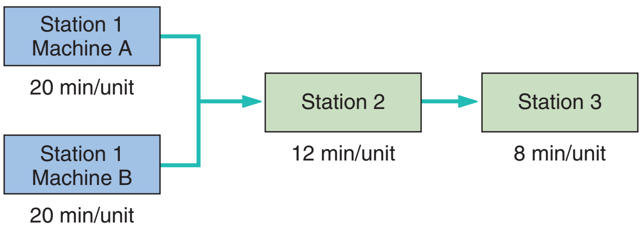


Figure **S7.8**

a) What is the throughput time of this work cell?
b) What is the bottleneck time of this work cell?
c) What is the bottleneck station?
d) If the firm operates 8 hours per day, 6 days per week, what is the weekly capacity of this work cell?

•• **S7.13** The Pullman Mfg., Inc., three-station work cell illustrated in Figure S7.8 has two machines at station 1 in parallel. (The product needs to go through only one of the two machines before proceeding to station 2.) The manager, Ms. Hartley, has asked you to evaluate the system if she adds a parallel machine at station 2.
a) What is the throughput time of the new work cell?
b) What is the bottleneck time of the new work cell?
c) If the firm operates 8 hours per day, 6 days per week, what is the weekly capacity of this work cell?
d) How did the addition of the second machine at workstation 2 affect the performance of the work cell from Problem S7.12?

• **S7.14** Klassen Toy Company, Inc., assembles two parts (parts 1 and 2): Part 1 is first processed at workstation A for 15 minutes per unit and then processed at workstation B for

10 minutes per unit. Part 2 is simultaneously processed at workstation C for 20 minutes per unit. Work stations B and C feed the parts to an assembler at workstation D, where the two parts are assembled. The time at workstation D is 15 minutes.
a) What is the bottleneck of this process?
b) What is the hourly capacity of the process?

•• **S7.15** A production process at Kenneth Day Manufacturing is shown in Figure S7.9. The drilling operation occurs separately from, and simultaneously with, sawing and sanding, which are independent and sequential operations. A product needs to go through only one of the three assembly operations (the operations are in parallel).
a) Which operation is the bottleneck?
b) What is the bottleneck time?
c) What is the throughput time of the overall system?
d) If the firm operates 8 hours per day, 20 days per month, what is the monthly capacity of the manufacturing process?

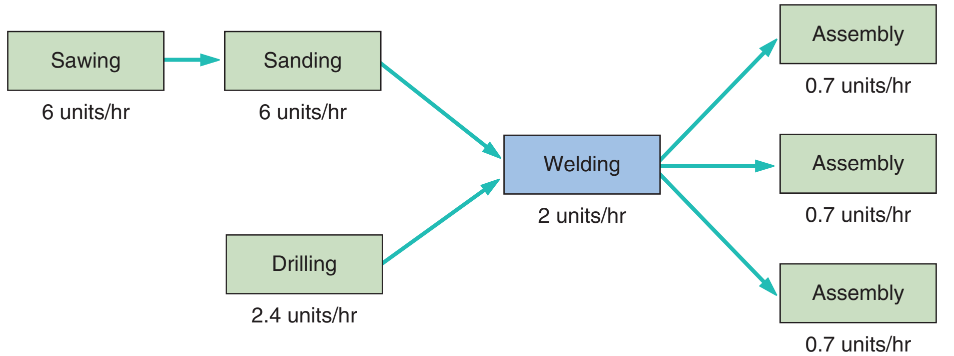


Figure **S7.9**

Problems S7.16–S7.31 relate to Break-Even Analysis

• **S7.16** Smithson Cutting is opening a new line of scissors for supermarket distribution. It estimates its fixed cost to be $500.00 and its variable cost to be $0.50 per unit. Selling price is expected to average $0.75 per unit.
a) What is Smithson's break-even point in units?
b) What is the break-even point in dollars? PX

• **S7.17** Markland Manufacturing intends to increase capacity by overcoming a bottleneck operation by adding new equipment. Two vendors have presented proposals. The fixed costs for proposal A are $50,000, and for proposal B, $70,000. The variable cost for A is $12.00, and for B, $10.00. The revenue generated by each unit is $20.00.
a) What is the break-even point in units for proposal A?
b) What is the break-even point in units for proposal B? PX

• **S7.18** Using the data in Problem S7.17:
a) What is the break-even point in dollars for proposal A if you add $10,000 installation to the fixed cost?
b) What is the break-even point in dollars for proposal B if you add $10,000 installation to the fixed cost? PX

• **S7.19** Given the data in Problem S7.17, at what volume (units) of output would the two alternatives yield the same profit? PX

•• **S7.20** Janelle Heinke, the owner of Ha'Peppas!, is considering a new oven in which to bake the firm's signature dish, vegetarian pizza. Oven type A can handle 20 pizzas an hour. The fixed costs associated with oven A are $20,000 and the variable costs are $2.00 per pizza. Oven B is larger and can handle 40 pizzas an hour. The fixed costs associated with oven B are $30,000 and the variable costs are $1.25 per pizza. The pizzas sell for $14 each.
a) What is the break-even point for each oven?
b) If the owner expects to sell 9,000 pizzas, which oven should she purchase?
c) If the owner expects to sell 12,000 pizzas, which oven should she purchase?
d) At what volume should Janelle switch ovens? PX


Corbis

•• **S7.21** Given the following data, calculate a) BEP_x; b) $BEP_\$$; and c) the profit at 100,000 units:

$$P = \$8/\text{unit} \quad V = \$4/\text{unit} \quad F = \$50{,}000$$ PX

•• **S7.22** You are considering opening a copy service in the student union. You estimate your fixed cost at $15,000 and the variable cost of each copy sold at $.01. You expect the selling price to average $.05.
a) What is the break-even point in dollars?
b) What is the break-even point in units? PX

•• **S7.23** An electronics firm is currently manufacturing an item that has a variable cost of $.50 per unit and a selling price of $1.00 per unit. Fixed costs are $14,000. Current volume is

30,000 units. The firm can substantially improve the product quality by adding a new piece of equipment at an additional fixed cost of $6,000. Variable cost would increase to $.60, but volume should jump to 50,000 units due to a higher-quality product. Should the company buy the new equipment? PX

•• **S7.24** The electronics firm in Problem S7.23 is now considering the new equipment and increasing the selling price to $1.10 per unit. With the higher-quality product, the new volume is expected to be 45,000 units. Under these circumstances, should the company purchase the new equipment and increase the selling price? PX

•••• **S7.25** Zan Azlett and Angela Zesiger have joined forces to start A&Z Lettuce Products, a processor of packaged shredded lettuce for institutional use. Zan has years of food processing experience, and Angela has extensive commercial food preparation experience. The process will consist of opening crates of lettuce and then sorting, washing, slicing, preserving, and finally packaging the prepared lettuce. Together, with help from vendors, they think they can adequately estimate demand, fixed costs, revenues, and variable cost per 5-pound bag of lettuce. They think a largely manual process will have monthly fixed costs of $37,500 and variable costs of $1.75 per bag. A more mechanized process will have fixed costs of $75,000 per month with variable costs of $1.25 per 5-pound bag. They expect to sell the shredded lettuce for $2.50 per 5-pound bag.

a) What is the break-even quantity for the manual process?
b) What is the revenue at the break-even quantity for the manual process?
c) What is the break-even quantity for the mechanized process?
d) What is the revenue at the break-even quantity for the mechanized process?
e) What is the monthly profit or loss of the *manual* process if they expect to sell 60,000 bags of lettuce per month?
f) What is the monthly profit or loss of the *mechanized* process if they expect to sell 60,000 bags of lettuce per month?
g) At what quantity would Zan and Angela be indifferent to the process selected?
h) Over what range of demand would the *manual* process be preferred over the mechanized process? Over what range of demand would the *mechanized* process be preferred over the manual process? PX

•••• **S7.26** As a prospective owner of a club known as the Red Rose, you are interested in determining the volume of sales dollars necessary for the coming year to reach the break-even point. You have decided to break down the sales for the club into four categories, the first category being beer. Your estimate of the beer sales is that 30,000 drinks will be served. The selling price for each unit will average $1.50; the cost is $.75. The second major category is meals, which you expect to be 10,000 units with an average price of $10.00 and a cost of $5.00. The third major category is desserts and wine, of which you also expect to sell 10,000 units, but with an average price of $2.50 per unit sold and a cost of $1.00 per unit. The final category is lunches and inexpensive sandwiches, which you expect to total 20,000 units at an average price of $6.25 with a food cost of $3.25. Your fixed cost (i.e., rent, utilities, and so on) is $1,800 per month plus $2,000 per month for entertainment.

a) What is your break-even point in dollars per month?
b) What is the expected number of meals each day if you are open 30 days a month?

••• **S7.27** As manager of the St. Cloud Theatre Company, you have decided that concession sales will support themselves. The following table provides the information you have been able to put together thus far:

ITEM	SELLING PRICE	VARIABLE COST	% OF REVENUE
Soft drink	$1.00	$.65	25
Wine	1.75	.95	25
Coffee	1.00	.30	30
Candy	1.00	.30	20

Last year's manager, Jim Freeland, has advised you to be sure to add 10% of variable cost as a waste allowance for all categories.

You estimate labor cost to be $250.00 (5 booths with 2 people each). Even if nothing is sold, your labor cost will be $250.00, so you decide to consider this a fixed cost. Booth rental, which is a contractual cost at $50.00 for *each* booth per night, is also a fixed cost.

a) What is the break-even volume per evening performance?
b) How much wine would you expect to sell each evening at the break-even point?

Additional problems **S7.28–S7.31** *are available in* MyOMLab.

Problems S7.32–S7.33 relate to Applying Expected Monetary Value (EMV) to Capacity Decisions

•• **S7.32** James Lawson's Bed and Breakfast, in a small historic Mississippi town, must decide how to subdivide (remodel) the large old home that will become its inn. There are three alternatives: Option A would modernize all baths and combine rooms, leaving the inn with four suites, each suitable for two to four adults. Option B would modernize only the second floor; the results would be six suites, four for two to four adults, two for two adults only. Option C (the status quo option) leaves all walls intact. In this case, there are eight rooms available, but only two are suitable for four adults, and four rooms will not have private baths. Below are the details of profit and demand patterns that will accompany each option:

	ANNUAL PROFIT UNDER VARIOUS DEMAND PATTERNS			
ALTERNATIVES	HIGH	*P*	AVERAGE	*P*
A (modernize all)	$90,000	.5	$25,000	.5
B (modernize 2nd)	$80,000	.4	$70,000	.6
C (status quo)	$60,000	.3	$55,000	.7

Which option has the highest expected monetary value? PX

•••• **S7.33** As operations manager of Holz Furniture, you must make a decision about adding a line of rustic furniture. In discussing the possibilities with your sales manager, Steve Gilbert, you decide that there will definitely be a market and that your firm should enter that market. However, because rustic furniture has a different finish than your standard offering, you decide you need another process line. There is no doubt in your mind about the decision, and you are sure that you should have a second process. But you do question how large to make it. A large process line is going to cost $400,000; a small process line will cost $300,000. The question, therefore, is the demand for rustic furniture. After extensive discussion with Mr. Gilbert and Tim Ireland of Ireland Market Research, Inc., you determine that the best estimate you can make is that there is a two-out-of-three chance of profit from sales as large as $600,000 and a one-out-of-three chance as low as $300,000.

With a large process line, you could handle the high figure of $600,000. However, with a small process line you could not and would be forced to expand (at a cost of $150,000), after which time your profit from sales would be $500,000 rather than the $600,000 because of the lost time in expanding the process. If you do not expand the small process, your profit from sales would be held to $400,000. If you build a small process and the demand is low, you can handle all of the demand.

Should you open a large or small process line?

Problems S7.34–S7.45 relate to Applying Investment Analysis to Strategy-Driven Investments

•• **S7.34** What is the net present value of an investment that costs $75,000 and has a salvage value of $45,000? The annual profit from the investment is $15,000 each year for 5 years. The cost of capital at this risk level is 12%. PX

• **S7.35** The initial cost of an investment is $65,000 and the cost of capital is 10%. The return is $16,000 per year for 8 years. What is the net present value? PX

• **S7.36** What is the present value of $5,600 when the interest rate is 8% and the return of $5,600 will not be received for 15 years? PX

•• **S7.37** Tim Smunt has been asked to evaluate two machines. After some investigation, he determines that they have the costs shown in the following table. He is told to assume that:

1. The life of each machine is 3 years.
2. The company thinks it knows how to make 12% on investments no more risky than this one.
3. Labor and maintenance are paid at the end of the year.

	MACHINE A	MACHINE B
Original cost	$10,000	$20,000
Labor per year	2,000	4,000
Maintenance per year	4,000	1,000
Salvage value	2,000	7,000

Determine, via the present value method, which machine Tim should recommend.

•••• **S7.38** Your boss has told you to evaluate two ovens for Tink-the-Tinkers, a gourmet sandwich shop. After some questioning of vendors and receipt of specifications, you are assured that the ovens have the attributes and costs shown in the following table. The following two assumptions are appropriate:

1. The life of each machine is 5 years.
2. The company thinks it knows how to make 14% on investments no more risky than this one.

a) Determine via the present value method which machine to tell your boss to purchase.
b) What assumption are you making about the ovens?
c) What assumptions are you making in your methodology?

	THREE SMALL OVENS AT $1,250 EACH	TWO LARGE OVENS AT $2,500 EACH
Original cost	$3,750	$5,000
Labor per year in excess of larger models	$ 750 (total)	
Cleaning/ maintenance	$ 750 ($250 each)	$ 400 ($200 each)
Salvage value	$ 750 ($250 each)	$1,000 ($500 each)

•••• **S7.39** Bold's Gym, a health club chain, is considering expanding into a new location: the initial investment would be $1 million in equipment, renovation, and a 6-year lease, and its annual upkeep and expenses would be $75,000 (paid at the beginning of the year). Its planning horizon is 6 years out, and at the end, it can sell the equipment for $50,000. Club capacity is 500 members who would pay an annual fee of $600. Bold's expects to have no problems filling membership slots. Assume that the interest rate is 10%. (See Table S7.2.)

a) What is the present value profit/loss of the deal?
b) The club is considering offering a special deal to the members in the first year. For $3,000 upfront they get a full 6-year membership (i.e., 1 year free). Would it make financial sense to offer this deal?

Additional problems **S7.40–S7.45** *are available in* MyOMLab.

CASE STUDY

Capacity Planning at Arnold Palmer Hospital

Video Case

Since opening day, Arnold Palmer Hospital has experienced an explosive growth in demand for its services. One of only six hospitals in the U.S. to specialize in health care for women and children, Arnold Palmer Hospital has cared for over 1,500,000 patients who came to the Orlando facility from all 50 states and more than 100 other countries. With patient satisfaction scores in the top 10% of U.S. hospitals surveyed (over 95% of patients would recommend the hospital to others), one of Arnold Palmer Hospital's main focuses is delivery of babies. Originally built with 281 beds and a capacity for 6,500 births per year, the hospital steadily approached and then passed 10,000 births. Looking at Table S7.4, Executive Director Kathy Swanson knew an expansion was necessary.

With continuing population growth in its market area serving 18 central Florida counties, Arnold Palmer Hospital was delivering the equivalent of a kindergarten class of babies every day and still not meeting demand. Supported with substantial additional demographic analysis, the hospital was ready to move ahead with a capacity expansion plan and a new 11-story hospital building across the street from the existing facility.

Thirty-five planning teams were established to study such issues as (1) specific forecasts, (2) services that would transfer to the new facility, (3) services that would remain in the existing facility, (4) staffing needs, (5) capital equipment, (6) pro forma accounting data, and (7) regulatory requirements. Ultimately, Arnold Palmer Hospital was ready to move ahead with a budget of $100 million and a commitment to an additional 150 beds. But given the growth of the central Florida region, Swanson decided to expand the hospital in stages: the top two floors would be empty interiors ("shell") to be completed at a later date, and the fourth-floor operating room could be doubled in size when needed. "With the new facility in place, we are now able to handle up to 16,000 births per year," says Swanson.

Discussion Questions*

1. Given the capacity planning discussion in the text (see Figure S7.6), what approach is being taken by Arnold Palmer Hospital toward matching capacity to demand?
2. What kind of major changes could take place in Arnold Palmer Hospital's demand forecast that would leave the hospital with an underutilized facility (namely, what are the risks connected with this capacity decision)?
3. Use regression analysis to forecast the point at which Swanson needs to "build out" the top two floors of the new building, namely, when demand will exceed 16,000 births.

*You may wish to view the video that accompanies the case before addressing these questions.

TABLE S7.4 Births at Arnold Palmer Hospital

YEAR	BIRTHS
1995	6,144
1996	6,230
1997	6,432
1998	6,950
1999	7,377
2000	8,655
2001	9,536
2002	9,825
2003	10,253
2004	10,555
2005	12,316
2006	13,070
2007	14,028
2008	14,241
2009	13,050
2010	12,571
2011	12,978
2012	13,529
2013	13,576
2014	13,994

- **Additional Case Study:** Visit MyOMLab for this free case study:
  Southwestern University (D): Requires the development of a multiproduct break-even solution.

Endnote

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.

Supplement 7 *Rapid* Review

Main Heading	Review Material	MyOMLab
CAPACITY (pp. 308–314)	■ **Capacity**—The "throughput," or number of units a facility can hold, receive, store, or produce in a period of 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. *Determining facility size, with an objective of achieving high levels of utilization and a high return on investment, is critical.* Capacity planning can be viewed in three time horizons: 1. *Long-range* (> 1 year)—Adding facilities and long lead-time equipment 2. *Intermediate-range* (3–18 months)—"Aggregate planning" tasks, including adding equipment, personnel, and shifts; subcontracting; and building or using inventory 3. *Short-range* (< 3 months)—Scheduling jobs and people, and allocating machinery ■ **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. ■ **Effective capacity**—The capacity a firm can expect to achieve, given its product mix, methods of scheduling, maintenance, and standards of quality. ■ **Utilization**—Actual output as a percent of design capacity. ■ **Efficiency**—Actual output as a percent of effective capacity. $\text{Utilization} = \text{Actual output}/\text{Design capacity}$ (S7-1) $\text{Efficiency} = \text{Actual output}/\text{Effective capacity}$ (S7-2) When demand exceeds capacity, a firm may be able to curtail demand simply by raising prices, increasing lead times (which may be inevitable), and discouraging marginally profitable business. When capacity exceeds demand, a firm may want to stimulate demand through price reductions or aggressive marketing, or it may accommodate the market via product changes. In the service sector, scheduling customers is *demand management,* and scheduling the workforce is *capacity management.* When demand and capacity are fairly well matched, demand management in services can often be handled with appointments, reservations, or a first-come, first-served rule. Otherwise, discounts based on time of day may be used (e.g., "early bird" specials, matinee pricing). When managing demand in services is not feasible, managing capacity through changes in full-time, temporary, or part-time staff may be an option.	Concept Questions: 1.1–1.4 Problems: S7.1–S7.8 Virtual Office Hours for Solved Problem: S7.1 ACTIVE MODEL S7.1
BOTTLENECK ANALYSIS AND THE THEORY OF CONSTRAINTS (pp. 314–318)	■ **Capacity analysis**—Determining throughput capacity of workstations or an entire production system. ■ **Bottleneck**—The limiting factor or constraint in a system. ■ **Process time**—The time to produce a unit (or batch) at a workstation. ■ **Bottleneck time**—The process time of the longest (slowest) process. ■ **Throughput time**—The time it takes for a product to go through the production process *with no waiting*, i.e., the time of the longest path through the system. If n parallel (redundant) operations are added, the process time of the combined operations will equal $1/n$ times the process time of the original. With simultaneous processing, an order or product is essentially *split* into different paths to be rejoined later on. The longest path through the system is deemed the throughput time. ■ **Theory of constraints (TOC)**—A body of knowledge that deals with anything limiting an organization's ability to achieve its goals.	Concept Questions: 2.1–2.4 Problems: S7.9–S7.15 Virtual Office Hours for Solved Problem: S7.5

Supplement 7 *Rapid* Review *continued*

Main Heading	Review Material	MyOMLab
BREAK-EVEN ANALYSIS (pp. 318–322)	■ **Break-even analysis**—A means of finding the point, in dollars and units, at which costs equal revenues. *Fixed costs* are costs that exist even if no units are produced. Variable costs are those that vary with the volume of units produced. In the break-even model, costs and revenue are assumed to increase linearly. $\text{Break-even in units} = \frac{\text{Total Fixed cost}}{\text{Price} - \text{Variable cost}} = \frac{F}{P - V}$ (S7-3) $\text{Break-even in dollars} = \frac{\text{Total Fixed cost}}{1 - \frac{\text{Variable cost}}{\text{Price}}} = \frac{F}{1 - \left(\frac{V}{P}\right)}$ (S7-4) $\text{Multiproduct break-even point in dollars} = BEP_{\$} = \frac{F}{\sum\left[\left(1 - \frac{V_i}{P_i}\right) \times (W_i)\right]}$ (S7-5)	Concept Questions: 3.1–3.4 Problems: S7.16–S7.31 Virtual Office Hours for Solved Problem: S7.3 **ACTIVE MODEL S7.2**
REDUCING RISK WITH INCREMENTAL CHANGES (pp. 322–323)	Demand growth is usually in small units, while capacity additions are likely to be both instantaneous and in large units. To reduce risk, incremental changes that hedge demand forecasts may be a good option. Four approaches to capacity expansion are (1) *leading* strategy, with incremental expansion, (2) *leading* strategy with one step expansion, (3) *lag* strategy, and (4) *straddle* strategy. Both lag strategy and straddle strategy delay capital expenditure.	Concept Questions: 4.1–4.4 **VIDEO S7.1** Capacity Planning at Arnold Palmer Hospital
APPLYING EXPECTED MONETARY VALUE (p. 323)	Determining expected monetary value requires specifying alternatives and various states of nature (e.g., 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.	Concept Questions: 5.1–5.4 Problems: S7.32–S7.33
APPLYING INVESTMENT ANALYSIS TO STRATEGY-DRIVEN INVESTMENTS (pp. 324–326)	■ **Net present value**—A means of determining the discounted value of a series of future cash receipts. $F = P(1 + i)^N$ (S7-6) $P = \frac{F}{(1 + i)^N}$ (S7-7) $P = \frac{F}{(1 + i)^N} = FX$ (S7-8) When making several investments, those with higher net present values are preferable to investments with lower net present values.	Concept Questions: 6.1–6.4 Problems: S7.34–S7.45 Virtual Office Hours for Solved Problem: S7.4

Self Test

■ **Before taking the self-test,** refer to the learning objectives listed at the beginning of the supplement and the key terms listed at the end of the supplement.

LO S7.1 Capacity decisions should be made on the basis of:
a) building sustained competitive advantage.
b) good financial returns.
c) a coordinated plan.
d) integration into the company's strategy.
e) all of the above.

LO S7.2 Effective capacity is:
a) the capacity a firm expects to achieve, given the current operating constraints.
b) the percentage of design capacity actually achieved.
c) the percentage of capacity actually achieved.
d) actual output.
e) efficiency.

LO S7.3 System capacity is based on:
a) the bottleneck.
b) throughput time.
c) time of the fastest station.
d) throughput time plus waiting time.
e) none of the above.

LO S7.4 The break-even point is:
a) adding processes to meet the point of changing product demands.
b) improving processes to increase throughput.
c) the point in dollars or units at which cost equals revenue.
d) adding or removing capacity to meet demand.
e) the total cost of a process alternative.

LO S7.5 Expected monetary value is most appropriate:
a) when the payoffs are equal.
b) when the probability of each decision alternative is known.
c) when probabilities are the same.
d) when both revenue and cost are known.
e) when probabilities of each state of nature are known.

LO S7.6 Net present value:
a) is greater if cash receipts occur later rather than earlier.
b) is greater if cash receipts occur earlier rather than later.
c) is revenue minus fixed cost.
d) is preferred over break-even analysis.
e) is greater if \$100 monthly payments are received in a lump sum (\$1,200) at the end of the year.

Answers: LO S7.1. e; LO S7.2. a; LO S7.3. a; LO S7.4. c; LO S7.5. b; LO S7.6. b.