Capacity and Constraint Management

7 SUPPLEMENT

PowerPoint presentation to accompany
Heizer, Render, Munson
Operations Management, Twelfth Edition, Global Edition
Principles of Operations Management, Tenth Edition, Global Edition

PowerPoint slides by Jeff Heyl

Outline

- Capacity
- Bottleneck Analysis and the Theory of Constraints
- Break-Even Analysis
- Reducing Risk with Incremental Changes

Outline - Continued

- Applying Expected Monetary Value (EMV) to Capacity Decisions
- Applying Investment Analysis to Strategy-Driven Investments

Learning Objectives

When you complete this supplement you should be able to:

- **S7.1** ***Define*** capacity
- **S7.2** ***Determine*** design capacity, effective capacity, and utilization
- **S7.3** ***Perform*** bottleneck analysis
- **S7.4** ***Compute*** break-even

Learning Objectives

When you complete this supplement you should be able to:

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

S7.6 ***Compute*** net present value

Capacity

- The throughput, or the number of units a facility can hold, receive, store, or produce in a period of time
- Determines fixed costs
- Determines if demand will be satisfied
- Three time horizons

Planning Over a Time Horizon

Figure S7.1

Options for Adjusting Capacity

<u>**Time Horizon**</u>	Modify capacity	Use capacity
Long-range planning	Design new production processes Add (or sell existing) long-lead-time equipment Acquire or sell facilities Acquire competitors	*
Intermediate-range planning (aggregate planning)	Subcontract Add or sell equipment Add or reduce shifts	Build or use inventory More or improved training Add or reduce personnel
Short-range planning (scheduling)	*	Schedule jobs Schedule personnel Allocate machinery

* Difficult to adjust capacity as limited options exist

Design and Effective Capacity

- **Design capacity** is the maximum theoretical output of a system
  - Normally expressed as a rate
- **Effective capacity** is the capacity a firm expects to achieve given current operating constraints
  - Often lower than design capacity

Design and Effective Capacity

TABLE S7.1	Capacity Measurements	
MEASURE	**DEFINITION**	**EXAMPLE**
Design capacity 	Ideal conditions exist during the time that the system is available	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**

Design and Effective Capacity

TABLE S7.1	Capacity Measurements	
MEASURE	**DEFINITION**	**EXAMPLE**
Effective capacity 	Design capacity minus lost output because of *planned* resource unavailability (e.g., preventive maintenance, machine setups/changeovers, changes in product mix, scheduled breaks)	Frito-Lay loses 3 hours of output per day (= 0.5 hrs./day on preventive maintenance, 1 hr./day on employee breaks, and 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**

Design and Effective Capacity

TABLE S7.1	Capacity Measurements	
MEASURE	**DEFINITION**	**EXAMPLE**
Actual output 	Effective capacity minus lost output during *unplanned* resource idleness (e.g., absenteeism, machine breakdowns, unavailable parts, quality problems)	On average, 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 and Efficiency

Utilization is the percent of design capacity actually achieved

Utilization = Actual output/Design capacity

Efficiency is the percent of effective capacity actually achieved

Efficiency = Actual output/Effective capacity

Bakery Example

Design Capacity

Actual production last week = 148,000 rolls
Effective capacity = 175,000 rolls
Design capacity = 1,200 rolls per hour
Bakery operates 7 days/week, 3 - 8 hour shifts

Design capacity = (7 x 3 x 8) x (1,200) = 201,600 rolls

Bakery Example

Utilization

Actual production last week = 148,000 rolls
Effective capacity = 175,000 rolls
Design capacity = 1,200 rolls per hour
Bakery operates 7 days/week, 3 - 8 hour shifts

Design capacity = (7 x 3 x 8) x (1,200) = 201,600 rolls

Utilization = 148,000/201,600 = 73.4%

Bakery Example

Efficiency

Actual production last week = 148,000 rolls
Effective capacity = 175,000 rolls
Design capacity = 1,200 rolls per hour
Bakery operates 7 days/week, 3 - 8 hour shifts

Design capacity = (7 x 3 x 8) x (1,200) = 201,600 rolls

Utilization = 148,000/201,600 = 73.4%

Efficiency = 148,000/175,000 = 84.6%

Bakery Example

Design Capacity

Actual production last week = 148,000 rolls
Effective capacity = 175,000 rolls
Design capacity = 201,600 rolls per line
Efficiency = 84.6%
Expected output of new line = 130,000 rolls

Design capacity = 201,600 x 2 = 403,200 rolls

Bakery Example

Effective Capacity

Actual production last week = 148,000 rolls
Effective capacity = 175,000 rolls
Design capacity = 201,600 rolls per line
Efficiency = 84.6%
Expected output of new line = 130,000 rolls

Design capacity = 201,600 x 2 = 403,200 rolls

Effective capacity = 175,000 x 2 = 350,000 rolls

Bakery Example

Actual Output

Actual production last week = 148,000 rolls
Effective capacity = 175,000 rolls
Design capacity = 201,600 rolls per line
Efficiency = 84.6%
Expected output of new line = 130,000 rolls

Design capacity = 201,600 x 2 = 403,200 rolls

Effective capacity = 175,000 x 2 = 350,000 rolls

Actual output = 148,000 + 130,000 = 278,000 rolls

Bakery Example

Utilization Efficiency

Actual production last week = 148,000 rolls
Effective capacity = 175,000 rolls
Design capacity = 201,600 rolls per line
Efficiency = 84.6%
Expected output of new line = 130,000 rolls

Design capacity = 201,600 x 2 = 403,200 rolls

Effective capacity = 175,000 x 2 = 350,000 rolls

Actual output = 148,000 + 130,000 = 278,000 rolls

Utilization = 278,000/403,200 = 68.95%

Efficiency = 278,000/350,000 = 79.43%

Capacity and Strategy

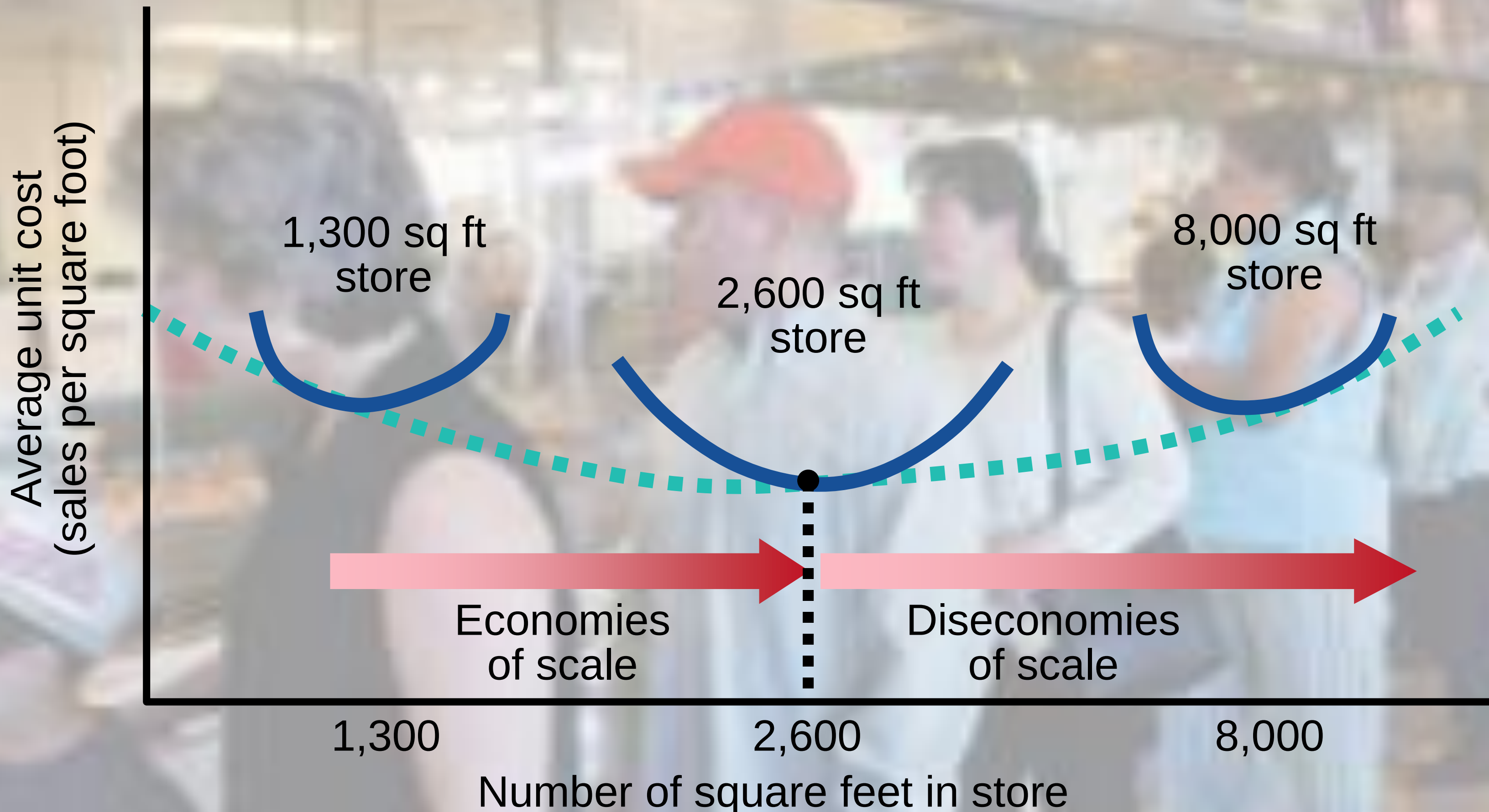
- Capacity decisions impact all 10 decisions of operations management as well as other functional areas of the organization
- Capacity decisions must be integrated into the organization’s mission and strategy

Capacity Considerations

1. *Forecast demand accurately*
2. *Match technology increments and sales volume*
3. *Find the optimum operating size (volume)*
4. *Build for change*

Economies and Diseconomies of Scale

Figure S7.2

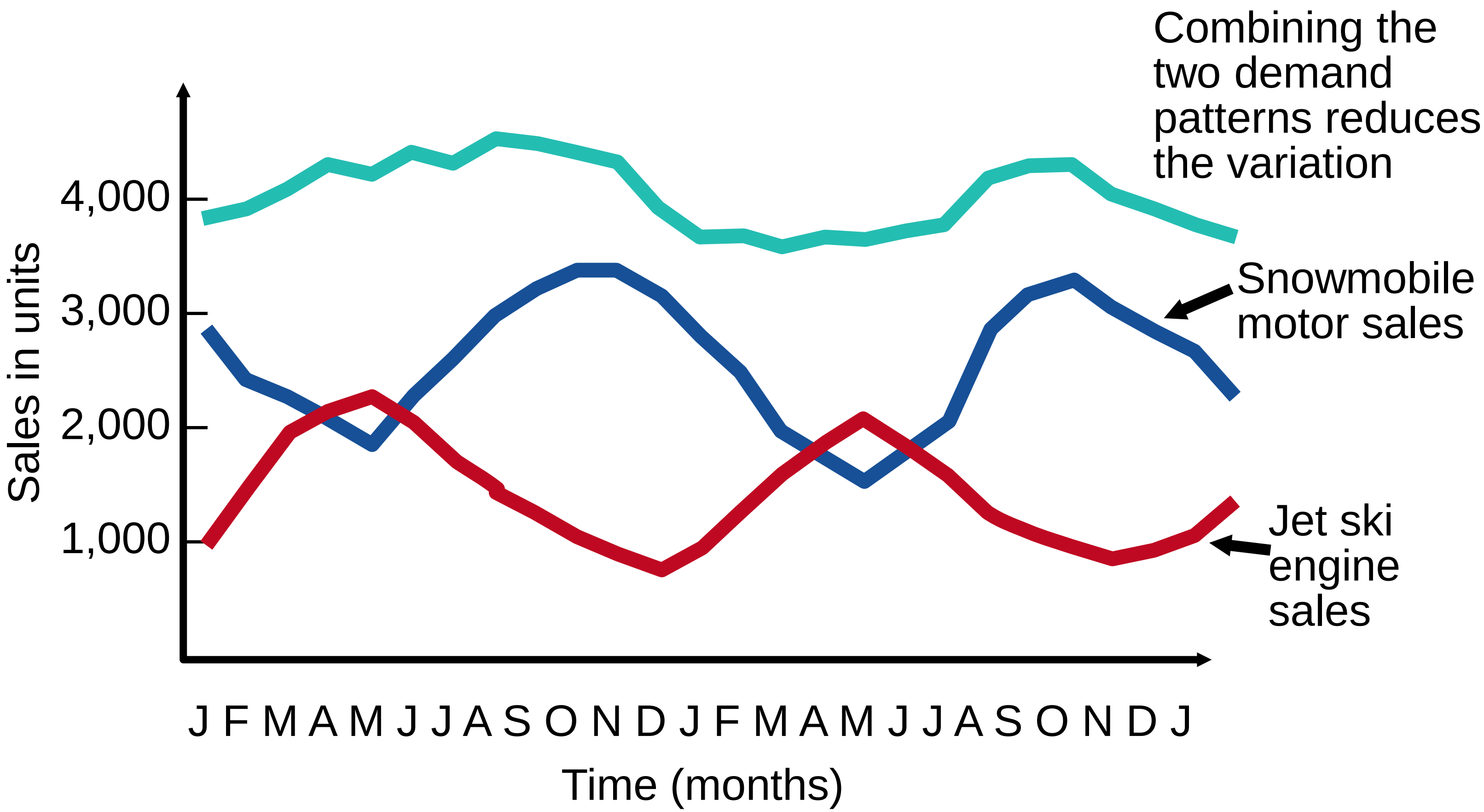


Managing Demand

- Demand exceeds capacity
  - Curtail demand by raising prices, scheduling longer lead times
  - Long-term solution is to increase capacity
- Capacity exceeds demand
  - Stimulate market
  - Product changes
- Adjusting to seasonal demands
  - Produce products with complementary demand patterns

Complementary Demand Patterns

Figure S7.3

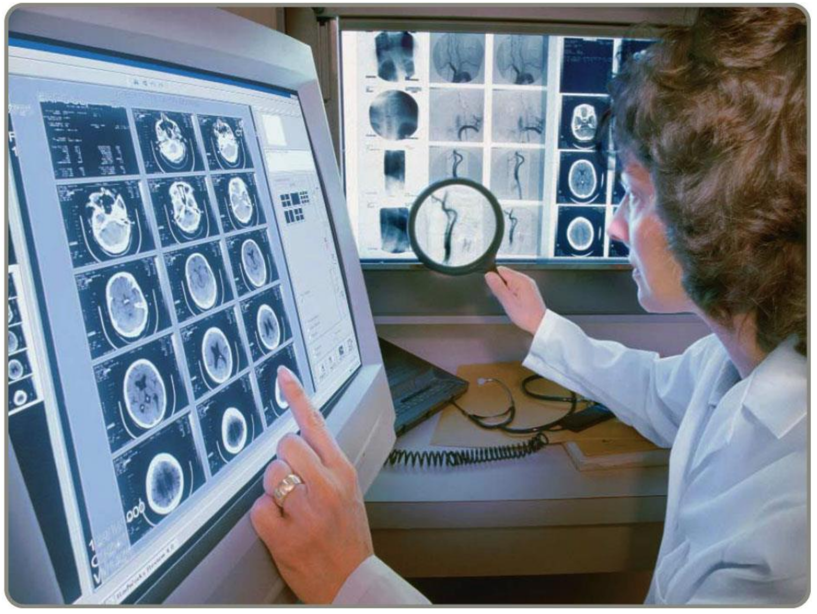


Tactics for Matching Capacity to Demand

1. Making staffing changes
2. Adjusting equipment
   - Purchasing additional machinery
   - Selling or leasing out existing equipment
3. Improving processes to increase throughput
4. Redesigning products to facilitate more throughput
5. Adding process flexibility to meet changing product preferences
6. Closing facilities

Service-Sector Demand and Capacity Management

- Demand management
  - Appointment, reservations, FCFS rule
- Capacity management
  - Full time, temporary, part-time staff



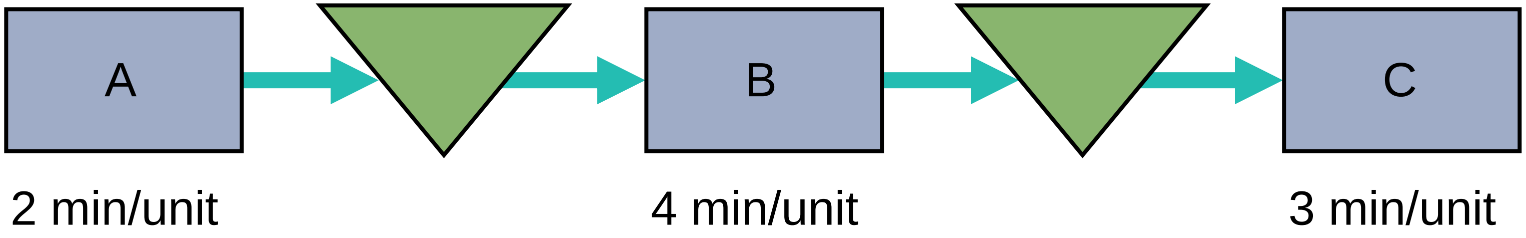
Bottleneck Analysis and the Theory of Constraints

- Each work area can have its own unique capacity
- **Capacity analysis** determines the throughput capacity of workstations in a system
- A **bottleneck** is a limiting factor or constraint
  - A bottleneck has the lowest effective capacity in a system
- The time to produce a unit or a specified batch size is the **process time**

Bottleneck Analysis and the Theory of Constraints

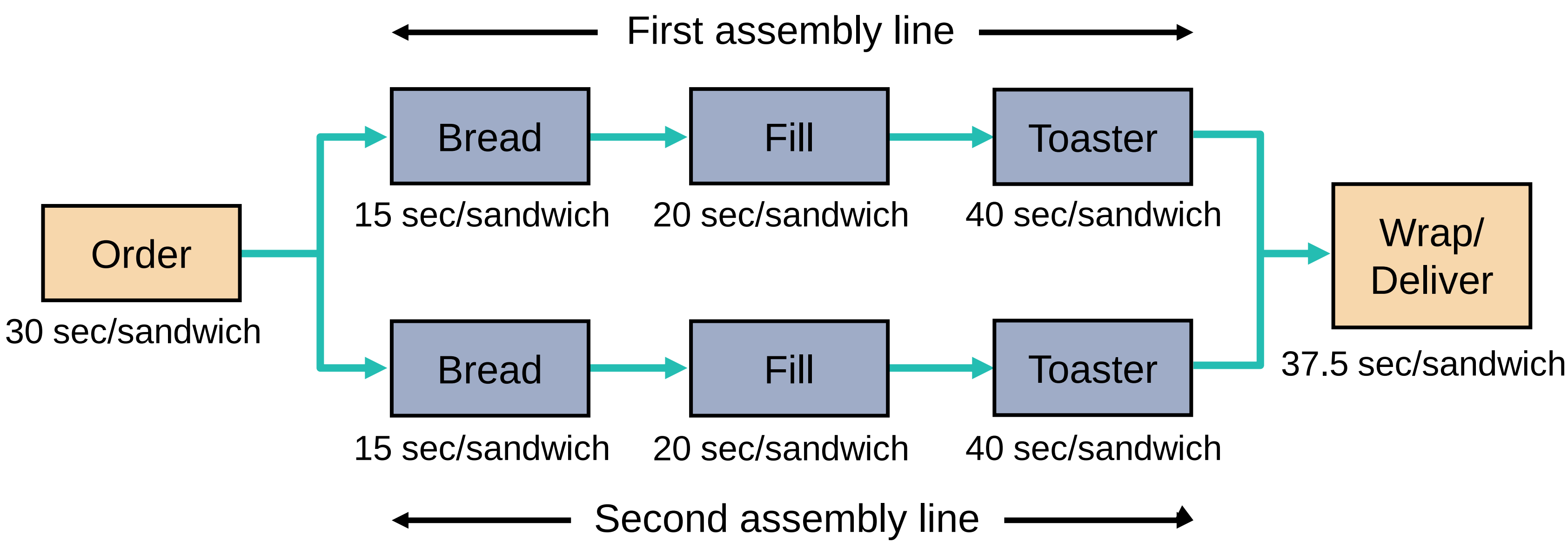
- The **bottleneck time** is the time of the slowest workstation (the one that takes the longest) in a production system
- The **throughput time** is the time it takes a unit to go through production from start to end, *with no waiting*

Figure S7.4

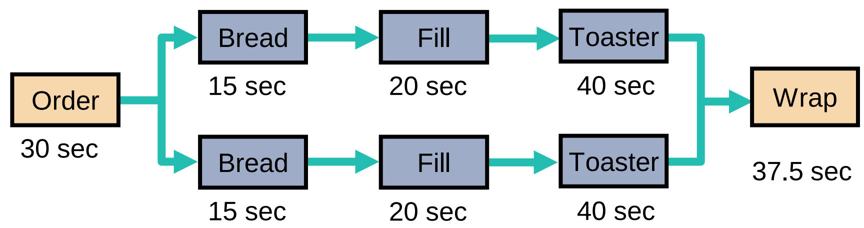


Capacity Analysis

- Two identical sandwich lines
- Lines have two workers and three operations
- All completed sandwiches are wrapped

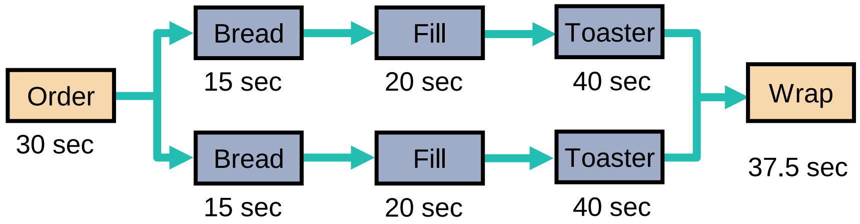


Capacity Analysis



- The two lines are identical, so parallel processing can occur
- At 40 seconds, the toaster has the longest processing time and is the bottleneck for each line
- At 40 seconds for two sandwiches, the bottleneck time of the combined lines = 20 seconds
- At 37.5 seconds, wrapping and delivery is the bottleneck for the entire operation

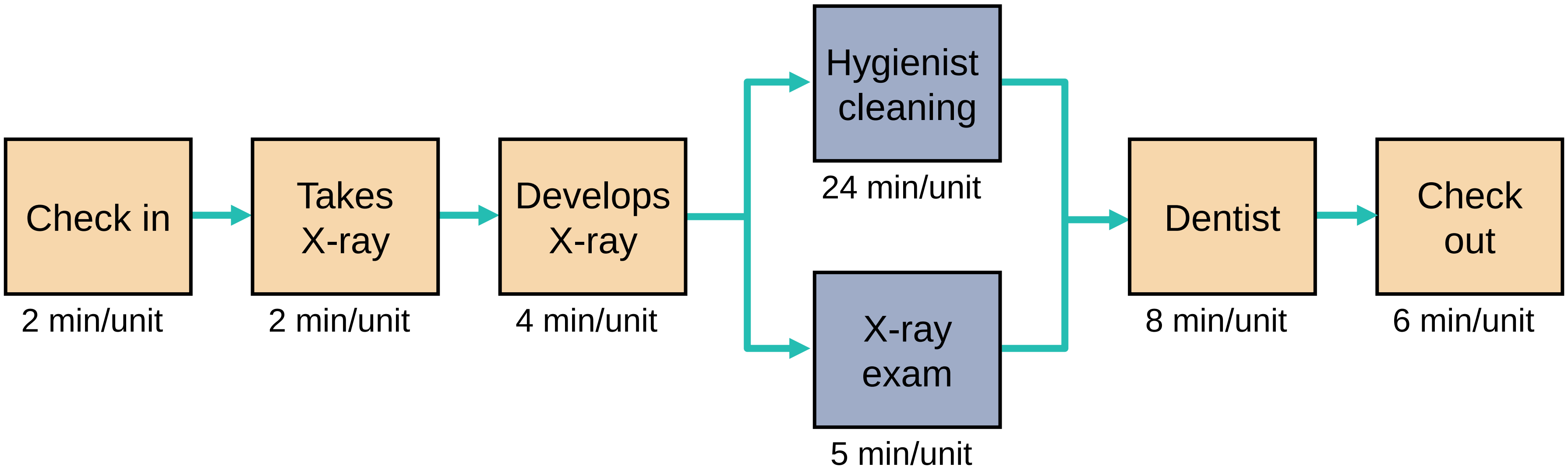
Capacity Analysis



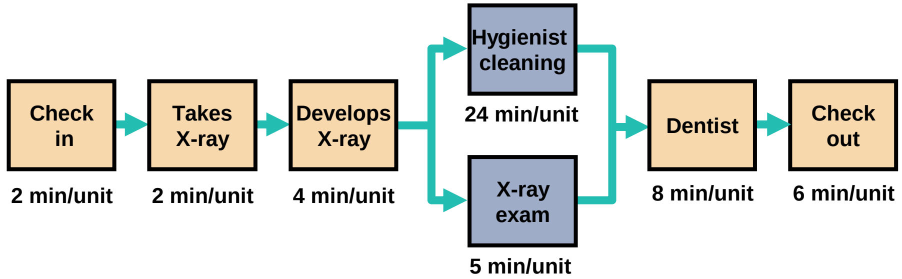
- Capacity per hour is 3,600 seconds/37.5 seconds/sandwich = 96 sandwiches per hour
- Throughput time is 30 + 15 + 20 + 40 + 37.5 = 142.5 seconds

Capacity Analysis

- Standard process for cleaning teeth
- Cleaning and examining X-rays can happen simultaneously



Capacity Analysis



- All possible paths must be compared
- Bottleneck is the hygienist at 24 minutes
- Hourly capacity is 60/24 = 2.5 patients
- X-ray exam path is 2 + 2 + 4 + 5 + 8 + 6 = 27 minutes
- Cleaning path is 2 + 2 + 4 + 24 + 8 + 6 = 46 minutes
- Longest path involves the hygienist cleaning the teeth, patient should complete in 46 minutes

Theory of Constraints

- Five-step process for recognizing and managing limitations

Step 1: Identify the constraints

Step 2: Develop a plan for overcoming the constraints

Step 3: Focus resources on accomplishing Step 2

Step 4: Reduce the effects of constraints by offloading work or expanding capability

Step 5: Once overcome, go back to Step 1 and find new constraints

Bottleneck Management

1. Release work orders to the system at the pace of set by the bottleneck's capacity
   - ***Drum, Buffer, Rope***
2. Lost time at the bottleneck represents lost capacity for the whole system
3. Increasing the capacity of a nonbottleneck station is a mirage
4. Increasing the capacity of a bottleneck increases the capacity of the whole system

Break-Even Analysis

- Technique for evaluating process and equipment alternatives
- Objective is to find the point in dollars and units at which cost equals revenue
- Requires estimation of fixed costs, variable costs, and revenue

Break-Even Analysis

- *Fixed costs* are costs that continue even if no units are produced
  - Depreciation, taxes, debt, mortgage payments
- *Variable costs* are costs that vary with the volume of units produced
  - Labor, materials, portion of utilities
  - Contribution is the difference between selling price and variable cost

Break-Even Analysis

- *Revenue function* 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 is the break-even point

Break-Even Analysis

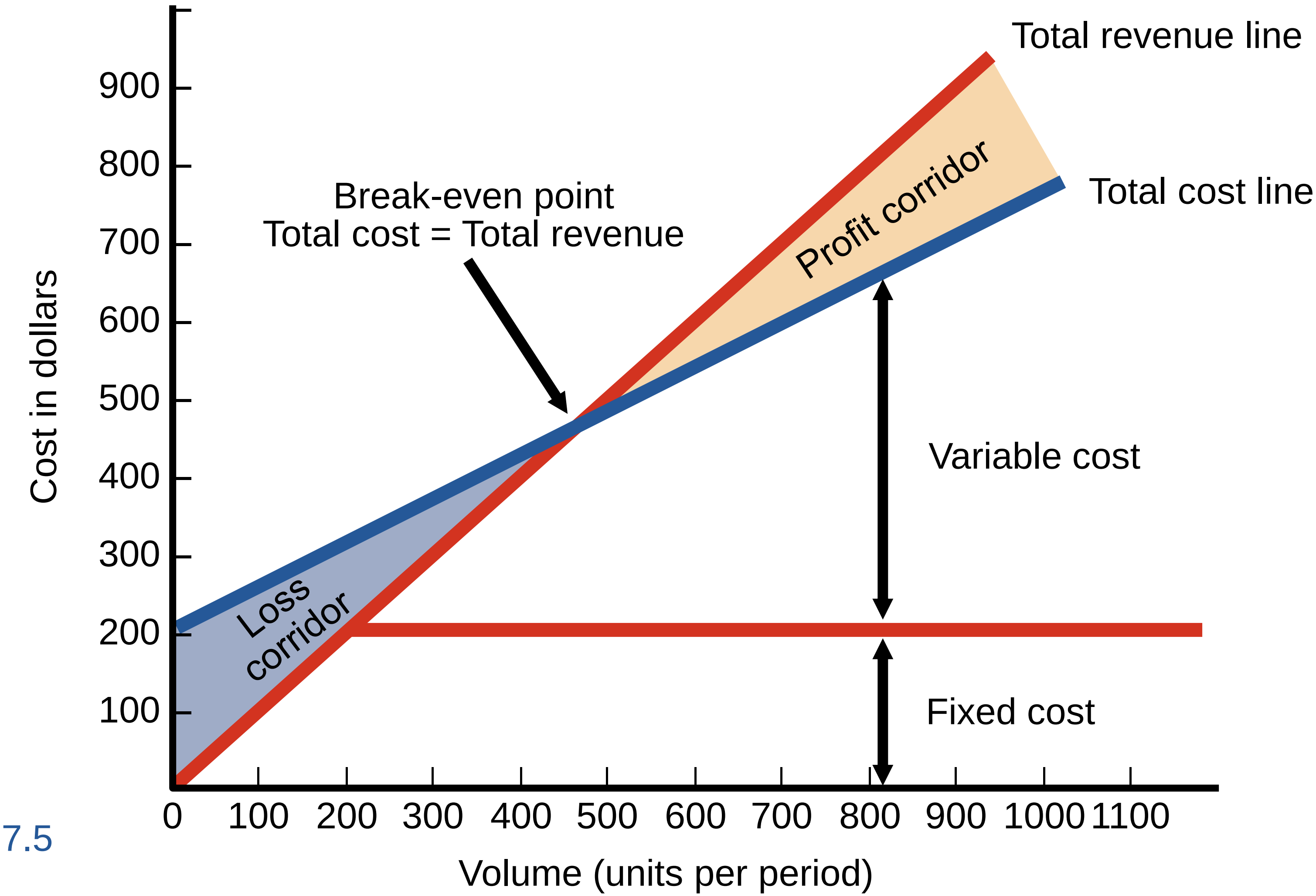


Figure S7.5

Break-Even Analysis

Assumptions

- Costs and revenue are linear functions
  - Generally not the case in the real world
- We actually know these costs
  - Very difficult to verify
- Time value of money is often ignored

Break-Even Analysis

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 cost per unit

TC = total costs = $F + Vx$

Break-even point occurs when

$$TR = TC$$

or

$$Px = F + Vx$$

$$BEP_x = \frac{F}{P - V}$$

Break-Even Analysis

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 cost per unit

TC = total costs = $F + Vx$

$$BEP_\$ = BEP_x P = \frac{F}{P - V}P$$

$$= \frac{F}{(P - V)/P}$$

$$= \frac{F}{1 - V/P}$$

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

Break-Even Example

Fixed costs = $10,000
Direct labor = $1.50/unit

Material = $.75/unit
Selling price = $4.00 per unit

$$BEP_\$ = \frac{F}{1 - (V/P)} = \frac{\$10{,}000}{1 - [(1.50 + .75)/(4.00)]}$$

$$= \frac{\$10{,}000}{.4375} = \$22{,}857.14$$

Break-Even Example

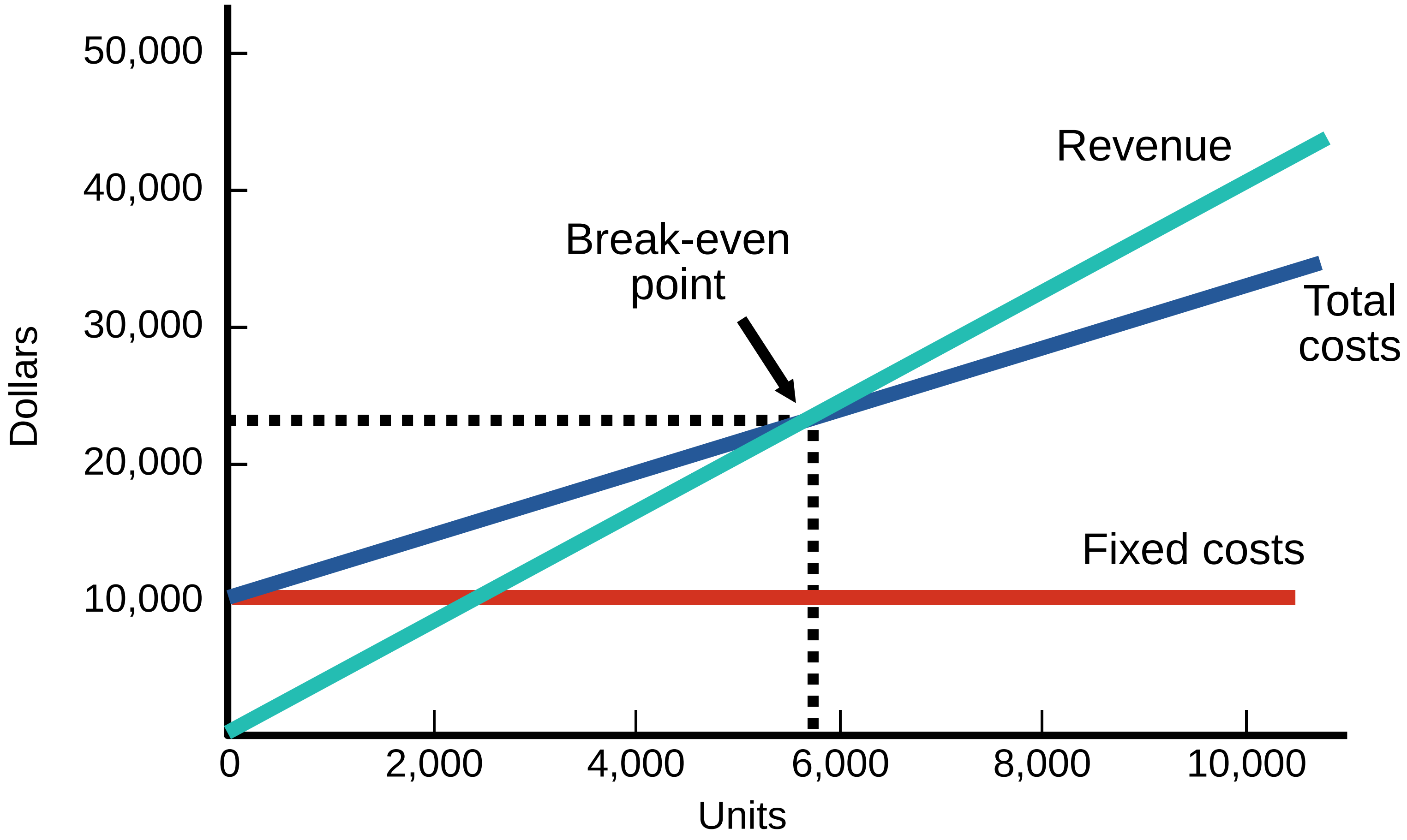
Fixed costs = $10,000
Direct labor = $1.50/unit
Material = $.75/unit
Selling price = $4.00 per unit

$$BEP_\$ = \frac{F}{1 - (V/P)} = \frac{\$10{,}000}{1 - [(1.50 + .75)/(4.00)]}$$

$$= \frac{\$10{,}000}{.4375} = \$22{,}857.14$$

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

Break-Even Example



Break-Even Example

Multiproduct Case

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

where

V = variable cost per unit

P = price per unit

F = fixed costs

W = percent each product is of total dollar sales expressed as a decimal

i = each product

Multiproduct Example

Fixed costs = $3,000 per month

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

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)	1 - (V_i/P_i)	ANNUAL FORECASTED SALES $	% OF SALES (W_i)	WEIGHTED CONTRIBUTION (COL 6 X 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

Multiprod

Fixed costs = $3,000 p

ITEM	ANNUAL FOREC SALES UNI
Sandwich	9,000
Drink	9,000
Baked potato	7,000

1	2	3	4	5				
ITEM (i)	ANNUAL FORECASTED SALES UNITS	SELLING PRICE (P)	VARIABLE COST (V)	(V/				
Sandwich	9,000	$5.00	$3.00	.6				
Drinks	9,000	1.50	0.50	.3				
Baked potato	7,000	2.00	1.00	.50	.50	14,000	.193	.097
						$72,500	1.000	.470

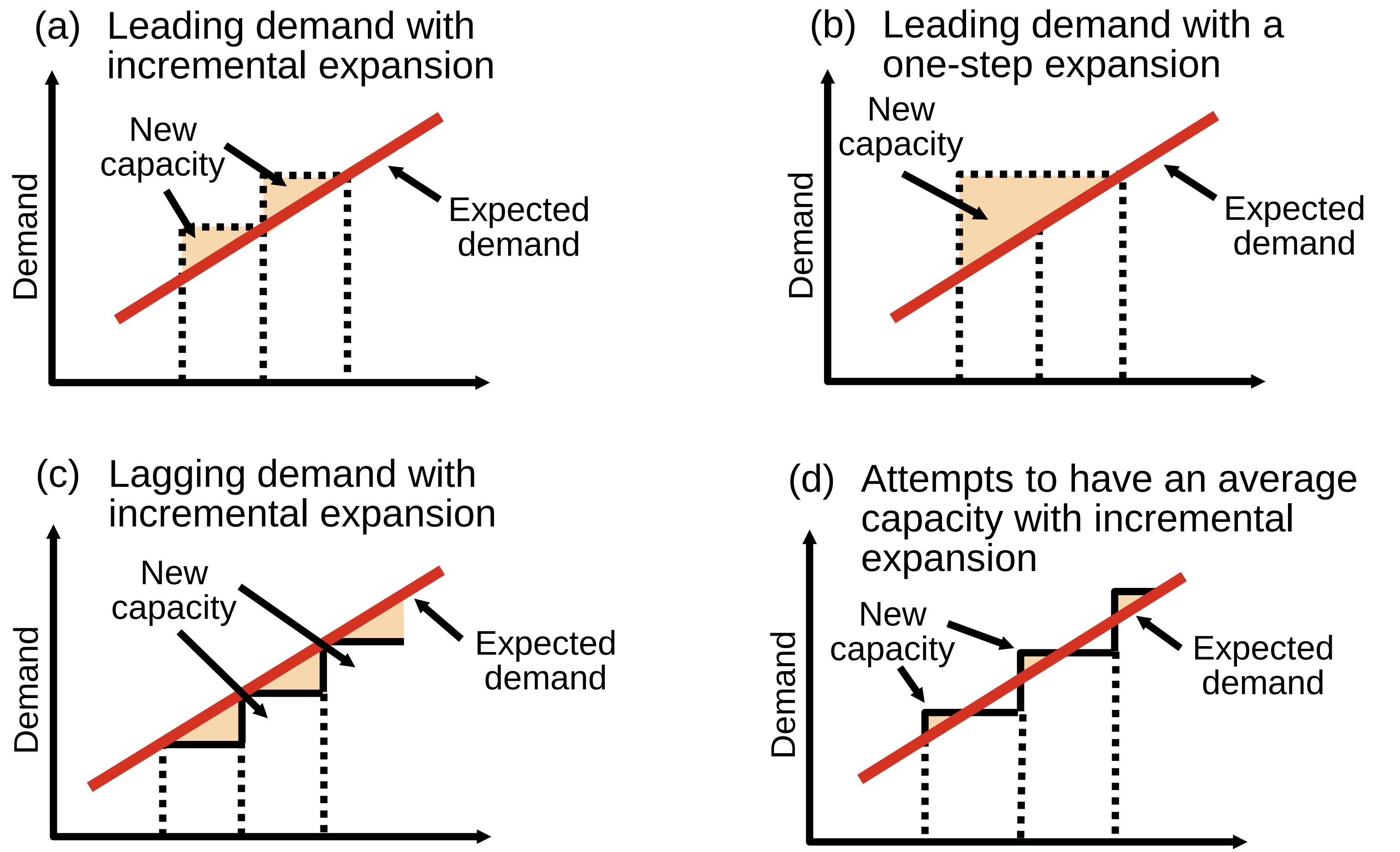
$$BEP_{\$} = \frac{F}{\sum \left[\left(1 - \frac{V_i}{P_i}\right) \times (W_i) \right]}$$

$$= \frac{\$3{,}000 \times 12}{.47} = \$76{,}596$$

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

Reducing Risk with Incremental Changes

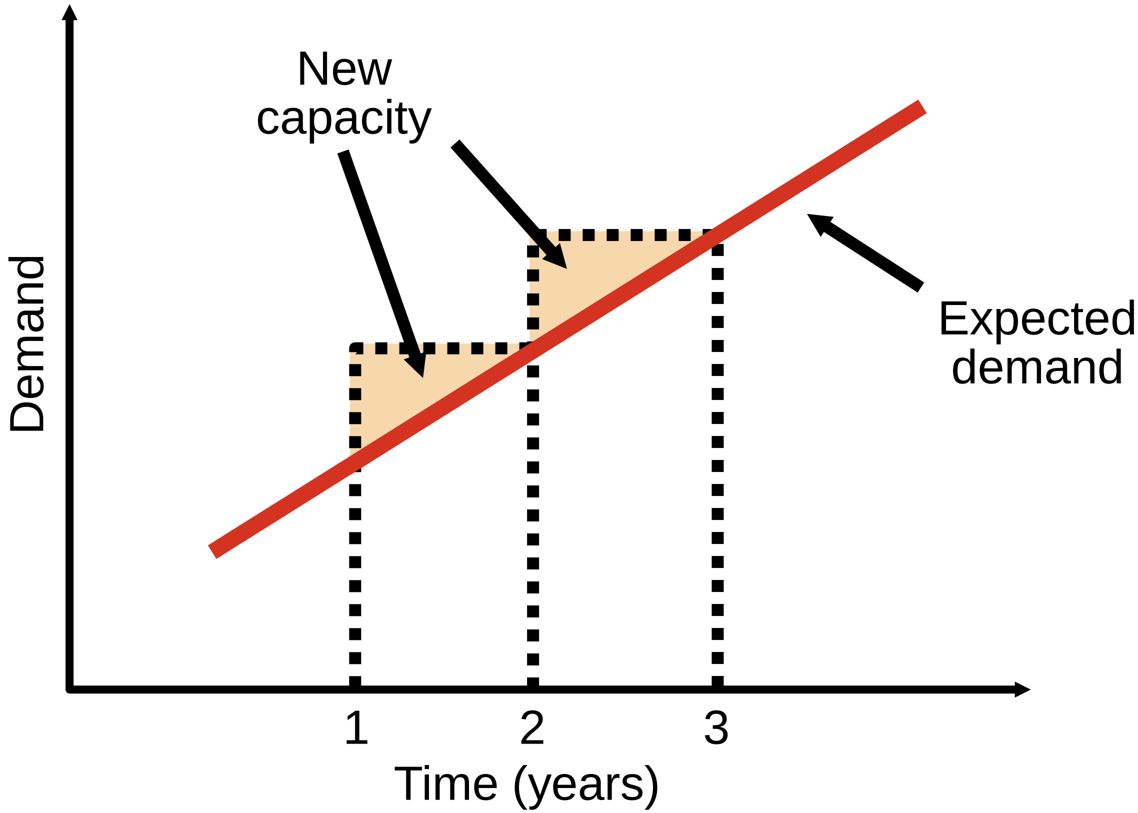
Figure S7.6



Reducing Risk with Incremental Changes

(a) Leading demand with incremental expansion

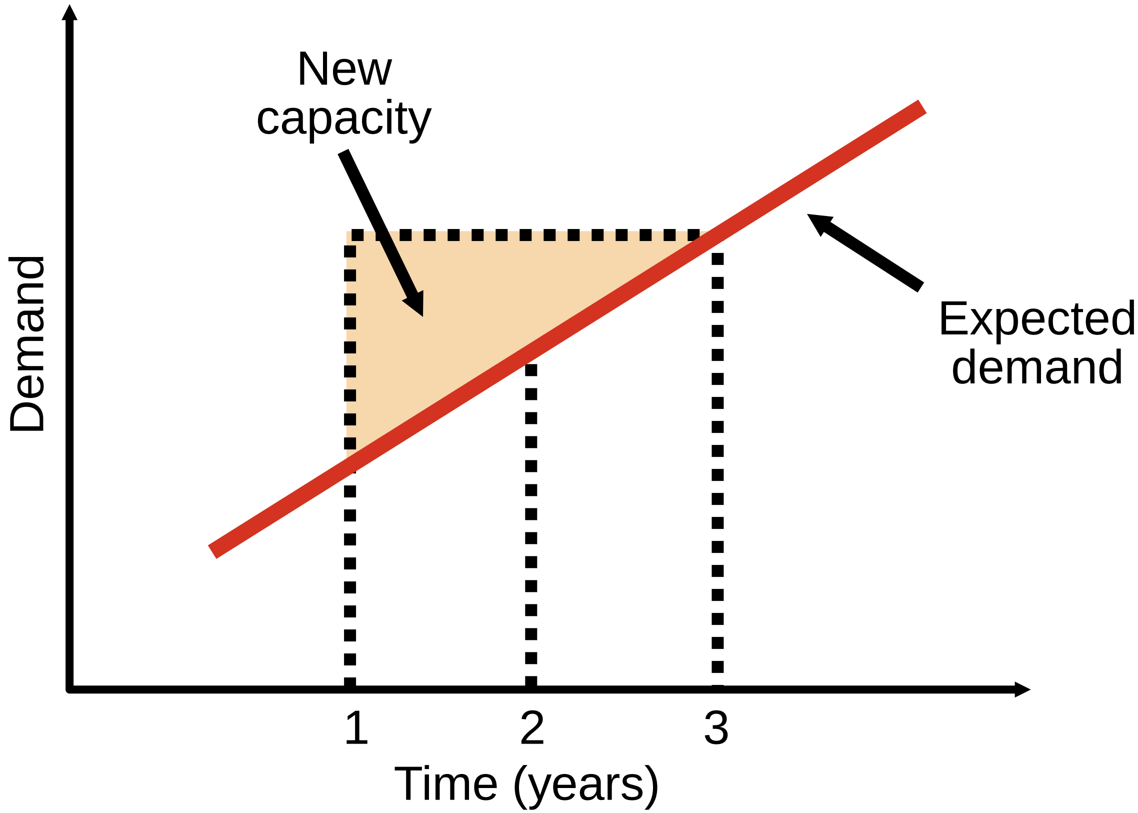
Figure S7.6



Reducing Risk with Incremental Changes

(b) Leading demand with a one-step expansion

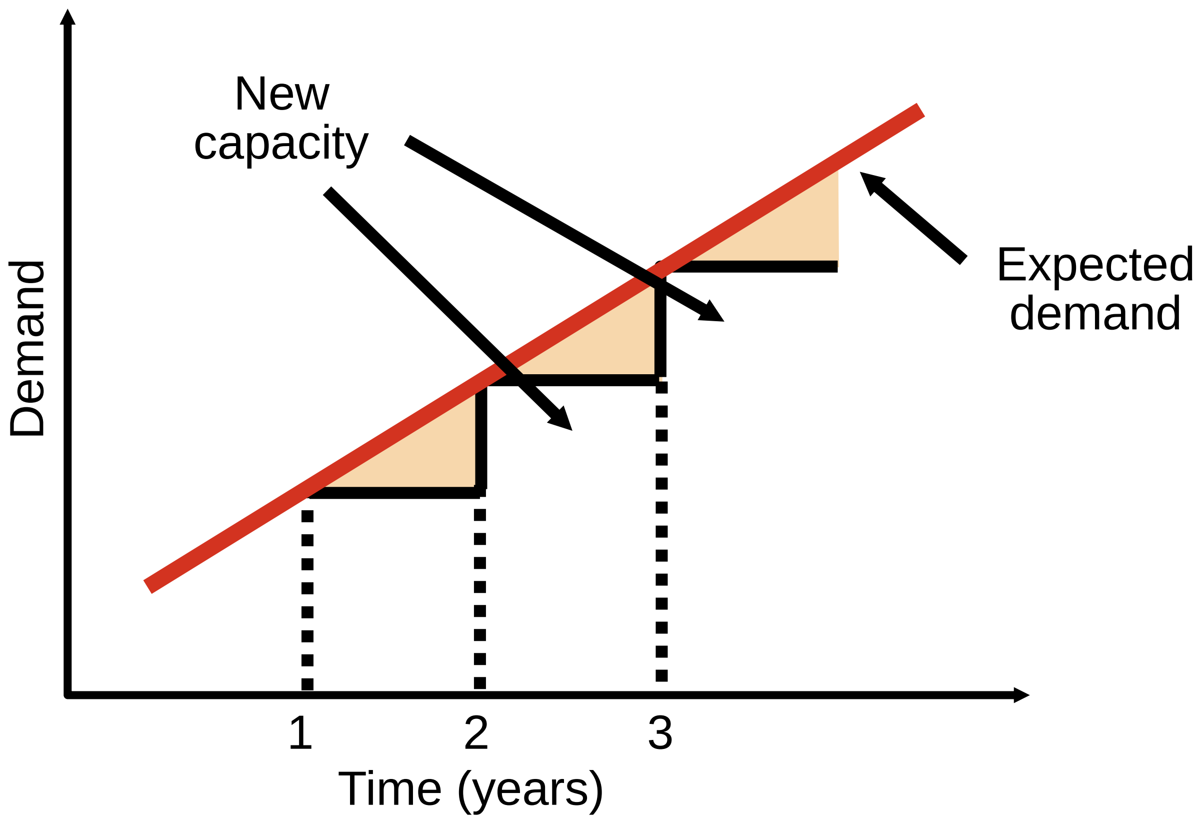
Figure S7.6



Reducing Risk with Incremental Changes

(c) Lagging demand with incremental expansion

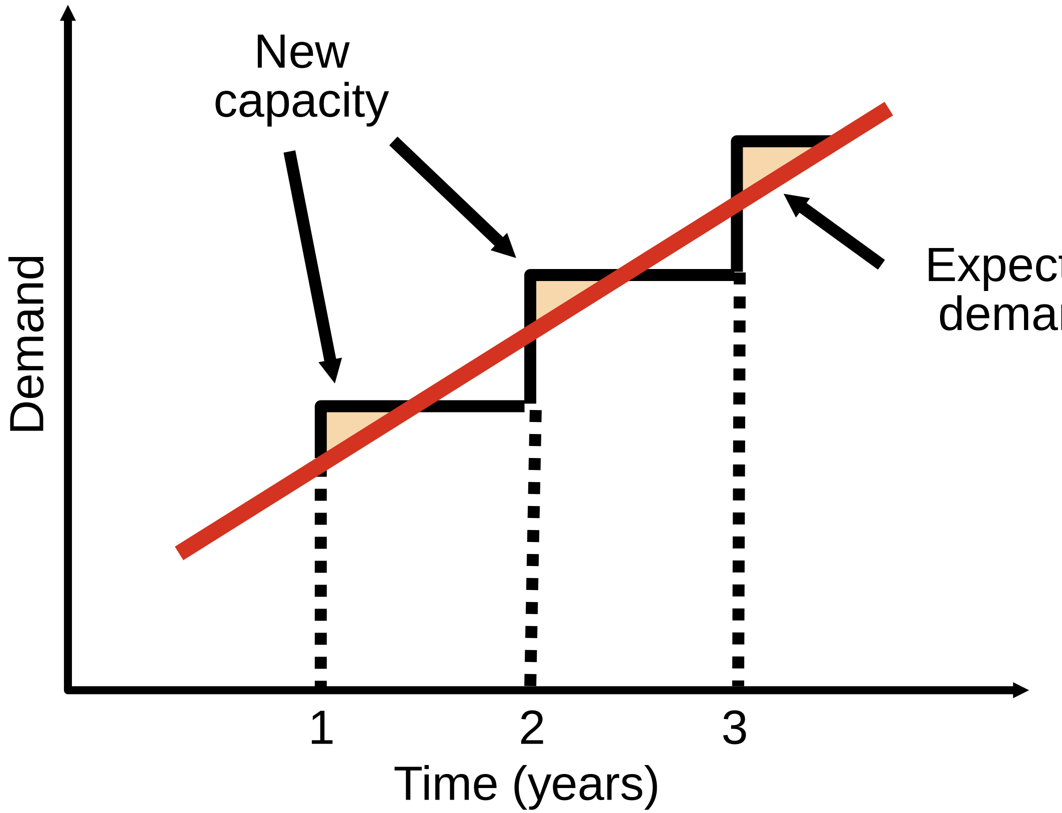
Figure S7.6



Reducing Risk with Incremental Changes

(d) Attempts to have an average capacity with incremental expansion

Figure S7.6



Applying Expected Monetary Value (EMV) and Capacity Decisions

- Determine states of nature
  - Future demand
  - Market favorability
- Assign probability values to states of nature to determine expected value

EMV Applied to Capacity Decision

- Southern Hospital Supplies capacity expansion

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

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

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

EMV (do nothing) = $0

Strategy-Driven Investments

- Operations managers may have to decide among various financial options
- Analyzing capacity alternatives should include capital investment, variable cost, cash flows, and net present value

Net Present Value (NPV)

In general:

$$F = P(1 + i)^N$$

where

F = future value
P = present value
i = interest rate
N = number of years

Solving for P:

$$P = \frac{F}{(1 + i)^N}$$

Net Present Value (NPV)

In general:

$$F = P(1 + i)^N$$

where

F = fu

P = pr

i = in

N = nu

While this works fine, it is cumbersome for larger values of N

Solving for P:

$$P = \frac{F}{(1 + i)^N}$$

NPV Using Factors

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

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

TABLE S7.2	Present Value of $1				
YEAR	**6%**	**8%**	**10%**	**12%**	**14%**
1	.943	.926	.909	.893	.877
2	.890	.857	.826	.797	.769
3	.840	.794	.751	.712	.675
4	.792	.735	.683	.636	.592
5	.747	.681	.621	.567	.519

Portion of Table S7.2

Present Value of an Annuity

An annuity is an investment that generates uniform equal payments

$$S = RX$$

where

X = factor from Table S7.3

S = present value of a series of uniform annual receipts

R = receipts that are received every year of the life of the investment

Present Value of an Annuity

TABLE S7.3	Present Value of and Annuity of $1				
YEAR	**6%**	**8%**	**10%**	**12%**	**14%**
1	.943	.926	.909	.893	.877
2	1.833	1.783	1.736	1.690	1.647
3	2.673	2.577	2.487	2.402	2.322
4	3.465	3.312	3.170	3.037	2.914
5	4.212	3.993	3.791	3.605	3.433

Portion of
Table S7.3

Present Value of an Annuity

- River Road Medical Clinic equipment investment

$7,000 in receipts per year for 5 years
Interest rate = 6%

From Table S7.3
$X = 4.212$

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

Limitations

1. Investments with the same NPV may have different projected lives and salvage values
2. Investments with the same NPV may have different cash flows
3. Assumes we know future interest rates
4. Payments are not always made at the end of a period